Whirled White Web: Art and Math in Snow

Brent Collins, Steve Reinmuth, Dan Schwalbe, Carlo Séquin, Stan Wagon

Contact: C. H. Séquin
EECS, CS Division, University of California
Berkeley, CA 94720-1776, U.S.A.
E-mail: sequin@cs.berkeley.edu

Abstract

At the 13th International Snow Sculpting Championship in Breckenridge, CO, Jan 28. – Feb.1, 2003, Team Minnesota, USA, consisting of the above five authors, carved a 12-foot tall, twisted Scherk-Collins Toroid celebrating a 7-year collaboration between Brent Collins and Carlo Séquin. This paper describes the concept, the detailed design, and the implementation of this very temporary piece of art.

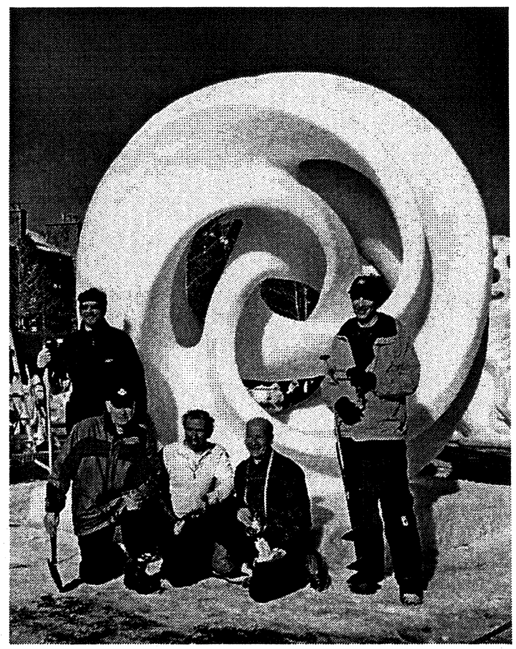

Figure 1. *"Whirled White Web," International Snow Sculpting Championships, Breckenridge, 2003.*

1. Introduction

The judges, in awarding second place to our snow sculpture, "Whirled White Web" (Fig.1), described the piece as a work of "sacred geometry of nature ... very intricate ... very 21st century." It was hard for viewers to reconcile this evaluation with the pile of rubble that lay outside the amphitheater. Yet it all made sense, physically, mathematically, and emotionally. For five years, team "USA-Minnesota" has been carving minimal surfaces at the International Snow Sculpting Championships in Breckenridge, CO. Each year they have tried something more challenging, always carving the snow thinner and thinner. When the temperature is low, it all works well, and the sculpture stays up for several days. When the sun shines brightly and the air gets warm, it may last for only a couple of hours – and snow sculpting becomes performance art!

2. Background

The international snow sculpting championships at Breckenridge have been held each January for the last 13 years; they are among the top events of this kind world-wide. From several dozen submissions, 16 entries are selected for the actual contest, which stretches over five days. Every team has four sculptors, plus an additional coordinator and spokesperson. The raw material is a 12-foot tall, 20-ton block of hard compact snow (machine-made, stomped by townsfolk into wooden forms) with a 10' by 10' base. Each year a wide variety of different styles of sculptures emerge from these blocks, ranging from natural renditions of animals or people to whimsical scenes, or to symbolical abstract forms. In the last few years, there have been teams from Russia, China, Switzerland, Germany, Mexico, Canada, France, Italy, and other countries.

Team USA – Minnesota, created five years ago by Stan Wagon [15] and Dan Schwalbe, has had a tradition of representing abstract geometrical surfaces in this transitory white medium, and over the years has demonstrated the remarkable strength of hard frozen snow. In their first year, 1999, Helaman Ferguson [4] was the artistic designer. Joined by a Macalester College student, the team created a rendition of a spherical cutoff of Costa's minimal surface, which they called "Invisible Handshake" (Fig.2a). The name refers to the fact that the volume of air between two hands that almost touch in a normal handshake has the topology of a genus-1 Costa surface. This structure, because of its thick surface and the internal bracing of the saddle surfaces of zero mean curvature, was extremely stable and durable. A full report of this first "snow math" construction is in [5].

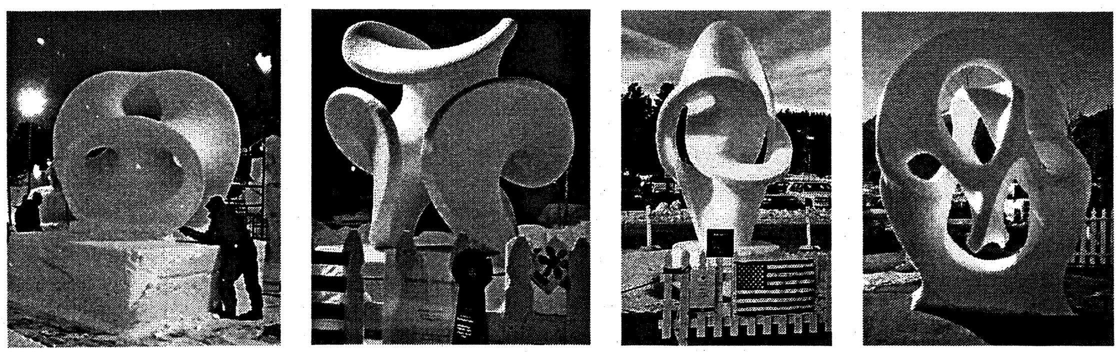

Figure 2. *Previous Work: (a) "Invisible Handshake" (1999), (b) "Rhapsody in White" (2000), (c) "White Narcissus"(2001), (d) "A Twist in Time"(2002).*

Spurred on by this success, the team attempted a more daring structure in 2000, a spherical cutoff of the center of a second-order Enneper surface, modeled after the graceful wood sculptures of Robert Longhurst [9], who had joined the team that year, along with engineer and amateur woodcarver John Bruning of Rochester, N.Y. The daring part was the large cantilevered lobe at the top of the sculpture (Fig.2b). A TV crew was standing by when the last support of this overhang was removed – and it held! The whole mathematical surface was also rendered with a thinner slab of snow than the previous year, and again the internal bracing of this minimal surface supported the bold conception. This sculpture earned second place in the championship [1].

The following year, Longhurst [9] was again the team artist, and Matthias Weber, a minimal surface expert, also joined the team. "White Narcissus," a very elegant, tall and slender monument (Fig.2c), celebrated another one of Longhurst's wood creations. In this form, the minimal surface saddles were a little less pronounced, and some ribbon-like features started to appear.

For 2002, Bruning suggested Bathsheba Grossman [7] as the team artist, and Team Minnesota took yet another leap in pushing the limits of demonstrating the strength of frozen snow. Grossman's design was a knotted structure of twisted ribbons with a large hanging feature in its very center. For the artist, as well as for a large fraction of the public, it seemed highly improbable that this structure could carry its own weight – but it did (Fig.2d). This creation earned an Honorable Mention for Expressive Impact; it was also the runnerup in the People's Choice voting.

3. The Design for 2003

For the 2003 championships, Stan Wagon invited Brent Collins [2] and Carlo Séquin [10] to come up with a suitable design. Collins first proposed to use the minimal trefoil (Fig.3a) that had resulted from their collaboration [3][11] more than five years ago. But Wagon felt that, compared to the team's work the previous years, this design did not offer any new challenges. Thus Séquin used his Sculpture Generator I [12] to produce a more complex design by replacing the ordinary biped saddles with third-order monkey saddles (Fig.3b,c). The complexity of this topology – a single-sided genus-7 surface with three edges – certainly rivaled the complexity of the previous year's sculpture. Also, the smooth-flowing lines of this geometry would present a particular challenge to the implementation of the sculpture, since the human eye would readily pick out any irregularities in the six spiraling flanges.

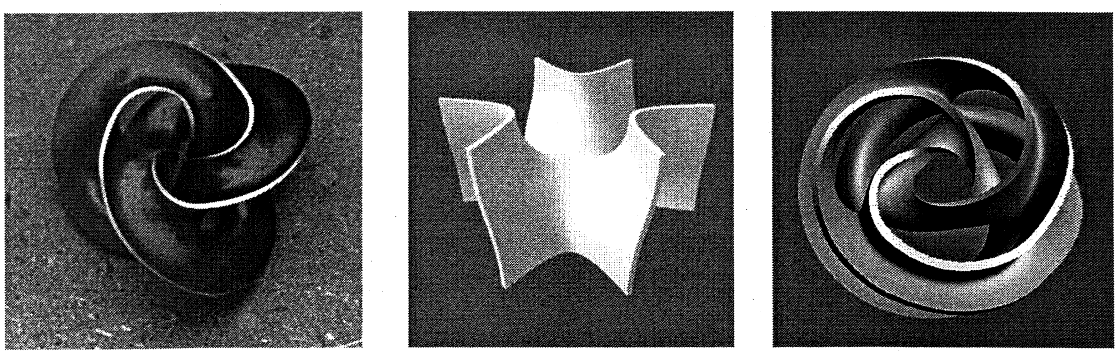

Figure 3. *(a) Minimal Trefoil (1997), (b) Monkey-Saddle, (c) Monkey-Saddle Trefoil (2002).*

For dramatic impact, this Scherk-Collins Toroid was stood on its edge and was made it as large as possible within the given block of snow. For stability, the toroid was placed symmetrically on two of its outermost flanges, with a single flange rearing up to the full height of 12 feet at the top center. Some experimentation on the computer revealed that by turning the major plane of the toroid 46.2° with respect to the frontal plane, the toroid's diameter could be maximized and also approach the 12 foot limit. Of course, the whole toroid would have to rest on some base and be partially sunk into it, so that there would be a reasonable amount of surface area to support the weight of the whole sculpture. The thickness of the flanges remains a final, field-adjustable variable; however, we determined by computer simulation, that an aesthetic optimum would lie around 5-6 inches, given a wheel diameter of 12 feet. Wagon, based on his experience of the previous years, was confident that this thinness could be achieved and would lead to a construction that was structurally sound. Figure 4 shows computer projections from different directions.

From this computer model, a couple of maquettes were built on two different types of rapid prototyping machines. ZCorporation's 3D-printer [16] quickly produced a very pleasing model, whose slightly grainy texture nicely represented the lighting effects we hoped to see in a final snow sculpture. This model is produced on a machine that is conceptually an ordinary ink-jet printer, except that the print head dispenses glue, rather than ink, and the glue falls onto a thin layer of plaster powder, rather than a sheet of paper. After a page has been "printed," the stage that carries the plaster powder layer is lowered by 0.007" and a new powder layer of that thickness is brushed on top of it. Any glue deposited on this top layer will fuse with any glued-together regions in the layer below. So, after a few hours, having deposited a thousand layers of powder and selectively infiltrated them with glue, one obtains a 7" high block of powder, that somewhere inside contains the desired part (Fig.5a).

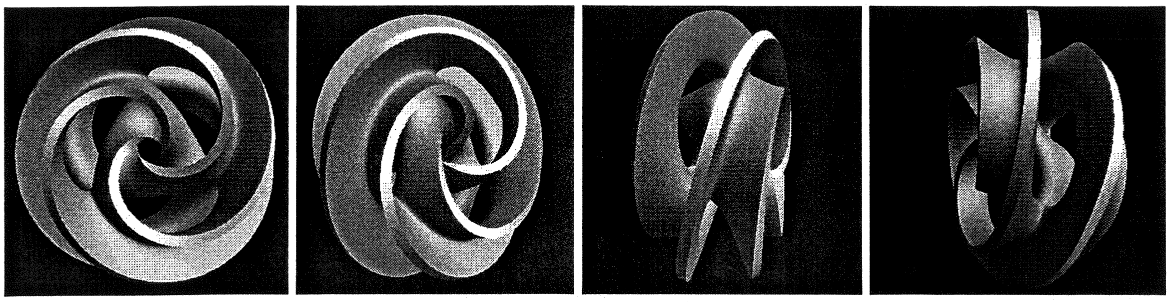

Figure 4. *Projections of the chosen design from different directions.*

The Fused Deposition Modeling (FDM) machine from Stratasys [14] builds the models also in a bottom-up, layer-by-layer manner. For each layer, a computer controlled nozzle moves in the x-y-plane (like the head on an old-fashioned pen plotter) to outline the desired shape and then to fill it in with a zig-zag path. Again the part is built on a stage that drops down after each layer by 0.01 inches. The nozzle dispenses a 20mil bead of ABS-plastic in semi-liquid form, which fuses and hardens as soon as it touches the colder material of the previous layer. Since this plastic goo cannot be deposited in mid-air, one has to build some scaffolding whenever one wants to construct an arch or some significant overhang (Fig.5b). For this purpose, the machine has a second nozzle that dispenses the same kind of material at a slightly lower temperature. The FDM machine's software computes where such scaffolding is necessary and then paints the necessary shapes on each layer. However, the scaffolding has to be removed by hand after the whole part has been built and has cooled down. Such an FDM maquette made in white ABS was used for our original submission to the competition; a larger green maquette (Fig.5c) was used in the field during the actual sculpting process.

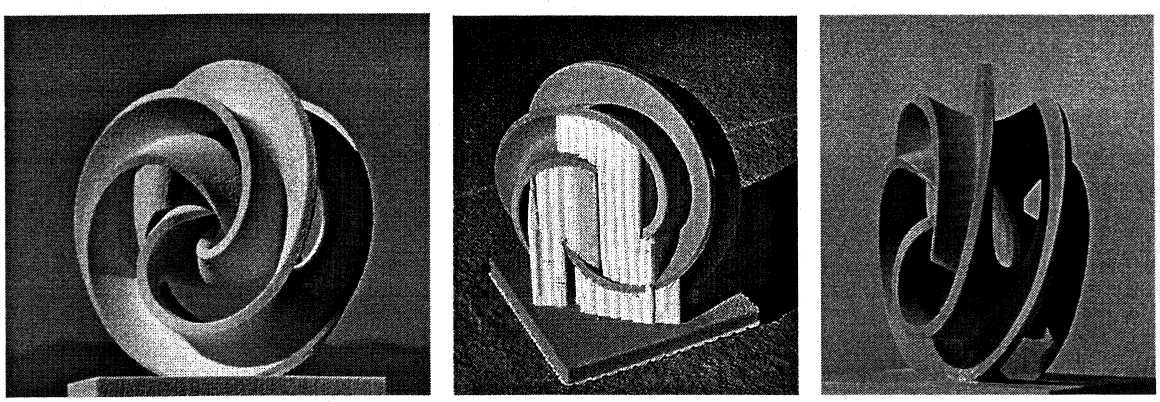

Figure 5. *Maquettes of the proposed submission to the championships: (a) 3D-Print, (b,c) FDM.*

The application also required a name for the artwork and a short narrative description. Coming up with a suitable name was a collaborative effort by e-mail that took several weeks. We considered many different combinations of some key words: Snow Flower, Winter Rose, Winter Whirl, Wild White Whirl, Webbed Wild Whirl, and the like, until we hit on the perfect homonym: "Whirled White Web." At first, we saw this name as just a clever pun. But upon further contemplation, we realized that this name was more than just word play, and that the sculpture actually was a symbolic representation of an essential aspect of the electronic World Wide Web. Like this global network, the ridges of our sculpture span the outer perimeters of the whole "globe", and then approach each other closely in the central hole. It illustrates how the World Wide Web can link together people from all over the planet.

4. Plan of Attack

Once we were accepted to the competition, we faced the problem of how we would get our design – for which we had a perfect little maquette – into that large block of snow! First, a larger, 6" tall model was made at the exact scale of 1:24. It was made on the FDM machine in green ABS plastic (Fig.5c), so it would contrast better with the snow when we would use it on-site in Breckenridge. But clearly, we could not get the larger dimensions transferred accurately enough by just eye-balling. We drew on the experience of the previous years, and prepared a set of large plastic sheets on a 1:1 scale with projections of the geometry from crucial directions. In particular, we planned to first cut out a large diagonal slab, called "the Monolith", from the block of snow, by removing two large triangular prisms and two smaller ones. Over this mostly rectilinear slab, we would then drape such a plastic template (12' by 18') carrying the top view (Fig.6a) and the dominant axial view (Fig.6c). It turned out to be quite challenging and tedious to produce these plastic templates (Fig.7); they were hand drawn using a 10" grid to scale up the corresponding printouts from the computer.

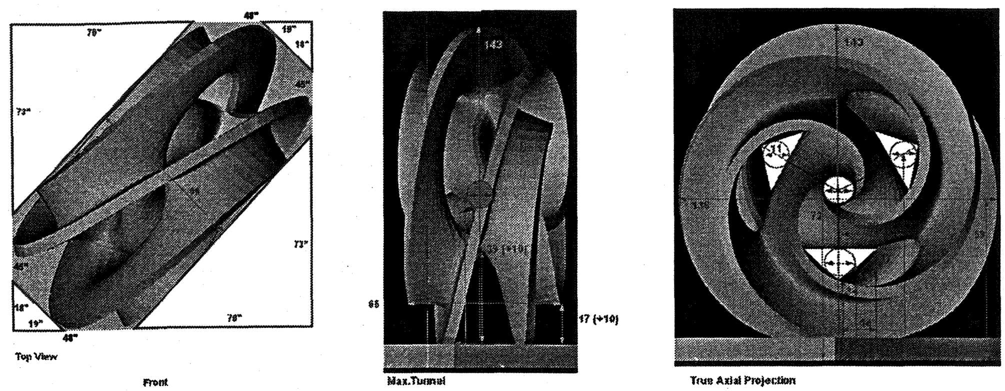

Figure 6. *Computer projections with dimensions: (a) top, (b) side, (c) axial view.*

Figure 7. *Production of the plastic templates by the classical grid method.*

5. Dress Rehearsal

Two days before the competition, the team gathered at Stan Wagon's house in Silverthorne. Steve Reinmuth [13], who had cast many of Collins' works, was also on our team. He brought along some new custom-made tools, which would prove extremely useful in shaping the twisty inner portions of our design; e.g., the "Devil's Toothbrush" consisted of a sturdy steel rod with several dozen nails welded to it.

In his back yard, Wagon had prepared a practice block at a 40% scale. We immediately set out to implement our plan of attack, and started carving into the 4' block of snow. For this trial exercise, Séquin had also prepared a second set of plastic templates at the 40% scale. The large triangular prisms came off in an hour, and we exposed the desired prismatic "monolith". We hung the templates over it and transferred the projections from the template to the slab of snow, using long nails, marker pens, and even spray paint for the large cutouts (Fig.8a). Then we started to carve in between the marked ribs (Fig.8b).

In doing this and trying to make the ribs follow their intended curves, we quickly lost all the original markings. Suddenly, there was no more help around the perimeter of the sculpture or in the inner hole, as to where the flanges should appear. We continued with a "free-hand" approach based on the maquettes we had, and we got the topology to come out all right (Fig.8c,d). But the spacing between the flanges turned out to be rather irregular, and even their slope angles were not what they were supposed to be. This made the sculpture look awkward and lopsided, and it was clear the result of such an approach would be unsatisfactory.

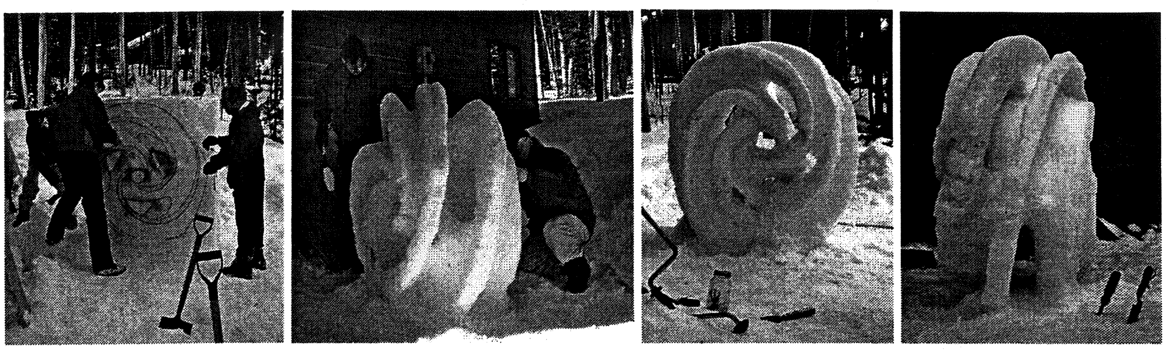

Figure 8. *Various stages of sculpting the 40%-scale practice block.*

The most important feature to obtain a pleasing and regular final sculpture was to have all flanges in exactly the right place. Because of the way the Sculpture Generator I deforms an original Scherk-tower into a twisted toroid, the flanges of the maquette lie more or less on the surface of a torus. We decided to regularize the sculpture in this way and to start from a perfect torus with a rather small hole, on which we would then draw a regular (6,3) torus knot, which actually decomposes into three intertwined (2,1) torus knots. Our sculpture would then comprise some kind of spanning surface within this framework of edges, forming three monkey saddles, and exhibiting (hopefully) perfect 3-fold (D_3) symmetry. We felt quite confident that we could free-hand sculpt an acceptable approximation to such a surface, once all the edges were in the right places.

6. Actual Implementation

Competitive sculpting on the large blocks started on Tuesday 1/28/03 at 11 am. We first drilled many closely spaced holes along the major faces of the monolith, to remove the triangular prisms in large hunks. By the evening of the first day we had removed more than 50% of the snow mass of the block, and the basic shape of the monolith containing the torus was clearly defined (Fig.9a).

On Day 2 we sculpted from about 8 am till about 8 pm to realize a clean torus geometry (Fig.9b). To assure the regularity of this shape, we first defined the central axis of the torus and inserted a metal rod for reference. From this center, we drew circles with the major radius of the torus, as well as with the projected outermost radius of the torus onto both major monolith faces (Fig.9a). In addition, we had made a half-circle plywood template with the minor radius of the torus. This template could be "swept" around the outer perimeter, while aligning its ends on the major-radius circles on the two monolith faces (Fig.9c).

In principle, the template could also have been used on the inside, by sticking it through the central hole; actually, we did carve most of the inside of the torus in "free-hand."

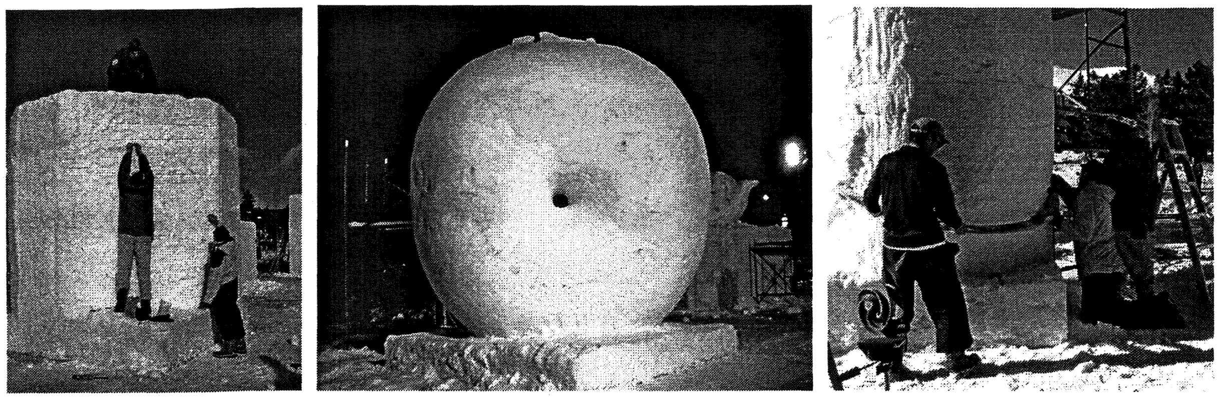

Figure 9. *Start of the implementation of the full-size sculpture.*

Most of the morning of Day 3 was spent marking the positions of the edges on this torus (Fig.10a). This was a slow and tedious process, even though we had marked up the plywood half-circle with suitable tick-marks where the flanges needed to be placed at 12 different major directions from the center of the torus. But eventually we had the three intertwined (2,1) torus knots drawn, and could start to carve in between the flanges (Fig.10b). A couple of cardboard templates provided guidance as to the depth and width of the channels that we could safely remove in this sculpting phase. Snow removal now continued rather speedily. Late in the afternoon, with our maquettes in hand, we started to punch through tunnels in the right places to selectively connect some of the grooves and to obtain the desired topology. By the end of the day we had the genus-7 structure underlying the "Whirled White Web" (Fig.10c).

All day Friday, from early morning till late into the night, we refined the geometry of the flanges, the internal bridges, and the monkey saddles. We stuck thin metal rods through the flanges to accurately measure their internal thickness and to pinpoint the precise locations of the monkey saddles. The biggest problem was the weather. The whole week had been unseasonably warm; on most days the temperature rose above freezing, and the sun was beating down on the delicate edges of the sculptures. Most groups mounted big sails on ladders and scaffolding to provide some shadow for their artwork. But strong gusty winds made this a challenging task. Nevertheless, shortly before midnight, all the flanges were of fairly uniform thickness, somewhere between 6 and 8 inches, except for the bottom two flanges, which we had kept closer to 10 inches, since they had to support the whole weight of the sculpture.

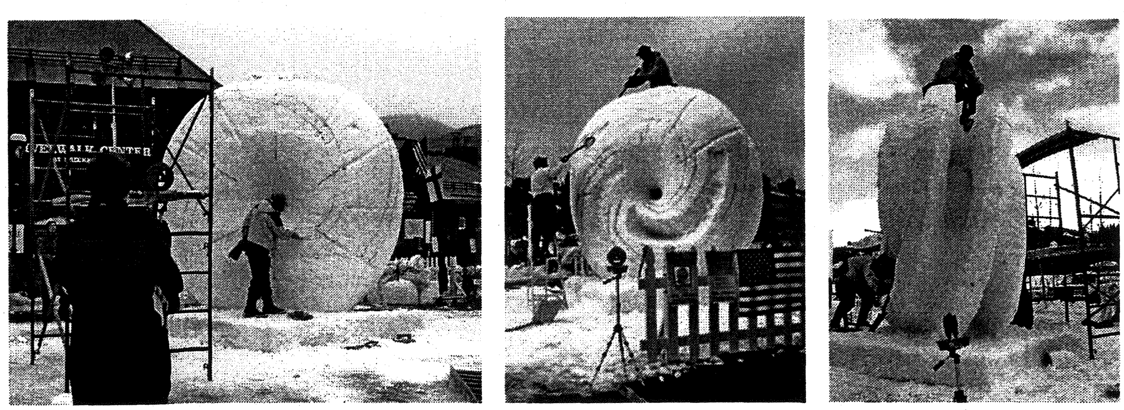

Figure 10. *Various stages of sculpting the full-size sculpture.*

Day 5, Saturday, was judging day. All sculpting had to be completed by 10 am. We made an early start (3 am for Stan) and worked the whole sculpture from top to bottom, thinning the flanges to a uniform 6 inches, and grinding and smoothing the surfaces with big rasps and with rough wire-mesh "gloves." The final tasks were to level the surface of the pedestal, to clean out the large horizontal tunnel under the sculpture, to tailor the shape of the two supporting flanges to match the flanges in the rest of the sculpture, and to create nice sharp creases where they disappeared into the pedestal. It was a race against time, not only because of the judging deadline, but also because the rising sun promised a day with record high temperatures. We completed our work to our satisfaction, and proudly showed it off to the judges and to a large and appreciative crowd of spectators from 10 am till noon (Fig.11a,b).

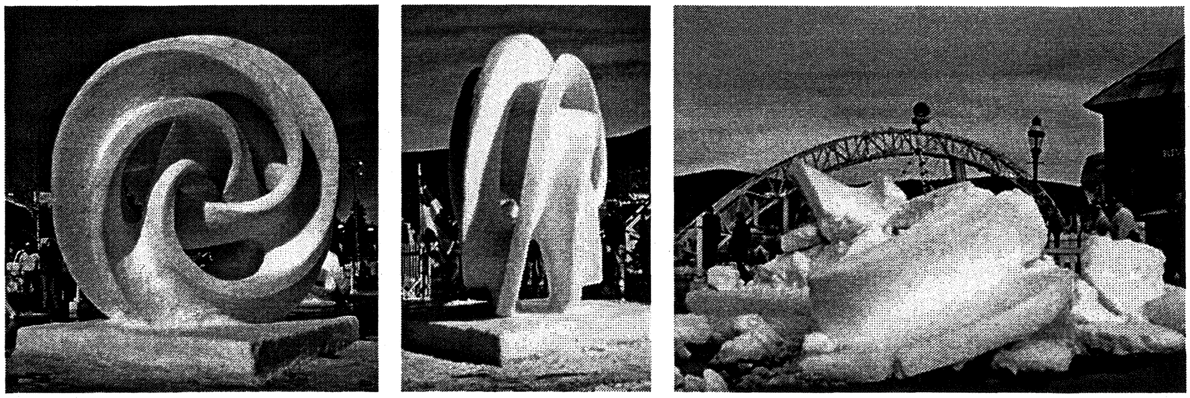

Figure 11. *The Final Result: (a,b) at judging time, (b) one hour later.*

7. The Final Drama

The sculpture collapsed at 12:40 pm (Fig.11c). The flanges that were directly exposed to the sun softened and started to turn into slush. The two bottom flanges could no longer support the bulk of the structure. At a nominal flange thickness of 6", our sculpture above the pedestal occupies 10.5% of the original snow volume of 1200 cubic feet. At a measured 38 pounds/foot^3, we calculate 20.6 metric tons for the whole block and estimate a weight of about 2.5 tons for our sculpture, since we deliberately made the saddle regions rounder and quite a bit thicker than the nominal 6". The supporting flanges were roughly 6"x48". If the weight were uniformly distributed, the average pressure in these flanges is thus about 8 – 9 psi; which seems quite reasonable for good quality snow. Though we had fully intended to push the limits of the "material" – we had no idea how close we were to those limits, given the unusual weather conditions.

8. The Winners

This was a very inspiring event. A wide variety of different sculpture styles and surface-finishing techniques were displayed. Our work was the only one with an abstract geometrical shape. (In previous years, there had also been Swiss teams who created highly regular and precise geometrical forms.) This year's first-place winner "Winter Comes" (Fig.12a), executed by the team from Canada – B.C., had a lot of drama and a strong emotional impact. They also had a great topical story: The snow-owl brings a tapestry of snow to the countryside. The bird had an immaculate surface finish – almost like silk. And overall, this piece of art had an incredible amount of detail: half a dozen separately carved houses, more than a dozen trees, and more than fifty individual snowflakes on the blanket behind the bird.

Third place went to a wonderful crowd pleaser – a very well executed whimsical story: "A Fishing Tail" (Fig.12c). A cat is reaching into a (virtual) fish bowl towards a fish suspended between several plants. This piece also had some tricky engineering: The tall thin plants support a disk of ice, on which the cat's paw rests above the bowl. In view of such strong competition, our team was very happy to have garnered the silver medal.

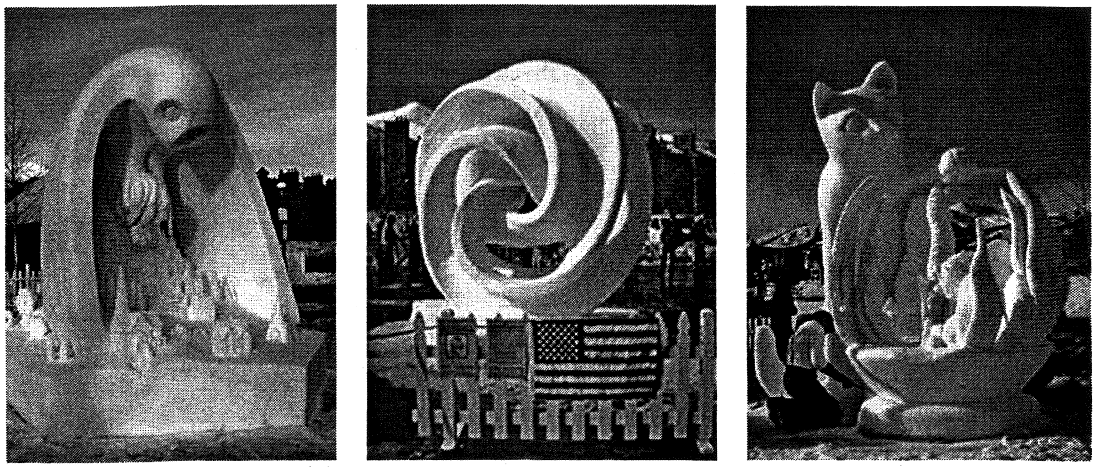

Figure 12. *(a) 1st: Canada – B.C., (b) 2nd: USA – Minnesota, (c) 3rd: USA – Breckenridge.*

9. Conclusions

Snow offers an "easy" way to make a rather large sculpture in a relatively short time – although the work is of a rather transitory nature. For the artist who has not had any commissions for any large sculptures beforehand, this medium offers the special thrill of seeing one of his or her creations in a larger-than-life realization. Another special thrill is to be present and involved in every phase of the implementation of the final artwork. For some large metal sculptures, pieces are cast or forged in possibly remote places, away from the direct experience of the artist, and these steps are carried out by other people or by machines, not by the artist. In snow sculpting the artist can personally participate in every step along the way.

For a sculpture like the "Whirled White Web", this direct involvement has another great benefit – particularly for the computer scientist on the team. The many hours spent so close to the desired geometrical shape gives a far more intimate understanding of the resulting form than one would have in simply preparing sketches and construction drawings. On the other hand, the precise knowledge how the shape had been designed – in this case, as a set of procedures that incrementally deform an initially rather simple geometry – actually helped in creating a viable plan of attack and in implementing precisely the desired form.

The success of our sculpture in this competition and the reaction of a large segment of the spectators, demonstrate that simple and bold geometrical shapes do indeed have a strong appeal for many people. This was further confirmed in April, when FOSI, Friends of Sculpting, Inc., named our "Whirled White Web" the "US Snow Sculpture of the Year" for works created in a competition [6]. Such shapes may actually have a much more durable and culturally independent appeal to them than pieces of art that make some critical or emotional statement about some particular aspect of our society or our civilization.

It is thus somewhat ironic, that we have created such a timeless form in such a transitory medium. This drives home the point, that in snow sculpting the **process** of creating the piece of art is most important. The knowledge how short-lived the final product may be, creates a more intense bond during the phase of creation. And, looking beyond our own hunk of cold snow, we also much enjoyed the warm camaraderie found among the many teams working side by side late into the night.

References

[1] J. Bruning, A. Cantrell, R. Longhurst, D. Schwalbe, and S. Wagon, *Rhapsody in White: A victory for mathematics,* The Mathematical Intelligencer, 22:3 (2000) 37-40.

[2] B. Collins, *Brent Collins – Gallery,* – http://www.sckans.edu/~bridges/bcollins/bcollins.html (2003).

[3] B. Collins, *Evolving an Aesthetic of Surface Economy in Sculpture*, Leonardo, Vol. 30, No. 2, 1997, pp. 85-88.

[4] H. Ferguson, *Helaman Ferguson Sculpture,* – http://www.helasculpt.com/ (2003).

[5] C. Ferguson, H. Ferguson, D. Schwalbe, T. Nemeth, and S. Wagon, *Invisible Handshake,* The Mathematical Intelligencer, 21:4 (Fall 1999) 30-35.

[6] FOSI, Friends of Sculpting, Inc., – http://web.northnet.org/friends_of_sculpting/SculptKlaus.htm (2003).

[7] B. Grossman, *Sculpting Geometry,* – http://www.bathsheba.com/ (2003).

[8] D. A. Hoffman, *Costa Surfaces,* – http://www.msri.org/publications/sgp/jim/geom/minimal/library/costa/indexd.html (2003).

[9] R. Longhurst, *Robert Longhurst Studio,* – http://www.robertlonghurst.com/portfolio.html (2003).

[10] C. H. Séquin, *Whirled White Web,* – http://www.cs.berkeley.edu/~sequin/SCULPTS/SnowSculpt03/ (2003).

[11] C. H. Séquin, *Virtual Prototyping of Scherk-Collins Saddle Rings,* Leonardo, Vol. 30, No. 2, 1997, pp. 89-96.

[12] C. H. Séquin, *Computer-Augmented Inspiration,* Proc. of ISAMA 99, 1st Int. Conf. of Int. Soc. of the Art, Mathematics, Architecture, pp 419-428, San Sebastian, Spain, June 1999.

[13] S. Reinmuth, *Reinmuth Bronze Studio,* – http://www.reinmuth.com/ (2003).

[14] Stratasys Corp., *FDM machine,* – http://www.stratasys.com/ (2003).

[15] S. Wagon, *Homepage, references to snow sculpting events,* – http://www.stanwagon.com/ (2003).

[16] ZCorporation, *3D-Printer,* – http://www.zcorp.com/ (2003).