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A Century of Ice: The Architecture of Phase Change

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The phrase "mon pays ce n'est pas un pays, c'est l'hiver" rings true for all Northerners, but it is particularly evocative for children and builders, who at the mere thought of winter conjure up visions of construction materials falling from the sky and water turning to rock. Snow forts and igloos have been the result of this insight by kids and the native Innu since time immemorial, while ice palaces have been built in Canada since 1883, as related in the excellent book *Ice Palaces*:

> At the 1882 banquet of the Montreal Snowshoe Club, R. D. McGibbon suggested holding a regular winter sports festival, in order to enjoy and show off the glories of Canadian Winter.... Ideal weather helped to make the 1883 Winter Carnival a resounding success. An estimated 15,000 foreign visitors flocked to the city.... McGibbon's inauguration of the ice palace was one of the highlights of the *fête*.[1]

Designed by local architect A.C. Hutchison, this first Montreal ice palace was a grand affair erected on what is now called Canada Square. Built of ice blocks sawn from the frozen St. Lawrence river—a technique long used to harvest ice intended for refrigeration—

Hutchison's ice palace started a boom of palace building in northern cities. Ever bigger palaces were built in Montreal, Quebec, Ottawa, St. Paul, Minneapolis and Leadville, Colorado, up until the end of the century, when the fervour to construct ice palaces started to die down. Even though ice structures continued to be built throughout the 20th century, never was the monumentality of the early era matched.

Let's jump forward to the McGill campus in the 1970s. Studying at the School of Architecture in the early seventies, my student friends and I were quite intrigued by an ice structure going up one winter. Built of manufactured ice blocks, the structure's size seemed disappointing in the context of the surrounding buildings. Word had it that the sponsor of the winter carnival donated a fixed annual amount for construction, so that inflation had gradually reduced the size of structures over time. We asked ourselves how we might reduce the cost of ice construction. Observing frozen laundry on a clothesline led us to design a fabric-formed ice structure, supported by a wooden triangle suspended from three sturdy campus trees. A few frosty nights of hosing this assembly down transformed it from a flapping in-the-wind sheet of tensile fabric into a rigid, compressive structure. I will never forget the excitement of cutting the three steel wires that initially held up the structure (fig. 1). Professor Peter Collins had lectured us on the inconvertibility of tensile forces into compressive ones, and proposed "a wager of ten dollars" that the structure would not stand. Rarely did beer taste sweeter than the supply bought with that ten dollar bill.

Lesson no. 1: It can be quite delicious to disagree with your professors, particularly when you're right.

A few days later, after a short thaw, the structure collapsed suddenly, giving rise to another lesson.

Lesson no. 2: Lightweight ice construction has little resistance against even short-term melting.

When a cold winter struck in 1981,the frozen-fabric idea was taken up in a new context; this time I was a teacher and the students were designers in competition with each other. Ed Hercun's concept was chosen, and what a striking structure he produced! Three graceful hyperbolic paraboloids assembled from 20 foot-long scaffolding pipes covered by a sown-together nylon membrane were erected on the lower campus and sprayed with water. These three "hypars" formed a complex double-curved nylon-reinforced ice space, admired by the master of the hyperbolic paraboloid, Felix Candela, when I once showed him photographs (fig. 2). The surface of the structure was barely an inch thick, and to make up for the sublimation of the ice ("gassing off"), we had to hose it down every other day. Frances Bronet, then a student, now the head of the School of Architecture at Rensselaer Polytechnic Institute in Troy, NY, did a snappy computer analysis of this structure's behaviour under wind loading. Red neon tubes were fastened to the edges of the structure. The most beautiful pictures were taken at night, when the ice conducted light along its surface and glowed in a red hue. The McGill flag that we had proudly fastened to the top, almost thirty feet in the air, was gone the next morning.

Lesson no. 3: Never underestimate the energy and ingenuity thieves and vandals will expend on an unusual structure.

The following year we continued to work on the nylon ice method. Randy Cohen's attempt to create a thirty foot crystal 'needle' protruding from the frozen campus, Howard Davies' inflatables, Stefan Wisniofski's tents and, most dramatic of all, Mark Pimlott's attempt to create an ambitious structure supported by a cable slung from the roof of the McLennan Library, all were valiant experiments that year.

In the cable suspended structure, however, the "limits of growth" were stretched too far: the exposed site and a stiff wind made it impossible to perform the magic of turning the flapping suspended structure into a rigid, self supporting one by simply spraying it with water. The material kept folding when the structure deformed under the weight of the water or when wind deflected it. Instead of a graceful free-form structure, a frozen lump of nylon was the result of this exercise, jokingly called the "Edsel."

Lesson no. 4: New techniques bring new opportunities as well as new problems.

Back to "Pure Ice." The ice-on-nylon method was deemed not "pure" by some critics, so we turned to methods of casting lightweight, low-cost blocks. The ubiquitous two-liter milk carton was chosen as the most suitable form. We tried to recycle used cartons, but were slow at acquiring the 2000 units needed. Fortunately one student had connections to a milk processing plant, and soon a full truck with empty milk cartons pulled

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up to the school. Unloading 2000 cartons, filling them with water, freezing them, submerging them in hot water to shake the ice blocks from the cartons and laying the blocks on the catenary formwork in a slush mortar turned out to be quite a task.

Lesson no. 5: Doing even the smallest thing two thousand times takes a lot of time.

Sometimes I wonder: did architecture student Robert Libman plot his future as the founder of the Equality Party while he was drudging away in the bitter cold of 1983?

Lesson no. 6: Cause and effect are not always easily linked ("the butterfly effect").

The design that year called for a catenary arch, twenty feet high spanning twenty feet. A formwork, eight feet wide was constructed in a catenary shape by simply following the curve traced out by a free hanging rope, sagging between two nails driven twenty feet apart into the wall of the engineering lab.

The plywood form was, of course, reversed to turn the downward tensile curve into an upward compressive one (fig. 3).

When we finished laying the blocks on the form it was almost dark, and it was decided to take the form out only after the deep frost expected overnight had done its work on the slushy array of ice blocks. The next morning a small void had formed between the top of the form and the ice: the slush joints had expanded when they froze overnight and lifted the whole twenty-ton shell off the form; having made that happy observation we were confident that "we can take the form out now."

It was sweet to see the civil engineers scratch their head once more; lesson no. 1 was paying off. In addition to getting praise for simply standing up, this particular structure was appreciated for the effortless elegance that comes so naturally to the catenary arch, as the work of Antonio Gaudi shows over and over again.

Lesson no. 7: Don't worry about emulating concepts—just make sure to pick good ones.

Reusing the wooden catenary formwork ribs a year later, and rearranging them to form a dome rather than a linear vault, was a simple experiment meant to prove how much stronger a double curved shell is than a single curved arch. The idea was to use an inflated plastic sheet as formwork between the radially arranged ribs; but hard-to-repair tears in the nylon made that plan impossible, and the plastic sheet was instead stretched between the ribs. The final form of the catenary dome was compromised by this change in technque: the level of grace of the previous year's arch was equalled only by the lumpiness of its successor.

Lesson no. 8: The aesthetic success or failure of a structure may depend on seemingly small variables.

The value of this experiment was revealed through the structure's demise. When the warm weather came, the dome melted on the sunny side, but of the six "slices" forming the original dome, two stood up for almost a week. This taught us that the double curved dome was much stronger than its single curved predecessor (which had collapsed quite suddenly).

Lesson no. 9: Double curved surfaces are much stronger than flat or single curved surfaces.

Every child discovers how easy it is to dig into a mound of snow or dirt, creating a cave. This "architecture of subtraction" is as old as architecture itself, and can be found in places as diverse in time and space as the dwellings dug from the ground now housing millions of people in China, the Roman temples carved out from the sandstone cliffs at Petra in Jordania, or the excavated churches of Ethiopia and Capadocia.

Making an "ice pub" for fifty people using snow and water was the assignment students received in the winter of 1994. After blowing a pile of snow twenty feet high with a snowblower, a dozen students dug to their heart's content. On a cold Friday night in January of 1994 we counted 52 people comfortably sipping drinks protected by the vaulted roof and walls of the ice pub.

Lesson no. 10: Subtraction can lead to the same result as addition in architecture, given the proper materials.

Centenary Ice: The Lessons Applied

In order to celebrate the School's centennial (later combined with the University's 175th anniversary), we came up with the idea of an ice structure. We wanted to evoke the grandeur of nineteenth-century ice structures using the experience we had garnered building with snow and ice since the 70s.

Lesson no. 2 had taught us that "small mass = short life," and ruled out a lightweight approach for a structure that had to serve various functions for two weeks. Lots of mass was the only defense against evaporation, a possible mid-winter thaw or rain. Depending on conditions, mass can be obtained by ice blocks, huge amounts of snow, or by injecting and spraying snow with water.

The search was on for a massive structure that would not only be interesting to build, but would be architecturally striking as well. It may well have been the presence of Orson Wheeler's cutaway model of the Pantheon in the glass case on the third floor of the school that gave the idea of using the Pantheon in Rome as the inspiration for the Centennial ice structure.

The Pantheon fitted our bill perfectly: the structure would be massive as well as novel. We intended to give Montreal's traditional look-at ice structures a new live-in character, analogous to the change in antiquity from Greek look-at architecture to Roman live-in architecture. The Pantheon offered two main challenges: spanning the space with a massive dome, and decorating the structure and adorning it with a monumental entrance.

The most difficult decision was the one of picking the size of the structure. The ice structures of the 60s had shown that in the context of the campus, anything under three storeys was too small to "hold its own." The biggest clear span we had reached so far in ice was 20 feet with the 4" thick catenary ice arch (1983) and dome (1984). Doubling that span seemed too ambitious, so we chose a span and height of about 32 feet (or 10 meters). That gave the Ice Pantheon a scale of a bit less than one to five of the original Pantheon. A scale of pi (1 to 3.14) would have been the most elegant one, but that scale would have pushed the span to a scary 45 feet.

After choosing the size of the project, we next determined the method of construction. One idea, following lesson 10, was to push the snow up into a 35-foot high mountain, and to carve the Pantheon out like the '94 snow pub. It was rejected because of worries whether the snow would be sufficiently stable to hold up before it could be reinforced by injected water. The plan to use precast snow-ice blocks moved into place by a crane was deemed too expensive in crane time (lesson 5: it takes time doing many things over and over again). Finally, a technique used for centuries in adobe construction was adopted. Lightweight, eight-foot long curved plywood elements, laterally clamped together, were the basis of the system. By stringing the elements along to form two parallel circular walls, kept apart by notched, two by four spreaders, a four foot high "donut" was formed, which was filled with snow. The forms were removed and reinstalled on top of the newly-cast snow below. Since the two-by-four spreaders holding the bottom of the form in place had to be pulled out of the wall, tell-tale holes were left, very much identical to the holes left by adobe construction. This system was very successful (following part one of lesson 4): the forms went up easily and the snow was dumped effortlessly by the frontloader of McGill's Facilities Development Department (fig. 4a, 4b, 4c). There was no shortage of snow in the winter of 95/96: like biblical manna, our building material fell from the sky in prodigious quantities.

Our pace of construction slowed down considerably when we reached level 4, 16 feet up. Handing up the forms to that height was becoming tricky in the wind, and the frontloader could no longer reach over the edge of the forms. We now had to shovel the snow from the frontloader bucket into the forms.

Even that method was impossible for the next level. For a while we used buckets and pulleys to get the snow in place, but 1600 cubic feet of snow were required per 4 foot layer of the structure. It became clear that working by hand we would run out of time. A roofer's motor-driven hoist proved to be too difficult to operate efficiently.

After discussions with the helpful people at Facilities Development, we conducted an experiment using the University's snow blower (fig. 4d). The machine was certainly able to blow the snow high enough; the problem was that it was hard to deposit the snow exactly in the forms. The filling of the first 4-foot layer of the structure resulted in almost as much snow falling inside the walls as inside the forms, and a massive cleanup of the inside space was needed. To avoid having to do this several more times, it was decided to try to roof the dome in one shot, rather than layer by layer. We also wanted to speed up the process: the opening date was only ten days away, and warm weather was in the forecast. The last twenty five feet of the thirty-two foot span was domed over in a hurry, using the inside as well as the outside wall forms, improvising patching for the pie-shaped spaces between the panels, and propping everything up from a central point on top of the scaffolding in the center of the structure. The beauty of the original design of the Pantheon became evident here: as the radius of the plan is the same as the radius of the dome, the curved plywood wall panels could be used as formwork for the dome as well (fig. 5).

On Tuesday afternoon, January 16, as snow was blown over the dome, disaster almost struck, (in accordance with the second half of lesson no. 4). Even though the blower operator had become a real artist, controlling the machine and dropping tons of snow with pinpoint accuracy, because he had to drive around the structure in order to blow the snow on top, it was inevitable that the dome was loaded asymmetrically for a few minutes at a time. We all had the scare of our lives when the wooden props inside started popping and buckling. Fearing that the whole form might give way under the weight of tons of snow we stayed close to the exit. But even though the form work settled a foot or so, the dome consolidated and held. As with the catenary ice dome, the beauty of the dome was marred by the unevenness introduced by these unforeseen events. Lesson no. 8 was learned again.

The next day a week long thaw started, with temperatures as high as 10 degrees, and all of McGill seemed to be concerned about the well-being of the Pantheon. Despite the tropical temperatures, the thermal mass of the structure prevented disaster, losing only a few inches of its bulk in a week of thaw. Lesson no 2 proved its worth.

The form work could be removed the day the temperature returned to normal arctic levels. We were proud to be able to show Mayor Bourque the structure just when the dome could be seen without props; and it was another proud moment to welcome Principal Shapiro and Chancellor Chambers as well as many members of the McGill community into the structure after it was opened on January 26. That evening a concert by a McGill music student jazz combo was a magical experience: the cool music, the candle-lighting, and the hot mulled wine all contributed to the unique event. The massive snow walls and roof created an outstanding acoustic environment, while hardly a note could be heard outside in the crisp minus 15°C air.

The Ice Pantheon was built primarily to celebrate the Centenary of the School of Architecture. Friday February 2 was the night chosen to begin the centenary festivities. For the event Professor David Covo had carved into the portico pediment a marvelous scene portraying the Macdonald-Harrington building, the Engineering library, the Ice Pantheon and several reclining figures. A group of over 125 members of the School community gathered inside the Ice Pantheon after dark for a historic picture-taking session. The slow exposure time required, combined with the minus 18°C temperature, froze that event in our memory as well as in our limbs, as the suitably serious faces in the picture shows. The Centenary Committee Chairman, Professor Bruce