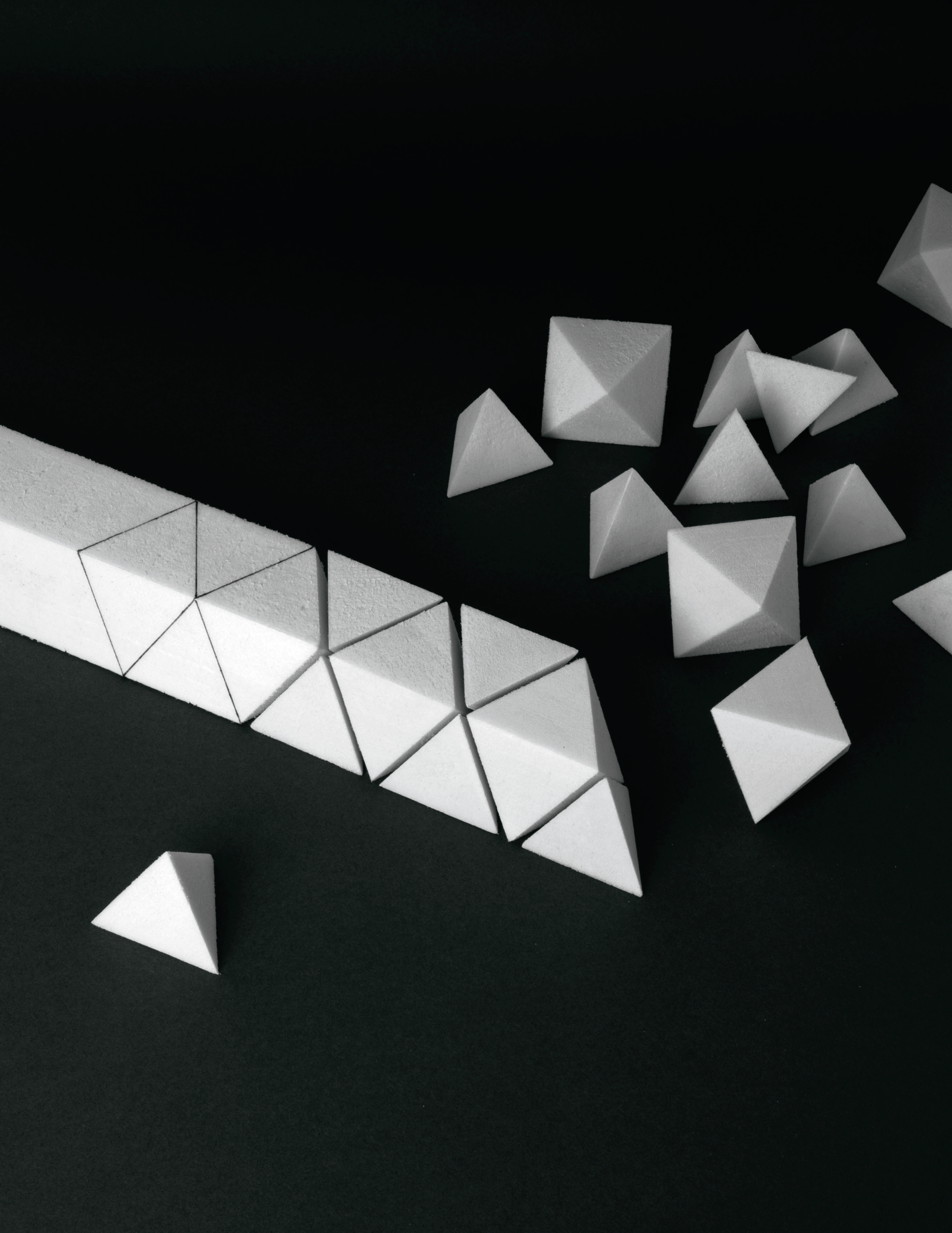


Alfred Lippincott

Fabricating the Sculpture of Tony Smith

When Tony Smith first came to Lippincott in 1979, the company had been fabricating sculpture for fourteen years—first in a wood-framed industrial hangar in North Haven, Connecticut, and from 1970 onward in a purpose-built, 20,000 square-foot facility located on the same site. Founded in 1966 by Donald Lippincott, the firm gained a reputation for its singular focus on working with artists to manufacture their sculpture in metal. The shop was an active and creative hub where artists could work among peers and see a broad range of projects in various stages of production. The fabrication process entails fully appreciating an artist's goals and then bringing state-of-the-art manufacturing, engineering know-how, and collaborative problem-solving to bear in order to realize the work at scale.

Always receptive to outside expertise, Lippincott complemented its in-house skills by regularly involving other companies. Following the closure of its own facility in 1994, Lippincott continues to fabricate and conserve sculpture in this manner. Having already produced steel sculpture at Industrial Welding in Newark, New Jersey, Smith was particularly interested in having Lippincott produce works in aluminum. Corrosion-resistant and one-third the weight of steel, aluminum was an excellent material for fabricating some of his pieces, especially the larger environmental sculpture. Since 1979, Lippincott has produced many of his works in both aluminum and steel. With their absorbing geometry, characteristic edge treatment, particular finishing requirements, and, in the case of his monumental works, surprisingly complex assemblies, Smith's sculpture poses considerable intellectual and fabrication challenges.

Previous spread: Plywood mock-ups in Smith's backyard, Orange, NJ, 1966–67: *Amaryllis*, *Cigarette*, and *Spitball*

Left: Space-filling polyhedra

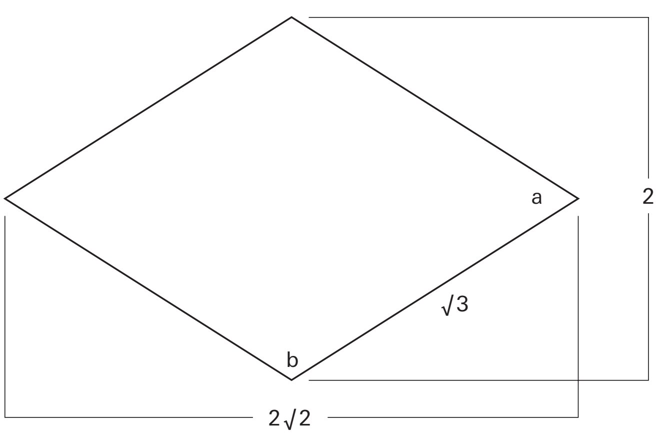
The Underlying Geometry

The fabrication of Smith's sculpture entails the practical and creative application of geometry at a basic level. Many of his works involve just two Platonic solids—the tetrahedron and octahedron—which serve as the organizing principles for making the forms. Smith understood that when placed closely together in a 2:1 ratio, these two polyhedra would form stackable rows capable of completely filling up space—just as cubes do, to cite a more familiar example. By arranging limited numbers of tetrahedra and octahedra while maintaining their space-filling relationship to one another, Smith developed a unique vocabulary and articulated a constellation of formal compositions. The resulting sculptures are simultaneously distinct from and embedded in this polyhedra-filled plenum, as though he had illuminated certain ones from within while leaving others in darkness.

This explains how works like *Bat Cave* (1969–71) can be arranged on a triangular grid, assembled from the ground up as individual polyhedra, and meet perfectly in space above—they exist within, and as a result of, the pervading geometric order. For Smith, this interplay of positive and negative space was an intrinsic quality of the works. Another innate quality of the dual-polyhedra construction that Smith observed and worked with compositionally was the multiple axes inherent in its basic arrangement. He understood that these multiple axes serve to animate the works by making surfaces and edges appear to slope and branch out in a variety of ways, even appearing completely vertical from certain angles as viewers move about them. This elegant geometry imbues the work with an enigmatic quality that holds viewers' attention and invites further examination. From a fabrication standpoint, the geometry serves as the unimpeachable guide for planning and assembly.

Smith's sculpture *Throwback* (1976), one of these dual-polyhedra constructions, was the first work Lippincott executed for the artist. Studying the geometry and seeing what Smith had done with earlier editions of this sculpture, the crew at Lippincott understood that the exterior surfaces of *Throwback* had to conform to the conceptual geometry, while the material thickness had to be resolved to the interior. This posed a significant layout challenge as panel dimensions departed from the theoretical surface geometry depending on their location, the angles at which adjacent surfaces meet, and whether panels abutted one another on inside surface edges or extended past one another. With the advent of computer-aided design (CAD) software, these kinds of complex calculations are made expeditiously today. But in 1979, each edge on each panel was considered separately using trigonometry to calculate the final panel sizes. Fabricated in aluminum with smooth, even radii at the panel edges, *Throwback* is a dynamic form that appears to zigzag through space and loop around upon itself as a viewer engages with its form. Interestingly, Smith rotated the piece out of its more conventional orientation—that is, sitting on one or another of its triangular surfaces—and instead set it on three linear edges, thereby adding to the spirited bearing of the sculpture.

Ten Elements (1975) is another painted aluminum sculpture with smooth radii at the plane intersections. Unlike *Throwback*, however, this group of forms does not involve assemblages of tetrahedra and octahedra. Instead, the work reflects Smith's interest in bisecting and rejoining parts of these two polyhedra and in creating prisms and rectangles from the sections exposed for use in further developing the forms. Dimensional relationships between edges based on the square roots of two and three ($\sqrt{2}$ and $\sqrt{3}$) can be found throughout. These relational harmonies were appealing to Smith, who employed comparable approaches to conceive and design other works, like *New Piece* (1966) and *Seed* (1968)—both parallelepipeds constructed using the



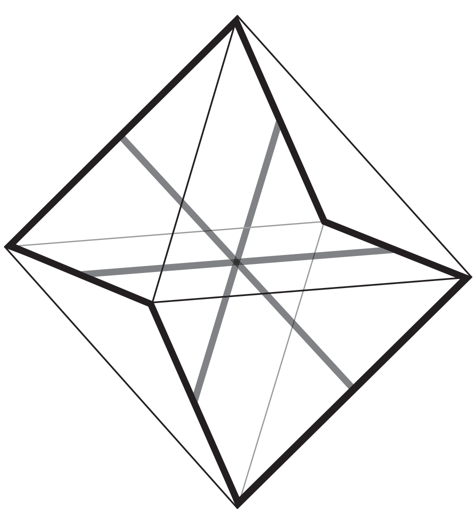
Typical rhombic dodecahedron panel


Moondog model with regular, rather than extended, octahedra

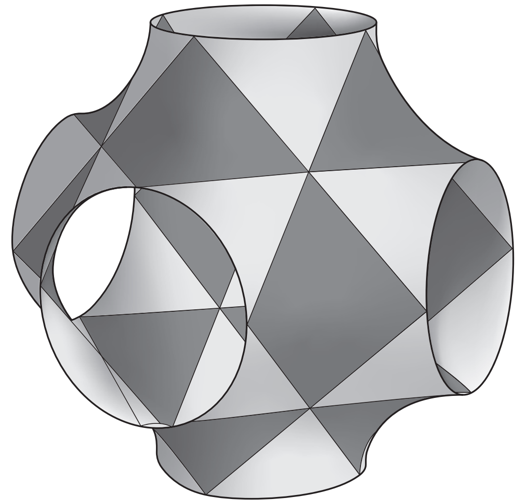
parallelogram found when bisecting an octahedron, or by considering the sides of a rhombic dodecahedron. Other sculptures combine the close-packed, dual-polyhedra orchestration of forms with the segmenting of components to create yet another branch of exploration. Most of the forms in Smith's *For* series, for example, exemplify this line of thought.

Perhaps the most radical and intriguing modification Smith made to the geometry used in designing his work is the elongation of the octahedra of an assembly along one axis while maintaining the tetrahedra in their customary position as junction units. The space-lattice sculptures *Moondog* (1964) and *Smoke* (1967) are examples of this simple yet innovative development. By telescoping the octahedra outward at 90° from the tetrahedral surfaces in this manner, Smith freed them from the rigidity of the close-packed, dual-polyhedra formula and enabled them to rise upward and outward from their established rows to create new angles of intersection and new spaces within. Lippincott made a model of *Moondog* using regular octahedra in order to observe this dramatic departure firsthand. The regular-octahedra version of *Moondog*, while pleasing, nevertheless appears squat, static, and earthbound in comparison to Smith's elongated-octahedra version. In the former, each of the four horizontal layers of the model remain stratified, and the openings, while composed of six octahedra, present themselves as primarily triangular apertures, whereas those in Smith's *Moondog* are dilated and ambiguous—neither triangular nor hexagonal but something in between. By extending the octahedra perpendicular to the angled surfaces of the tetrahedra, Smith effectively germinated the form, swelling it outward and lofting it into space. The transition from regular to elongated octahedra is even more pronounced in *Smoke*, which shares a similar arrangement of parts with *Moondog* but has additionally elongated octahedra, creating openings in the form that read as fully hexagonal when viewed straight on.

Another example of Smith's intriguing use of geometry can be found in *Fermi* (1973), one of his few works to incorporate a compound curve surface. Based on the artist's original vision, Lippincott was asked in 2012 to explore the possibility of manufacturing *Fermi* as a fifty-six-foot-tall inflatable vinyl structure. The resulting analysis led to yet another absorbing mathematical phenomenon: the minimal surface—or, more specifically, the Schwarz P (periodic) minimal surface, which is built from a network of identical skew quadrilaterals, each having a minimal surface spanning its four equal-length, non-coplanar sides. This basic skew quadrilateral is one of six that are formed when a skew hexagon, constructed using six of the twelve edges of an octahedron, is subdivided by lines connecting the middles of opposite sides. The minimal surface between the four sides of this repeating unit is simply the surface with the smallest possible area. When arranged with every other unit flipped over, in checkerboard fashion, the result is a triply periodic crystalline structure



Skew hexagon, composed of six skew quadrilaterals. Each plateau quadrilateral has two right angles, two angles of 60°, and four equal sides.

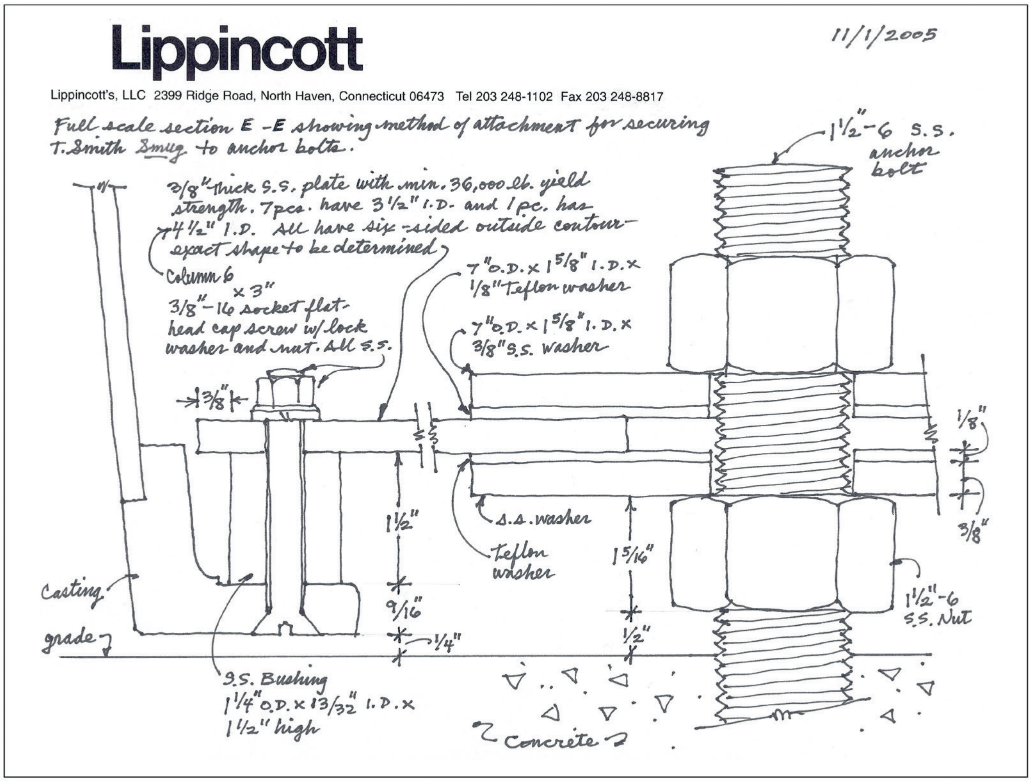


Triply periodic crystalline structure composed of skew quadrilaterals

that repeats itself in three dimensions such that the spaces within and outside of the surface are distinct and identical. A basic component of this labyrinth is the fireplug-shaped, space-filling element Smith stacked together to compose *Fermi*. Interestingly, Smith modified the Schwarz P form to suit his aesthetic. By altering the ends on the six arms of the fireplug element from a "squircle" (between square and circle) to a perfect circle—and making a subtle change to the minimal surface so that, when stacked together, the empty space within would remain isometric to the assembled form—Smith transmuted the organic, arterial quality present in the initial structure into something purely geometric. The intertwining of form and void in this case results in a work that is simultaneously there and not there: presence and absence in perfect balance. The seemingly paradoxical and not so easily visualized phenomenon of a constantly curving surface crisscrossed by straight lines adds to the existential mystery of this piece.

Structural Engineering

Structural-design criteria for large-scale sculptures, such as Smith's, are evaluated by structural engineers who consider a range of issues relating to the work. Among other things, they consider the strength of mechanical connections and calculate the forces that extreme wind and seismic loading can exert upon the forms. Based on their findings, guidance on such matters as internal structural reinforcing, fastener sizing, and provisions for anchorage are incorporated into the plans for construction. Structural reinforcing is typically achieved by



Section drawing showing anchor bolt detail of *Smug*

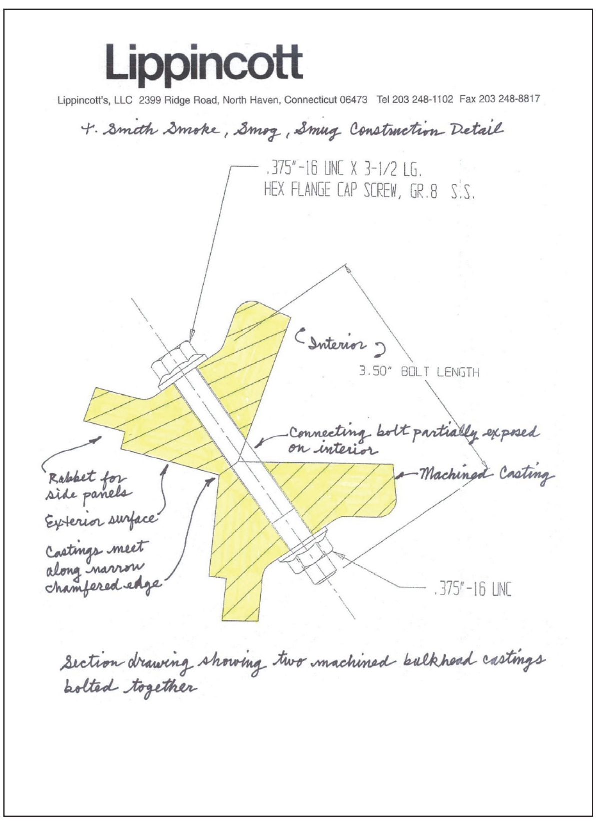
mounting angles and flat bars in a triangular grid against interior surfaces, combined with adjustable struts that run between opposing sides. Anchorage customarily involves incorporating gusset-reinforced, heavy-plate base flanges into the fabrication. These flanges are drilled to accommodate multiple threaded below-grade anchors. It is not unusual for the structural engineer to consider both the sculpture and the foundation design. For temporary exhibitions where sculptures need to remain freestanding, live-loading is also a matter for engineering analysis, and ballast is sometimes mounted strategically within a work to develop a margin of safety against overturning.

Smith's environmental sculpture *Smug* (1973) provides a good example of how engineering analysis can inform structural design. Covering an area of seventy-eight by sixty-four feet, this expansive, painted aluminum sculpture was too large not to account for the expansion and contraction that would occur during daily heating and cooling cycles. After calculating the magnitude of this potential movement, the structural engineer determined that the sculpture could expand and contract as much as three-quarters of an inch during each thermal cycle. Attaching the piece firmly to its foundations was, therefore, not advisable as it would result in racking and strain that would unnecessarily stress the construction. To address this, Lippincott designed a support system that met with engineering approval and allowed the sculpture to slide horizontally as it warmed and cooled. This system consisted of an inset stainless steel base plate within each of the twenty-two base prisms that rested atop a seven-inch-diameter Teflon disc with a similarly sized stainless disc just beneath it. These support discs were drilled to fit over one-and-a-half-inch-diameter, cast-in-place anchor bolts, one per prism, and held at the correct elevation by a nut and washer that had been located using a transit. To prevent uplift, the sculpture's bases were captured by a corresponding set of discs located above the base plate. These upper discs were secured by a nut and washer but not so tightly as to prevent the horizontal movement that needed to occur when the sculpture expanded and contracted.

Fabrication: Welding and Joining

With geometry and structural engineering taken into account, and material having been procured, the next steps in a typical Smith project are assembly and welding. Assembly for all but the monumental works is a painstaking but straightforward matter: using overhead cranes and forklifts, the sculpture's various panels and internal components are slowly stitched together while keeping track of angles of intersection and triangulating dimensions to ensure the work retains the proper shape. For works like *Throwback* that have smooth, even radii at the edges, welds are carefully ground down and dressed accordingly. For most of his works, however, Smith preferred the welds to remain as they are placed by the welder: neat, straightforward, and with the characteristic texture that naturally results when an experienced welder with equipment calibrated properly consistently weaves the molten puddle of metal in increments according to their reach, at which point they reposition themselves and start again. The welds for Smith's work are of the highest importance because, in addition to knitting the plates together, they function as a visual counterpoise to the planar surfaces.

The fabrication of Smith's monumental sculptures involves subdividing them into components that can be transported and assembled on site. Matching one component to another so that common surfaces are on-plane and connections are tightly fitting is accomplished by incorporating accurately machined, matched perimeter flanges into the construction wherever a join occurs. Made from heavy plate, these flanges are ground flat and precisely machined to reflect the geometry at the area to be joined. The outside edges of the flanges are machined with a step-shaped rabbet for the surrounding surface panels to lock into. Alignment pins and an array of matching through-holes in each set of flanges allow the two pieces to be located and bolted together. Smith's thirty-four-foot-tall sculpture *Generation* (1965) is composed of eleven such over-dimensional components—each so large that the trucks transporting them had to obtain special travel permits, follow prescribed routes during specific times of day, and move only with escort cars accompanying them front and back.



Section drawing showing bulkhead connection between units

Fabrication: Painting

To prepare surfaces for finishing, several techniques are employed. Steel and bronze sculptures are media-blasted with one or another abrasive grit products depending on how aggressive a cut is required and what surface profile is specified for a given coating. Aluminum sculptures are either media-blasted or machine-sanded using handheld, dual-action, random-orbit pneumatic sanders. Monumental works, like *Gracehoper* (1962) and *Generation*, require special fixturing to support their massive subcomponents during surface preparation, painting, and shipping. Steel fabrications typically receive a zinc-rich epoxy base-layer primer and an epoxy intermediate primer, with epoxy or polyester fairing compound applied as needed to address surface irregularities. Aluminum pieces are similarly treated but without the zinc-rich primer. Occasionally, a thin layer of zinc or aluminum is applied to steel faying surfaces, such as mating flanges, in a process known as thermal spray metallizing. This serves to forestall corrosion and prevent rust stains from weeping out from joins in the construction.

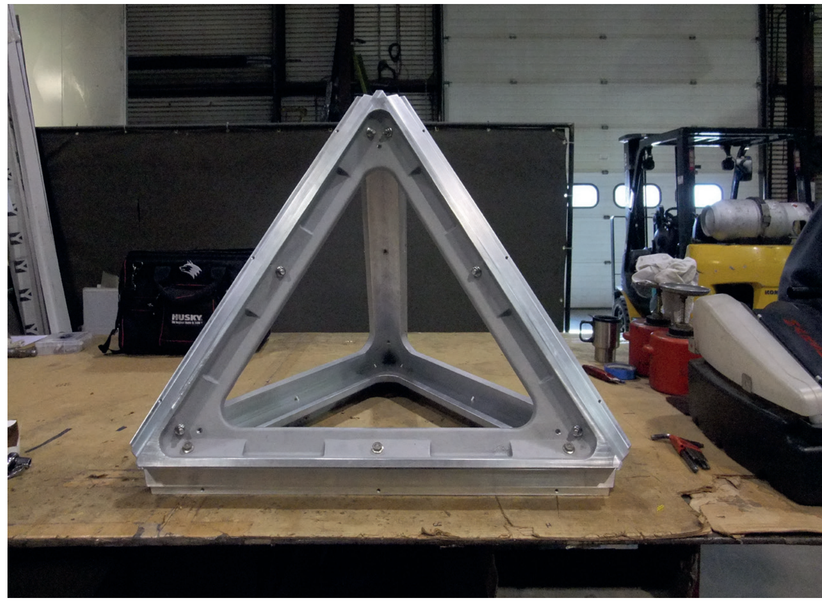
Applying a uniform topcoat of paint that is free of irregularities is the most difficult part of the painting process. A 1972 film shows the fabrication of *Gracehoper* at Industrial Welding and its subsequent installation at the Detroit Institute of Arts. The crew, working under Smith's watchful eye, brushes and rolls black paint on the sculpture following installation. In the early years, Lippincott likewise brushed and rolled works like *Marriage* (1961) and *Moses* (1968). A skilled painter can achieve a uniform application of paint while minimizing the patterning that results from roller overlap as they work across a surface. This application method, however, works best with single-component paints. More durable coatings—like catalystcured urethanes and, more recently, fluoropolymers—produce the most attractive finish when spray-applied. Brush and roller application continues to be used on Smith's sculptures located in high-traffic public settings where surfaces must be regularly repainted.

Small-scale sculptures, or those reducible to modestly sized components like *Smoke*, *Smog* (1969–70), and *Smug*, are easier to paint via spray application than large-scale works. Not only do they fit into an industrial spray booth, but their surfaces can be covered in short order so that the coating can level out without dryness or overspray. Larger works with expansive surfaces pose the greatest challenge to achieving a uniform, dust-free topcoat. Like rolled-on paint, spray-applied paint involves laying on the material in bands, first in one direction, then again in a perpendicular direction so as to minimize any application pattern and achieve a full, wet coat. Adding to the challenge, most coatings have specifications for dry film thickness that, unless carefully observed, can alter the gloss level from one area to another, resulting in a surface that looks splotchy and irregular. Some degree of mil thickness variation is unavoidable given the complex shapes of Smith's sculptures. Fortunately, with their many planar surfaces, Smith's forms can be painted in sections, and even one surface at a time, by masking the remainder off along the welds.

Fabrication: Precision Assemblies

Smith's environmental sculptures *Smoke*, *Smog*, and *Smug* are uniquely challenging to manufacture. The numerous elements composing these works have to seamlessly link together in space to form multiple hexagonal rings in order for the entire assemblage to come together successfully. Dimensionally, every component has to accord closely enough with the theoretical geometry so that minor deviations can be addressed by drawing components into position with custom clamps during installation. Each step in the manufacturing process is, therefore, geared toward achieving high dimensional accuracy, and every component is carefully evaluated to assure that finished parts are interchangeable.

During the construction of Smith's full-scale edition of *Moondog*, Lippincott developed the idea of a machined aluminum bulkhead that would serve as the primary interface at every junction in a space-lattice assembly. The bulkhead concept was further refined for the environmental works by increasing its size and strength so that it could house the bolts required for assembly, provide a rabbet for seating the side panels, and furnish an opening big enough for workers to pass through. Oversized aluminum castings are procured and then reduced to their final dimensions on a six-axis milling machine. The component forms of *Smoke*, *Smog*, and *Smug*, whether they were extended octahedra, regular octahedra, or prisms, all converge upon a tetrahedron when assembled. The bulkhead concept works because a portion of it extends into this tetrahedral hub. A common-angle chamfer is machined around the bulkhead's perimeter so that it occupies a portion of the hub's interior sufficient to accommodate bolting. Bolt holes are drilled perpendicular to the chamfer so that bolts can pass through adjoining bulkheads and hold them fast.



Bulkheads converging at tetrahedral hub

Initially, Lippincott made a four-piece, proof-of-concept bulkhead assembly to demonstrate how sculpture components would converge at the tetrahedral hubs. Next, a robust and highly accurate machined steel fabricating fixture was manufactured to hold two bulkheads the correct distance apart and at the right rotation during fabrication of the regular and extended octahedra. With a removable end to allow for disengaging the completed part, the fixture holds the bulkheads firmly while six accurately machined side panels are first bolted, then tack-welded, and finally fully welded in position. This practice of bolting and welding allows all the parts to be perfectly aligned and locked together prior to welding, thus minimizing warpage that might otherwise occur. Another feature of the fabricating fixture is that it allows for the part to be rotated while being worked on so that seams in the construction can always be upward-facing and accessible for each of the procedures. Once welded, parts are removed from the fabricating fixture and placed in individual, rolling frames that—like the fabricating fixture—allow the parts to rotate along their axis for easy access. Parts remain in their frames through finishing, painting, and shipping to minimize handling and protect delicate edges and points.

Interior Spaces

Many minds and hands have contributed to the fabrication of Smith's work. As mentioned earlier, Lippincott involves outside expertise whenever it adds substantively to the overarching goals of a project. Metallurgists, engineers, foundrymen, machinists, other fabricators, and even spelunkers have been recruited from time to time. Indeed, spelunkers proved invaluable for assembling *Smoke* and *Smug* as the assembly process required installers to crawl through the highly confined interiors of the components in order to bolt the parts together and fine-tune the fit-up. Equipped with headlamps and heavy kit bags, they navigated the branching, mazelike interior, moving from one unit to the next by wriggling through the triangular bulkheads that bookend each component. At ease within the restricted interior, the spelunkers worked efficiently and without incident, often taking the long route out so they could experience the interior of the assembly.

Fabrication of *Smoke*, showing partial assembly of sculpture, 2004

Smith's larger sculptures likewise contain remarkable interior spaces. When viewed from the outside, a sculpture like *Gracehoper* or *Generation* is quite naturally apprehended as a distinct object in space having identifiable features and attributes, surrounded by all of our usual reference points. The experience of the interior, however, is altogether different: sloping surface planes and structural reinforcements zigzagging throughout suddenly challenge customary reference points, and one's standing as an observer starts to feel strangely porous as the realization settles in that observer and sculpture are not entirely distinct from one another. The sculptural form becomes an inhabitable space, while everything outside its walls must be imagined. One is hard-pressed to rectify the interior space with one's understanding of the sculptural form as the geometry shifts from being an observable attribute to being directly experiential. With its encompassing embrace like a hand fixed mid-grasp, Smith's sculpture *Bat Cave* conveys this geometry-forward quality more than any of his other pieces, especially as it was presented at the Los Angeles County Museum of Art in 1971. There, visitors walked through the sculpture and experienced a roughly equal balance of positive and negative massing.

Tony Smith is one of many artists for whom Lippincott has produced sculpture since 1966. His work stands out both for its absorbing mathematical underpinning and its uniquely demanding fabrication and finishing requirements. Over the course of constructing more than a hundred of Smith's sculptures, Lippincott has developed a firsthand appreciation of the towering creativity he brought to bear in conceiving these objects, and the many challenges involved in producing works that optimally serve his aesthetic concerns. With their dimensional precision and complex construction, Smith's environmental space-lattice sculptures are arguably among the most exacting projects Lippincott has undertaken in its more than fifty years of fabricating artwork.

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