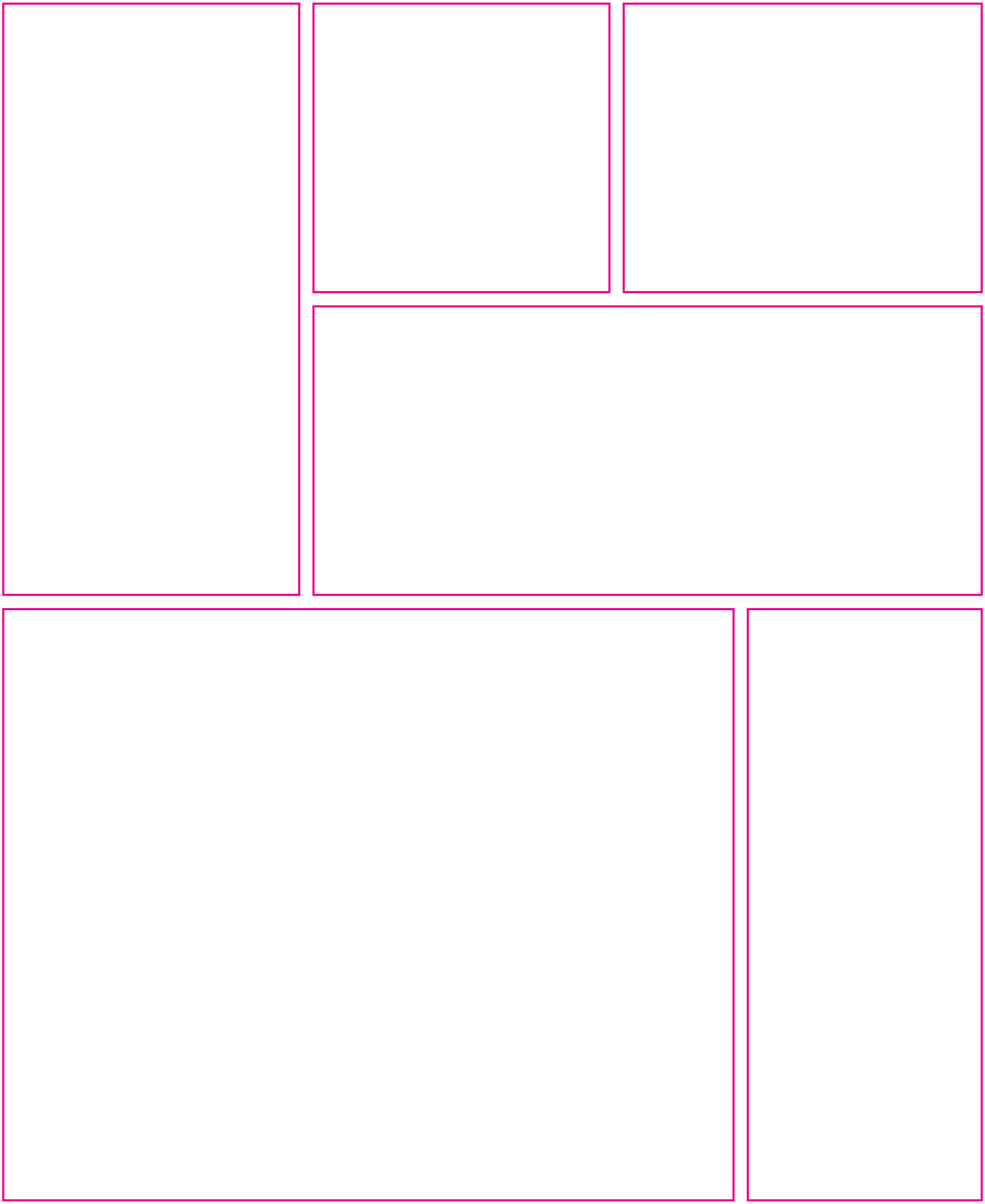
NANOARCHITECTURE

A NEW SPECIES OF ARCHITECTURE



NANOARCHITECTURE
A NEW SPECIES OF ARCHITECTURE

BY **JOHN M. JOHANSEN**

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PREFACE

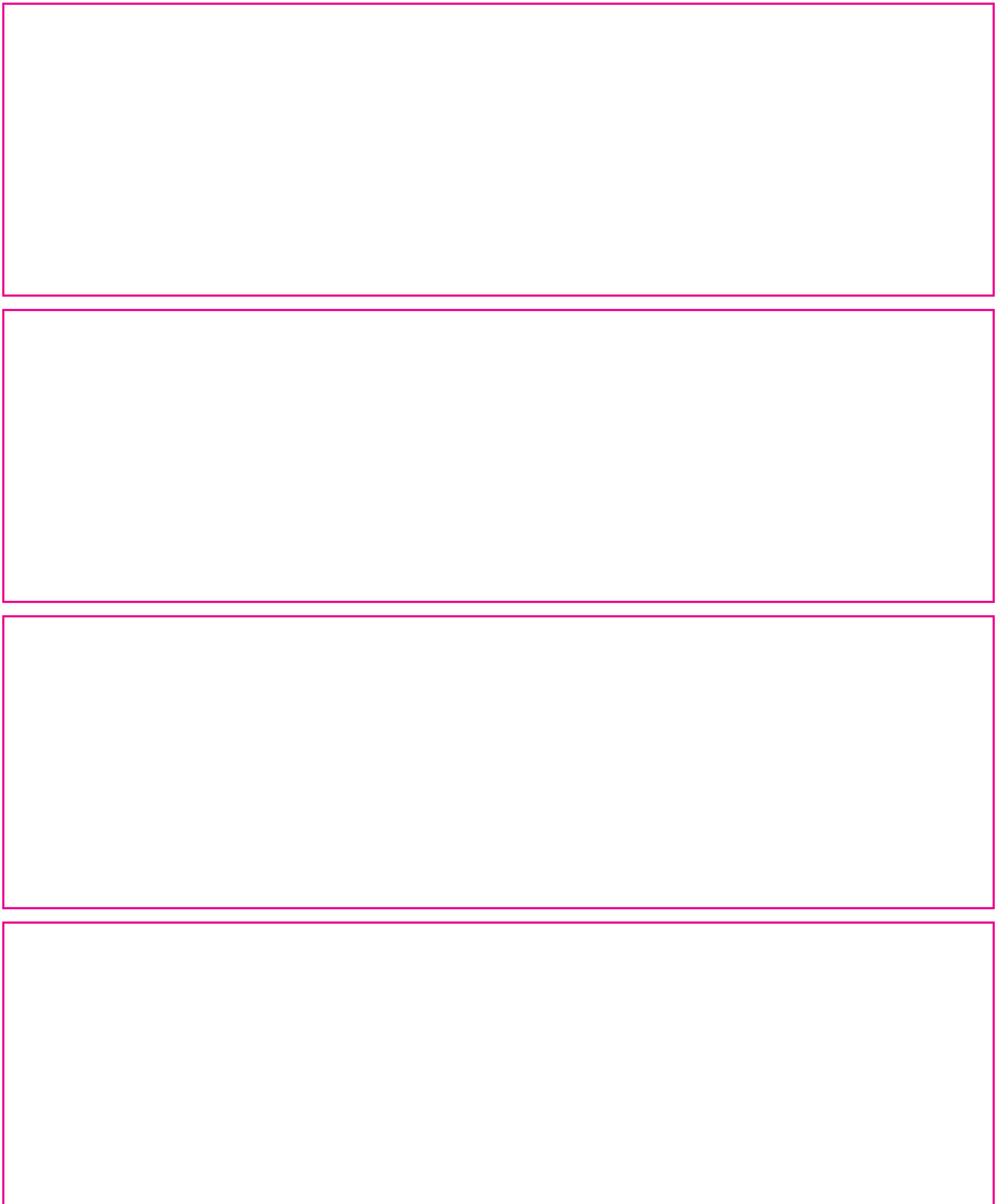
Although I have spent my career engaged in the practice of an architecture that deals with realities, the works presented here are, in a sense, not real. That does not make this a book of science fiction. The projects that follow apply emerging building technologies, some not yet in common use, others barely in the processes of research and development. These investigations use the power of the imagination in a search for an architectural expression that naturally evolves from each of these building technologies.

Some architects envision the future by concerning themselves with cultural change, demographics, functional accommodation, or a new aesthetic. I find my way into the future by seeking out newly developing building technologies. I am firmly of the opinion that architecture is, ipso-facto, structure, and that architecture, distinct from the other arts, is a "service art"; it is an art only insofar as its aesthetic expression draws from how it is built and how it serves.

In each of my projects there is, as well as a new structural system, a purpose and program of functional performance. As opposed to those architects who proceed in their designs from a preconceived final image to uncertain methods of construction—design from the top down—I insist on designing from construction to image. On the strength of these basic principles, there emerges a new aesthetic with a corresponding emotional impact. This aesthetic often makes reference to primordial and timeless spatial symbols, expressed in the updated terms of the new technologies.

Some of the projects included here demonstrate advanced applications of technologies already familiar to architects, such as hydraulics and pneumatics. Others borrow from more radical fields of technology: thin fiberglass shells (used in large boat hulls); kinetic structures (developed by NASA for use in space); electromagnetics; molecular engineering. Speculations as to when these technologies might come into common use vary from ten to one hundred years.

While we must wait for the realization of such proposals, we may contemplate or conceive of the nonexistent as possible. Imagination is sparked by an eager desire to know; by curiosity or inquisitiveness. It has been said that "much of yesterday's fiction is now reality, and that much of today's fiction may be the reality of the future." It is the human imagination that leads us.



JOHN JOHANSEN'S RESTLESS SPIRIT

KEVIN C. LIPPERT

On first meeting, John Johansen is an unlikely prophet of a new millennial architecture based on the latest revolutions in science and technology. Now in his mid-eighties, slightly stooped and hard of hearing, it seems a more propitious moment for him to bask in the current admiring rediscovery of midcentury modernism, including many elegant houses he built in the 1950s, than to be taking to the pulpit of experimental design based on nanotechnology, bioengineering, magnetic levitation, self-regulating structures, composite materials, and other developments more likely to be found in the pages of *Popular Mechanics* than the newsletter of do.co.mo.mo. It's a surprising twist for an octogenarian and former outspoken defender of the high-modern faith.

But the career of John MacLean Johansen, born 1916, the son of two successful New York studio painters, has been nothing if not full of surprising twists and turns. A 1942 graduate of Walter Gropius's Bauhaus-in-Boston Harvard Graduate School of Design, Johansen began his career at the apogee of American modernism. However, unlike most of his classmates, including Paul Rudolph, Philip Johnson, Edward Larrabee Barnes, and I.M. Pei, Johansen's dedication to the modernist gospel was not deep-seated, and even early on he proved himself a restless experimenter.

In truth, alternative voices were never entirely exiled from Harvard: Le Corbusier was a frequent visitor, and the venerable Frank Lloyd Wright urged students in his lectures—from which faculty were excluded—to "leave Harvard immediately" before they were corrupted. The influence of Alvar Aalto's organic romanticism could also be felt moving up the Charles River from MIT. The young Johansen was attracted to it all: in a kind of Borgesian catalogue he lists as early influences Wright, the "haunting austerity" of Gropius (who was to become his father-in-law), the "humble, almost childlike innocence" of Marcel Breuer, and the sculptural elementality of Le Corbusier's Ronchamp. To this list he later added: the thin-shell structures of Félix Candela and Pier Luigi Nervi, the strut construction of R. Buckminster Fuller, the rationalism of Mies van der Rohe's steel frames, Andrea

Villa Ponte (Warner House), New Canaan, CT, 1957

Palladio, Carl Jung's theory of archetypes, Gaston Bachelard's *Poetics of Space*, Italian Renaissance painting, systems theory, Japanese Metabolism, chaos theory, and more. Throughout his career, Johansen has been a kind of architectural omnivore, always fascinated by the stylistic, intellectual, and technological currents that have swirled around him.

In spite of his wide-ranging interests, Johansen's earliest works were nonetheless straightforward postwar modernism. After Johansen graduated from Harvard he spent the remaining war years building wood-frame Navy barracks and subsequently working as a researcher for the National Housing Agency. After the war, he was employed briefly as a draftsman for Breuer, and joined Skidmore, Owings & Merrill, where he worked "on loan" on the United Nations project under Wallace Harrison. In 1948 Johansen moved to New Canaan, Connecticut, where several other Harvard colleagues—including Breuer, Johnson, Eliot Noyes, and Landis Gores—were already encamped. This loose-knit circle, more social than professional, came to be known as "The Harvard Five."

Over the next ten years, Johansen built a series of elegant modern houses typical of the period. Johansen calls this his "Neo-Palladian" phase. Certainly the possibility of European travel after World War II provided a source of inspiration and delight for Johansen and his peers, especially given the antihistoricist stance at Harvard. Johansen wrote in *Architectural Forum* in late 1955 of "a new interest in the architecture of the past," and of the "timeless importance" of the abstract qualities of space and mass that he found in the Italian Renaissance—qualities hardly inconsistent with the kind of "domesticated" Yankee modernism already pioneered by Gropius and Breuer, and under further development in the hands of Johnson, Rudolph, and others.[1]

The houses of this period—like the Goodyear House of 1955 and the Villa Ponte, or Warner House, of 1957—were formally inventive, engaged their sites in clever ways (Villa Ponte literally bridged a stream), made use of luxurious materials, and were accomplished in their knowledge of the stylistic and tectonic developments of their day. They were also well received—the

Warner House was a *Record* house in 1958—and Johansen's residential practice flourished.

Johansen found the simplicity, balance, and order of these Neo-Palladian designs "exhilarating," so it makes the out-of-left-field appearance of his "Spray-Form" projects—thin-shelled concrete structures that resemble nothing if not flowers—that much more startling. Commissioned by the American Concrete Association as part of an ongoing series of demonstration projects, the British critic Reyner Banham hailed them as symbolic of a conversion to the religion of technology; Johansen remembers them more as an effort to distance himself from "the modern box" as well as experiments symptomatic of his "insistent spirit of investigation."[2]

Spray House #2 of 1955 typifies these projects. Intended as a residence for Johansen and his family, the house was framed by steel rods bent into shell-like shapes that were fastened together at a central point. These rods were then covered with smaller rods, and again with paper-backed steel mesh. Concrete was to be sprayed directly onto the armature, making a rigid shell approximately 8 inches thick; the resulting shell was to be coated outside with plastic for waterproofing, and inside with sprayed insulation and paint. Clear plastic would fill gaps between the shapes to create windows. Floors, walls, and ceiling would form one continuously smooth surface, like the inside of a seashell. Radiant heating coils would be embedded in the walls; furniture, steps, and shelves were similarly to be incorporated into the structure itself. The great advantage of this construction process was that no formwork was required, resulting in both more organic forms than traditional poured concrete would allow, as well as lower cost.[3]

Although "gunite"—sprayed concrete—was invented in 1907 by Carl Ethan Akeley, who needed a way to spray aggregate onto mesh to build dinosaur models, the technology was, and is, more commonly used for building swimming pools. Le Corbusier used it at Ronchamp (1950–55) with an effect on the architectural world as electric as Frank Gehry's Bilbao Guggenheim today, and was most likely the inspiration for Johansen's explorations in crustacean forms. It is also likely that Johansen was aware of the highly publicized thin-shell structures of Félix Candela and the ferro-cimento structures of Pier Luigi Nervi. Whatever its origin, the biomorphic appears as a liberation for Johansen, and, although Spray House #2 was never built, he used the idea for a series of projects that followed in rapid succession, including the United States Trade Pavilion at the International World's Fair in Zagreb (1956), a church in Norwich, Connecticut (1957), and a restaurant and motel compound in Mt. Kisco, New York (1957). It seems likely that his spray-form houses influenced the architect/artist Frederick Kiesler, who developed a series of versions of his own "Endless House," a similar biomorphic shell structure. Certainly Sanford Hohauser's 1956 project for a Beach House, also to be built with gunite, closely echoes Johansen's earlier design.[4]

Unlike Kiesler and Hohauser, however, Johansen succeeded in having one of his shell projects built: the Zagreb Trade Pavilion. It was not, however, a happy experience: Johansen complained that the Yugoslav concrete, and workers, were of low quality, and the structure consequently required secondary support. Whatever the failings of the project, it did attract attention in Europe: in London, the Archigram group went so far as to label Johansen's "stomach-like" shapes "Bowellism," "For the boys in Archigram," wrote Archigram member Michael Webb, "(Johansen) was our genuine American hero: each successive project a radical departure not only from conventional practice, but even from his own previous oeuvre."[5]

While Johansen's experiments in biomorphism garnered him notoriety among the European avant-garde, it was his reputation as a classical modernist that procured him the commission to design the American Embassy in Dublin in late 1956. The project went through six iterations, as Johansen struggled to find a solution that would be acceptable to a series of committees made up of technocrats, architects, and politicians. The final design, a three-story circular tower, became a political football, and was built only after the direct intervention of newly elected President John F. Kennedy, eager to improve relations with Ireland. Even within the simple parti of the drum, however, Johansen could not resist a bit of

Spray House #2, 1955

structural bravado: The embassy, completed in 1963, is assembled from a series of interlocking precast concrete panels with twisted vertical supports.

If Johansen was looking for the Dublin Embassy to bring him institutional commissions, his wish was soon granted: on the heels of the Dublin embassy followed Clowes Memorial Hall and Opera House on the campus of Butler University in Indianapolis (1964), the Orlando Public Library (1966), the Morris Mechanic Theater in Baltimore, Maryland (1967), and the Goddard Library of Clark University in Worcester, Massachusetts (1968).

These buildings fit neither the modern nor biomorphic molds of Johansen's work to that point, but mirrored new tendencies in the architecture of the period, of which two stand out: First was the so-called New Brutalism, pioneered by Le Corbusier, codified by the critic Reyner Banham, and imported into the United States by Louis Kahn and Paul Rudolph, under whom Johansen taught at Yale from 1955–60. The second was the bias toward engineering and systems theory seen in the work of Archigram, R. Buckminster Fuller, and others. All were symptomatic of the breakdown of modernism and the expansion of architecture to include broader social, technological, and even political agendas. Johansen's buildings of the immediate post-Dublin period reflect these influences: like many of his peers—Eero Saarinen, often criticized for his eclecticism, comes immediately to mind—Johansen was warily feeling his way, and would later write that his buildings of this epoch suggested "no clear direction of design."[6]

US Embassy, Dublin, 1956-63

The Library at Clark University is the most successful of Johansen's brutalist buildings. Johansen called it his "first modern building," meaning the first where he "presided" over the design of the building, "letting it exercise its growing confidence and will and assert its purpose."[7] The spiritual overtones were a direct nod to Louis Kahn's dictum "what the building wants to be"—Kahn was on the faculty at Yale with Johansen until 1959—as was Johansen's strategy to let the form emerge through the revelation of the constructional process.[8] Writes Johansen:

> On encountering the final form, there is a feeling that one has come

Morris Mechanic Theater, Baltimore, 1967

upon the various parts of the building in the process of assembly or attachment. The form is evolving and alive, not fully at rest. It is, in the terms of systems theory, a configuration: "an integrated whole whose ultimate value is greater than the sum of the properties and functions of its parts."[9]

If the rhetoric derived from systems theory, the tectonic vocabulary was pure brutalism: Johansen described the elevations, admiringly, as "like the rear side of a Xerox copier with the components and their connections rigged on a structural chassis and simply exposed."[10] The "push and pull" external aesthetic treatment, resulting in highly articulated facades—glass reading rooms angled out on the west, carrels protruding on the east—were lavishly praised at the time: Melvin Charney heralded the "frank accumulation of the parts." Peter Blake concurred: "(Here) Johansen places himself firmly on the side of letting the unpredictable happen, without preconceptions of order."[11] Even the sometimes cantankerous Sibyl Moholy Nagy found in the exteriors "a true dynamism," although she derided Johansen's description of the building as "a combination of rigidly predetermined, dehumanized solutions of 'electronic devices' coupled with an adolescent romanticism, addicted to the unpredictable happening, without preconceptions of order." It is at the Clark that we see the first inklings of Johansen's coupling of scientific theory with his already well-developed interest in structural exhibitionism.

This interest in systematics found freer expression in other, non-institutional projects. The admiration of Archigram was mutual, and Johansen felt that they, along with the English-based Team 10 and the Japanese Metabolists, had "awakened architecture to new ideas." Founded in 1960, Archigram shook the architectural world on both sides of the ocean with its comic-book images of intricate architectural structures ranging in size from the personal to the colossal. Among these, founding member Peter Cook's Plug-in City of 1963–64, infinitely changeable by plugging or unplugging habitable capsules by means of cranes carried on tracks across vast multistoried structures, had special resonance for Johansen.

If the Clark Library was conceptually a building as frame, that is, a chassis from which the “components” or rooms would be hung and connected via “circuits” or halls, Johansen House #2 (1972) was literally a chassis. Thirty feet square, three stories high with tapered sides, and hand-built by Johansen, the house is a steel frame with sixty-four “attachment points” from which platforms and living spaces are suspended, braced by high-tension steel cables. The entire house is covered by translucent plastic panels, giving the appearance of a plastic tent. Ductwork is intended to be ad hoc, assuming “serpentine forms as they wait to heat rooms in a future whose location is yet to be determined.”[12] This “plug-in/clip-on” strategy, a direct nod to Archigram, allowed great flexibility in reconfiguring living spaces and was economical to build: Johansen intended to market the house as a kit, and figured a house could be constructed for a few thousand dollars.

Johansen’s interest in the kinetic dated back to 1960, when he designed a house with rooms mounted on railroad tracks to allow easy reconfiguration, based on weather, functional requirements, or simply whim. These ideas were transposed to a larger scale in the Leapfrog City proposal of 1966, a theoretical project exhibited at the Metropolitan Museum of Art. Here Johansen imagined a structural latticework that would straddle New York, serving as scaffolding to provide travel, services, and clip-on buildings: as the new infrastructure developed above the existing ground plane, the old city could be removed, possibly reverting to “field and stream.”[13] A smaller, and more realizable, version of this idea resurfaced as late as 1985 in Johansen’s proposed Miami Beach Resort Hotel, where prefabricated guest rooms would be attached to a pyramidal steel framework.

These two influences—brutalism and systems theory—came together in Johansen’s most successful project of this period, the Mummers Theater (now Oklahoma Theater Center) in Oklahoma City (1965–70). In describing the building in an article for *Architectural Forum*, in May 1968,

Goddard Library, Clark University, Worcester, MA, 1986

Miami Beach Resort Hotel, 1985

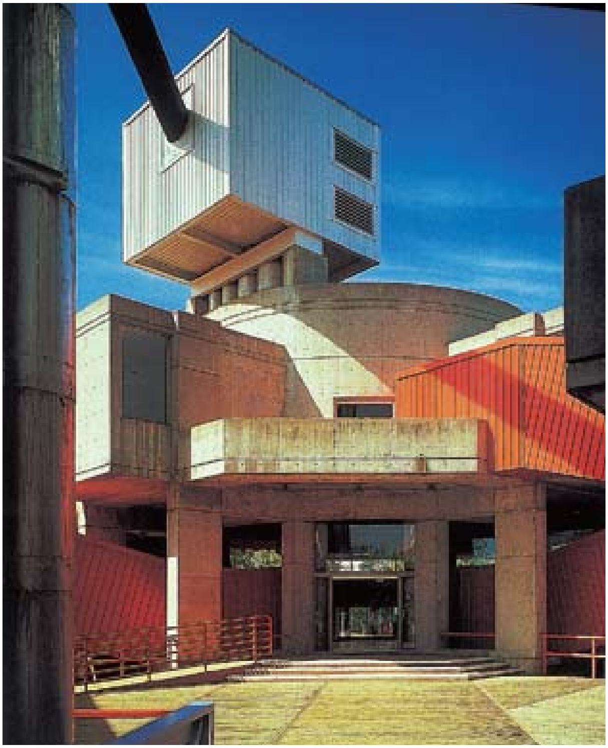
Johansen was already taking pains to distance himself from “classicists” like Johnson and SOM and “picturesque designers” like Kahn and Rudolph. He self-deprecatingly includes himself—at least his earlier work—in this category, and, willing to leave it all behind, states his “new position,” one concerned “not with gestural form and with masterworks of architecture, but rather with processes, with action, with behavioral patterns, and how most simply all these may be accommodated. This new position is concerned with an ‘organizing idea’ or an ‘ordering device.’ The idea or device will derive from motivating processes—processes of personal and of societal behavior, and of highly industrialized building techniques.”

“Architecture as we knew it,” concludes Johansen, “is no longer effective in its solutions, nor even compelling in its esthetic expression.”[14] Certainly evocative of the antiestablishment rhetoric of May 1968, and inspired by his readings of media critic Marshall McLuhan and cybernetics guru Norbert Wiener, Johansen declared his new Mummers Theater “not a building as we have known it, but a fragment.” Indeed, Johansen found his formal inspiration in the complex beauty of electronic circuit boards, with their “components and subcomponents” plugged into a “chassis” and connected by “circuiting systems” superimposed at different levels to avoid cross-circuits. The Mummers Theater reflects these subdivisions by dividing its component programmatic elements— a school and two theater spaces—with their "subcomponent" support spaces (offices, backstage), and joining these with "circuitry," both circulation, such as ramps, stairs, and bridges, and mechanical systems, like ductwork and plumbing.[15] Materials reinforce these subdivisions: component pieces are blocks of raw poured-in-place concrete, while subcomponents are of brightly painted sheet metal. It seemed to the critic Michael Sorkin "a bubble diagram come to life," and the resulting "ad-hocism" presages the neo-expressionism of Hans Scharoun and Frank Gehry, and certainly seems the progenitor of the color-coded, inside-out Pompidou Center (1971– 76).[16]

The sense of spirit exhibited in the Mummers Theater all but disappeared in Johansen's work in the period from 1973 to 1987, when he shared an office in New York with Ashok Bhavnani; many of the buildings of this time, such as his Roosevelt Island housing projects (1975–76) were nondescript, and Johansen, now in his sixties, clearly felt betrayed by the "trivialities" of post-modernism.[17] But, perhaps not coincidentally, Johansen's spirit of experimentation seems to have taken refuge in his sketchbooks, in a series of conceptual, unrealizable projects. Although many were no more than doodles based loosely on scientific ideas, they provided the seeds for the conceptually rich projects that followed. The sketchbook projects of this period range from the whimsical, if not frivolous—for example, the Pavilion of Earthly Delights, a "gravity-free spatial adventure" where "rising passions set up an electro-magnetic field that neutralizes gravity"—to the visionary, like the Simulated Cloud of 1985, proposed first as a chapel for the Miami Beach Resort Hotel and then as a "free-floating," helium-supported conference center—a clear antecedent to Diller + Scofidio's much-publicized Blur Building of 2001.[18]

As early as 1966, Johansen wrote, in *The American Scholar*, of "An Architecture for the Electronic Age," in which he identified numerous influences of electronics on architecture. These included: the imitation of electronic equipment in the forms of architecture; the adoption of the organizing principles of electronic systems (as in the Mummers Theater project); the use of computer graphics and image processing (which, in hindsight, seems particularly prescient); a communications explosion, leading to more dispersed societal and building patterns; the rise of television (and subsequently computers and electronic games), which have "retrained the perceptive habits" of younger architects; and finally cybernetics, which can eliminate the need for humans in certain roles. Almost twenty years later, Johansen repeated his belief in a "technological imperative" for architecture, but now found in technology not only a practical or mimetic function, but a poetic one as well: it provides an "inspirational spin-off" and "romantic excursions into tech-

Miami Beach Resort Hotel



no-esthetics and fantasies of the future" drawn from "science fiction, or more correctly, technology-fiction."[19]

By the late 1980s, Johansen was trumpeting a "New Modernity," one based on a more holistic reading of science and technology. In an eponymous article, published in 1989, Johansen urges a rejection of the mechanistic model of Cartesian and Newtonian science in favor of a "holistic and ecological" world view, a "systems view of life." Influenced by his reading of systems theorist Frijtof Capra, Johansen called for an architecture where "all functions, services, structures, equipment, and aesthetic effects (are) designed as an inseparable whole."[20] The machine is replaced as a paradigm by the organism: function is no longer determined by structure, but structure is now determined by process. The house is no longer a machine for living, but lives itself. Johansen imagines buildings less as "static and lifeless mechanisms," but more as self-organizing and self-regulating, like "programmed walking robots, approaching the nature and characteristics of living systems." To do this will require new materials—Johansen envisions carbon-plastic composites, structural foams, and sprayed-on membrane skins of "adjustable permeability to light, temperature, and air"—kinetically controlled by a central nervous system. Computers monitoring sensors will allow self-regulating buildings, up to and including structure: cables supporting buildings might be adjusted in real time to accommodate

The Mummers Theater, (Oklahoma Theater Center), Oklahoma City, OK, 1965-70 shifting loads. Alternately, traditional structure—posts, beams, panels, et al.—could be phased out in favor of "fused" enclosures of seamless continuity. Gravity itself might be cheated, via magnetic levitation: if Japanese passenger trains can hover, why may we not "fully expect to reshuffle parts of our buildings"?[21]

While many of the technological elements Johansen envisions do in fact exist, the ten hypothetical projects illustrated in this volume have an overlay of science fiction. A boy's model-making fantasy come true, Johansen's models have a bric-a-brac quality, courtesy of his collecting trips for surplus hardware and industrial parts on New York's Canal Street, and his use of scale figures and backdrops create a science fiction, stage-set atmosphere. But Jetsons-chic aside, most of the projects herein are based on the sophisticated—if currently unfeasible—technological concepts Johansen outlined in his "New Modernity" article of 1989. The Froth of Bubbles posits permeable, "living" membranes and serpentine, magnetically levitated elevator capsules. The Web, a conference center that would have been suspended between the towers of the World Trade Center, requires a self-regulating structural system to dynamically tension the supporting cables in response to shifting wind or live loads. The Mag-Lev Theater expands the flexibility of the Mummers Theater to new heights, with either a magnetically levitating stage or a magnetically levitating audience.

But most radical are Johansen's "molecularly engineered" projects, buildings that are developed from an architect's code—presumably a sort of tectonic DNA—and then literally grown on site. The petal-like structures clearly echo his earlier Spray-Form houses—and indeed, furniture and equipment grow "as extensions of the house structure itself"—but now the building, responsive, adaptive, self-sufficient, has intelligence of its own, capable of learning from its environment and changing in response, "resulting in a higher state than we now conceive of contextualism and environmentalism."

The architect has become simply the parent who endows his creation with the seeds of his knowledge, and sends it on its way to grow and hopefully flourish in the world. While some might see in this scenario the seeds of Dr. Frankenstein (what if your new house gets hungry?) or a naïve oversight of the darker sides of modern technology, it signals, in the view of Lebbeus Woods, a radical transformation of architecture:

> Composition is gone, because the thing continually recomposes itself within an almost infinite range of possibilities. Function is gone, because it is unknown in advance. Structure...is gone, because it is entirely fluid-dynamic, nonlinear, even mathematically chaotic. All that remains is an intimate and unpredictable interaction between the inhabitant and the architecture.[22]

If Johansen's built works seem in many instances emblematic of the

The Froth of Bubbles, 1988

The Web, 1989

stylistic and intellectual concerns of their time, it is these latest, most fantastic, projects—many undertaken in Johansen's ninth decade—that promise to be his most lasting contribution to the architectural canon. They speak of a man who has tirelessly refused to abandon his optimistic faith in the processes of science—"search, exploration, invention, deductive thinking, problem solving"[23]—undertaken in the pursuit of transforming ourselves and the world. "The task for architects today," writes Johansen, "is to seize hold of new technologies, judiciously apply them to building, delight in the symbolic potential, and endow them with poetic expression." If we take anything away from this book, it should be a healthy dose of this optimism.

01 See Alastair Gordon, *Weekend Utopia: Modern Living in the Hamptons* (New York: Princeton Architectural Press), 59; and Ulrich Conrads and Hans Sperlich, *The Architecture of Fantasy* (New York: Praeger, 1960), 78–9.
02 John M. Johansen, *A Life in the Continuum of Modern Architecture* (l'Arca Edizioni, 1995), 31.
03 "Sculpting with sprayed concrete," *Architectural Forum* (October 1959): 167–8.
04 Gordon, *Weekend Utopia*, 59; and Conrads and Sperlich, *Architecture of Fantasy*, 78–9.
05 Johansen, *Continuum*, 33.
06 Johansen, *Continuum*, 37.
07 "John M. Johansen Declares Himself," *Architectural Forum* (Jan.–Feb. 1966): 64–7.
08 See Kenneth Frampton, *Modern Architecture: A Critical History* (London: Thames and Hudson, 1992), 243–6 on Kahn's principles.
09 "Johansen Declares Himself," *Architectural Forum*, 64–7.
10 The building recalls Stirling's Leicester Laboratory (1959), which Johansen had visited with the architect a year before designing Clark. Johansen also recalls Stirling "extolling the rear undesigned sides of buildings" at dinner parties Johansen hosted during his Yale days; Stirling had been a visiting critic at Yale in 1959 at Rudolph's invitation. Johansen, *Continuum*, 19 and Robert A. M. Stern, "Yale 1950–1965," in *Oppositions 4* (October 1974): 51.
11 Melvin Charney and Sibyl Moholy-Nagy,

"The Rear End of the Xerox or How I Learned to Love that Library," *Architectural Forum* (May 1966): 60–1.

12 Johansen, *Continuum*, 60.

13 Ibid., 12.

14 John Johansen, "The Mummers Theater: A Fragment, Not A Building," *Architectural Forum* (May 1968): 65.

15 Ibid.

16 John Pastier, "Something Else Altogether in Oklahoma City," *AIA Journal* (August 1981): 40–6.

17 Lebbeus Woods has called postmodernism Johansen's "*bete noire*," and indeed it corresponded to a decline in his commissions. Following the Roosevelt Island housing project, he built only a cluster of office buildings in Quincy, Massachusetts. Lebbeus Woods, "John Johansen's Present Tense," in Johansen, *Continuum*, 156–66.

18 Johansen, *Continuum*, 115–21.

19 John M. Johansen, "Architecture: Three Imperatives" *Architecture* (March 1984): 156–64. Johansen's two other imperatives—"Organic" and "Psychosocial"—are also framed in scientific terms: "The principles of this (organic) model draw from the natural sciences." The "Psychosocial" is a plea for calling on and communicating certain Jungian archetypes—the cave, house, forest, labyrinth, and the tower. Johansen updated this essay for his 1995 *Continuum* book, re-entitled "Degeneration and Regeneration: Postmodernism and the Prodigal Sons."

20 John Johansen, "The New Modernity," *A+U* (September 1989).

21 Ibid.

22 Woods, "Johansen's Present Tense," 156–65.

23 Johansen, "The New Modernity."

The Maglev Theater, 1990

Multistory Apartment Building, 2001

THE NEW SPECIES OF ARCHITECTURE

What are the grounds for my claim that a new species of architecture is evolving? First of all, it must be stated that *species*, a biological term, is only an analogy. By definition, a species is a category within a system of classification of living organisms, and new species are recognized by their distinctively different characteristics. This applies to a new breed of architecture that takes advantage of the remarkable capacities of electronic intelligence. The popular term "smart building" can only begin to explain the profound nature of this architecture and the transformation it augurs.

Indeed, the analogy between buildings and organisms is only becoming more evident. Even today, buildings, in their content, design, and performance, can meet the definition of an organism: a whole with interdependent parts (organs). In the case of contemporary buildings, these organs translate to vertical transportation, HVAC (heating, ventilation, and air-conditioning), and security systems, among others.

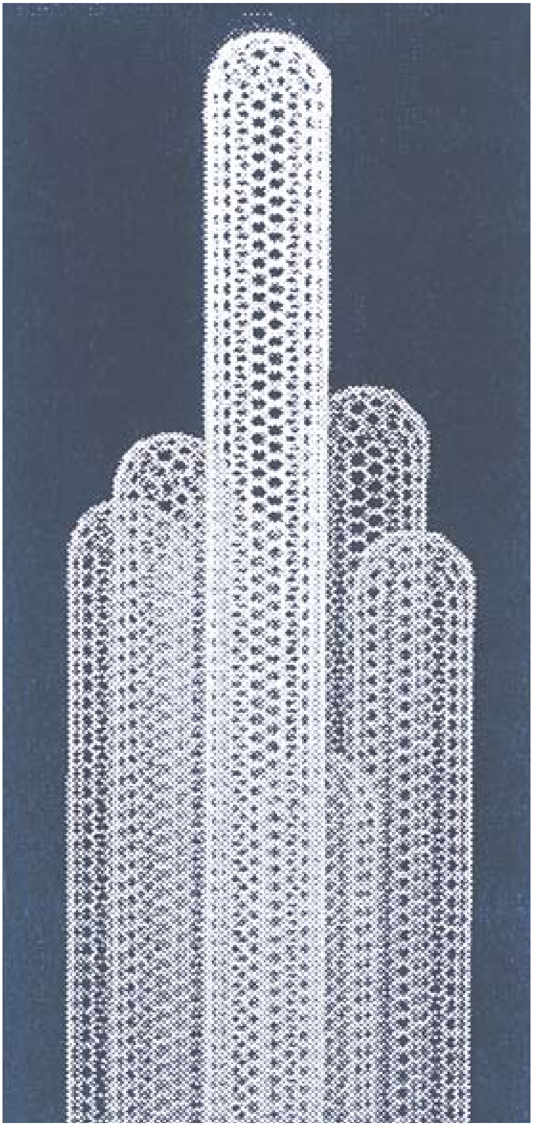
The new species of architecture, however, will acquire attributes more directly analagous to those of living organisms, in four general categories:

– First is self-organization, the interrelation and interaction of the organism to its immediate environment. Here, the organism adjusts or adapts to surrounding conditions. It responds to all manner of local, seasonal, and daily, conditions.

– Second is self-regulation, by which the organism coordinates the functions of its independent organs to mutually advantageous performance. In architectural terms this translates to the constant monitoring of the needs of the occupant and the building itself, and in response to those needs, the coordination of all services and technical functions.
– Third is self-diagnosis of malfunction. The system of the living organism is uniquely equipped to perform in this capacity. Soon, buildings will do so as well.
– Fourth is self-healing, the rebuilding of deteriorated materials as the organism replaces damaged tissue.

These four capacities until now have been recognized as being faculties endowed only to living organisms. As high-tech buildings advance in sophistication, they appear to incorporate, artificially, the processes and performances of Nature itself. To speak in biological terms is to see buildings differently, and psychologically to be liberated from outdated concepts and experiences of buildings as we now know them.

As we move into the future, the field of molecular engineering represents a new frontier for architecture. In the process of computer coding, buildings will be designed, grow, and perform just as living organisms directed by their built-in DNA. At some point the relationship between the building and the living organism will be more than the subject of analogy; they will be one and the same.



PARTNERS IN SPRING
(with reference to molecular engineering in the year 2199)

In the company of all that grows this spring
I grow my house!
With curiosity, man has always witnessed Nature
in this, her secret process.
Now man, in Nature's process can take part.

I place a “seed,” artificial DNA,
blueprints for what my house will be.
Planted, as in earth, the roots reach down
to nourishment for its upward growth,
as molecules replicate and vastly multiply.

A vascular system distributes up as well,
through stalks and trunk—my columns;
to branch and rib—my structure and support;
into living membranes—my canopy and roof.
Will I live within my living house, in symbiotic peace?

I may live there with troubled soul.
For I have intervened in Nature's secret ways.
Again, I may find peace, if I design with spirit
Yet not "outdo the modesty of Nature."
So will I be her partner in the glory of his spring.

—John M. Johansen

FROTH OF BUBBLES

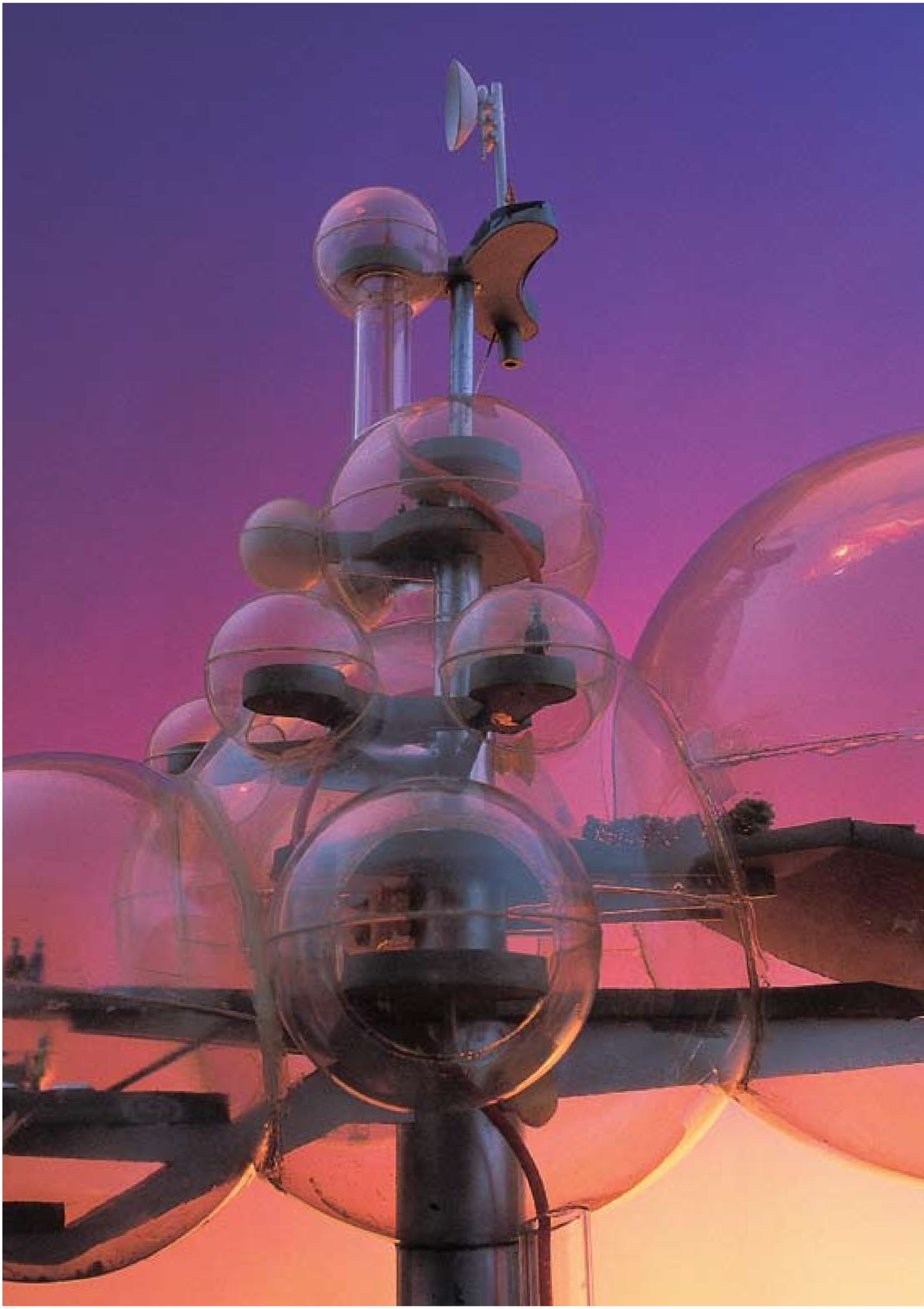
This conference center grafts onto the roof of another building. Its support structure is a self-extendable telescoping mast, delivered by helicopter. Transfer of the central load of this mast is distributed by a space frame that connects to the structural system of the existing building.

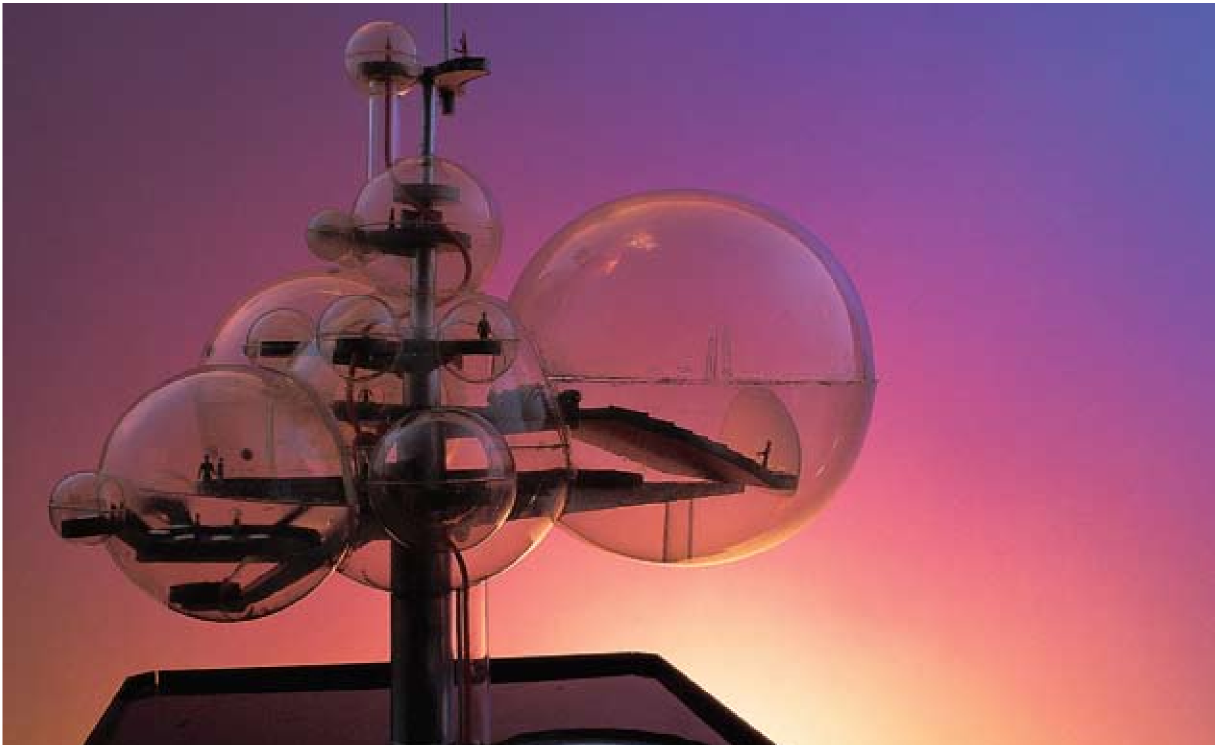
From the mast, lock-hinged brackets fold out to support the various floor platforms of the center. Inflated "living membranes"—balloons—then enclose the platforms. Such inflatable membranes have been in use for some time, though a cluster of air chambers of this complexity has never been realized. The primary difficulty is the equalization of air pressures sustained in the various spherical volumes. Here, this process is controlled by monitors connected to a central computer that activates air pumps that stabilize the various bubbles.

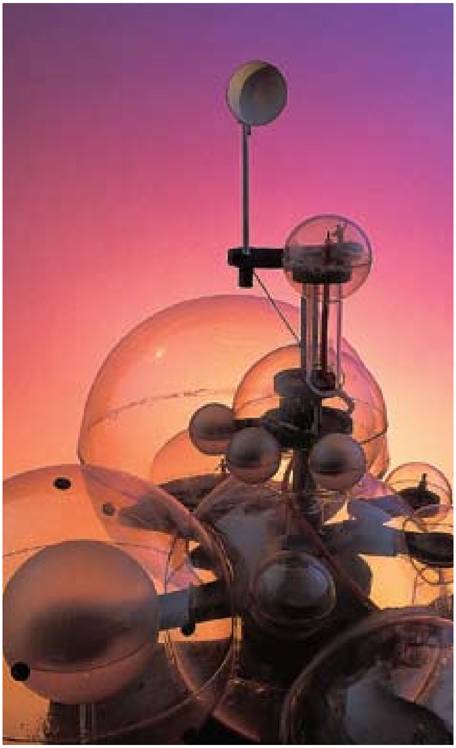
At the electromolecular level, the spheres' skins respond to light and heat. Glass and plastic panels that change from opaque to translucent when charged with electric current are already available. Here, a more sophisticated system will allow the bubbles to respond not just to a manually activated switch, but to the changing climate and weather conditions of the natural environment. The bubble's molecules could be aligned for selected levels of permeability in response to light, heat, and even insulation values. They would be "living membranes."

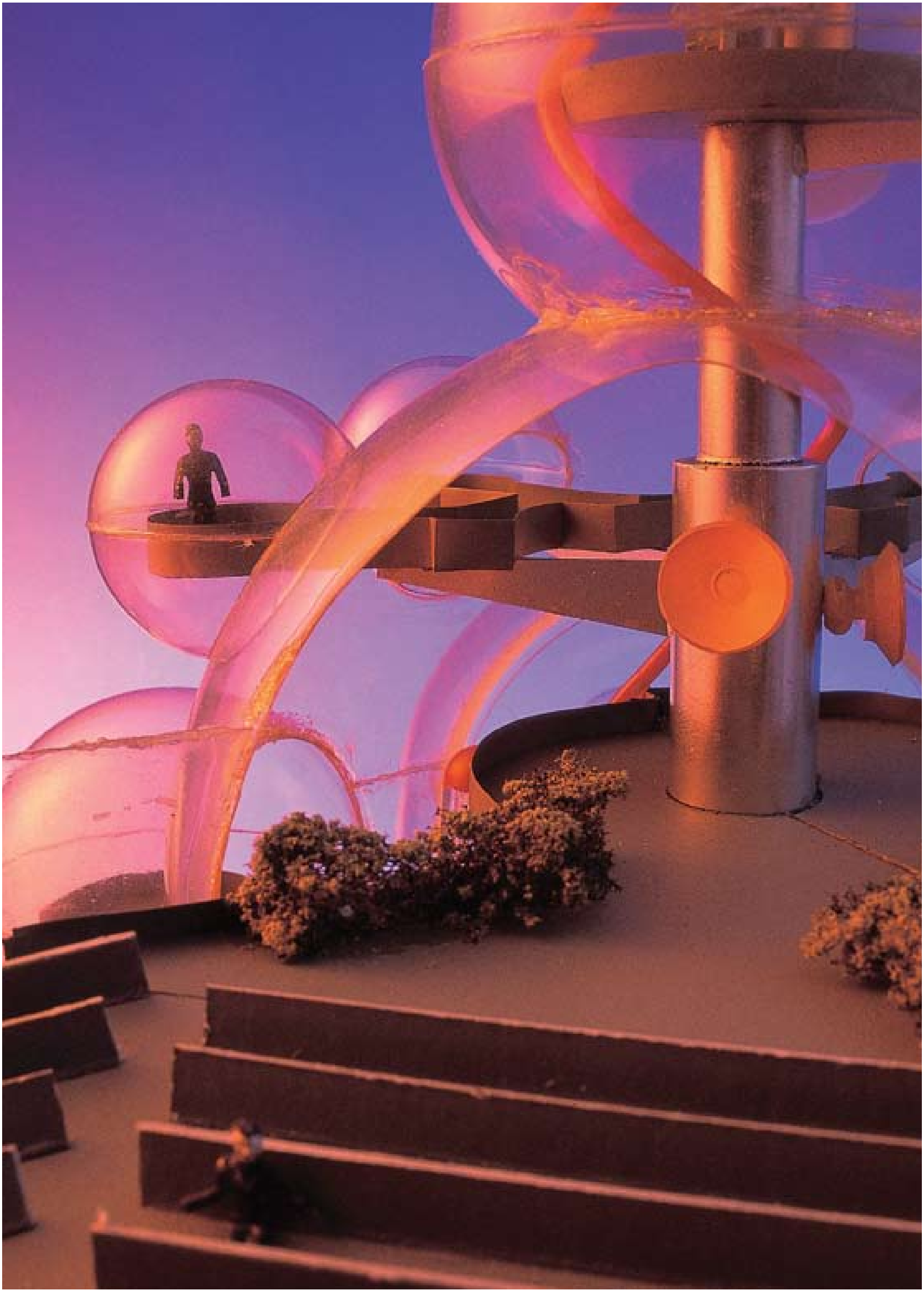
Another feature of this project is the "levitator," a replacement for the conventional elevator. In this device, capsules will carry people along a serpentine electromagnetic track powered by linear induction motors. For both practicality and novel experience, the levitators will travel in serpentine patterns about the complex.

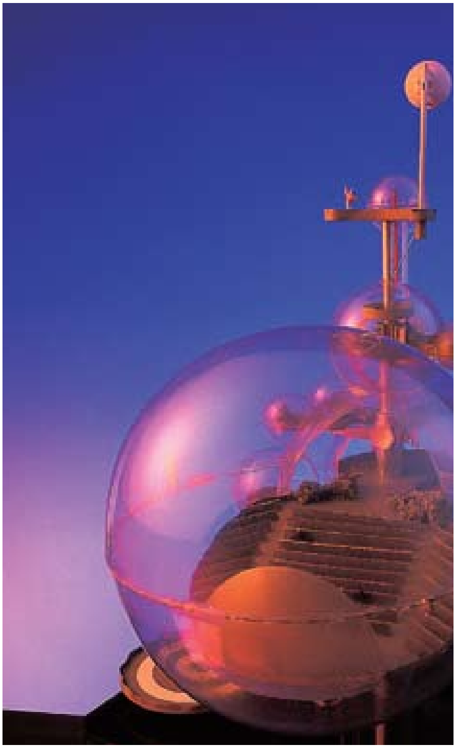
The cluster of bubbles, seen from outside, will certainly make for a striking image on the urban horizon. The experience of movement along a serpentine path through the coalescing spaces of these spherical membranes, which change opacity to accommodate interior and exterior conditions, would be unprecedented. Symbolically, the spherical forms represent containment and wholeness; the absence of angular form metaphorically eradicates disturbing or discordant experience. Travel along the serpentine rail calls to mind cosmic motion, creativity, growth, wisdom—all meanings appropriate to the purposes of a conference center. (1988)

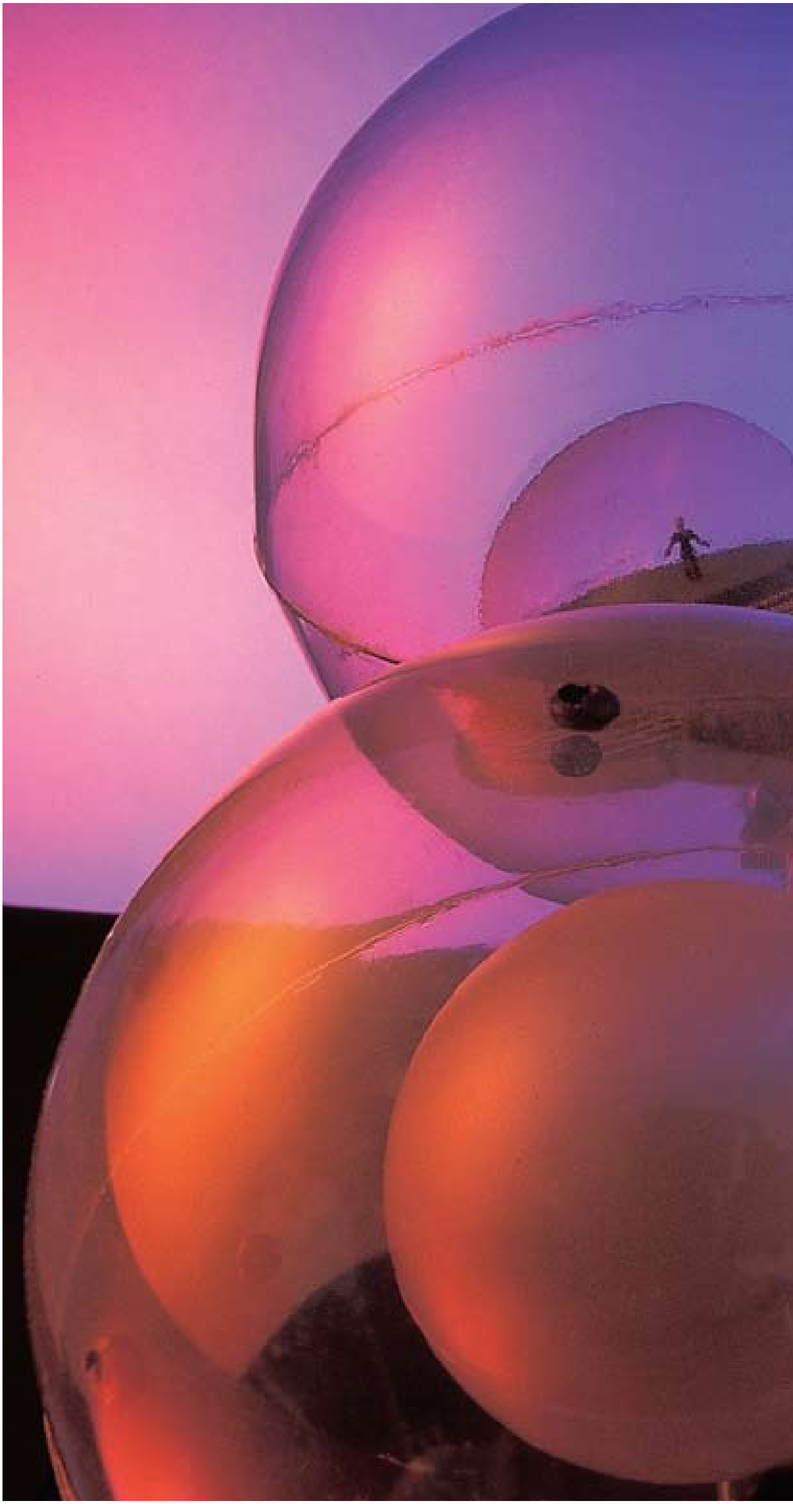


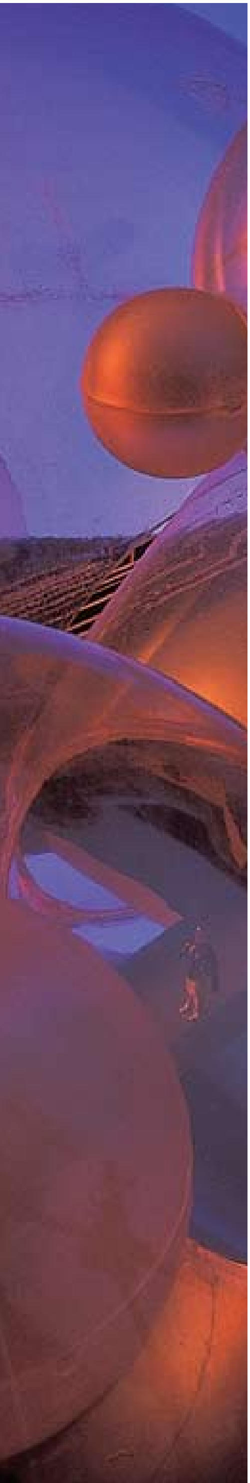


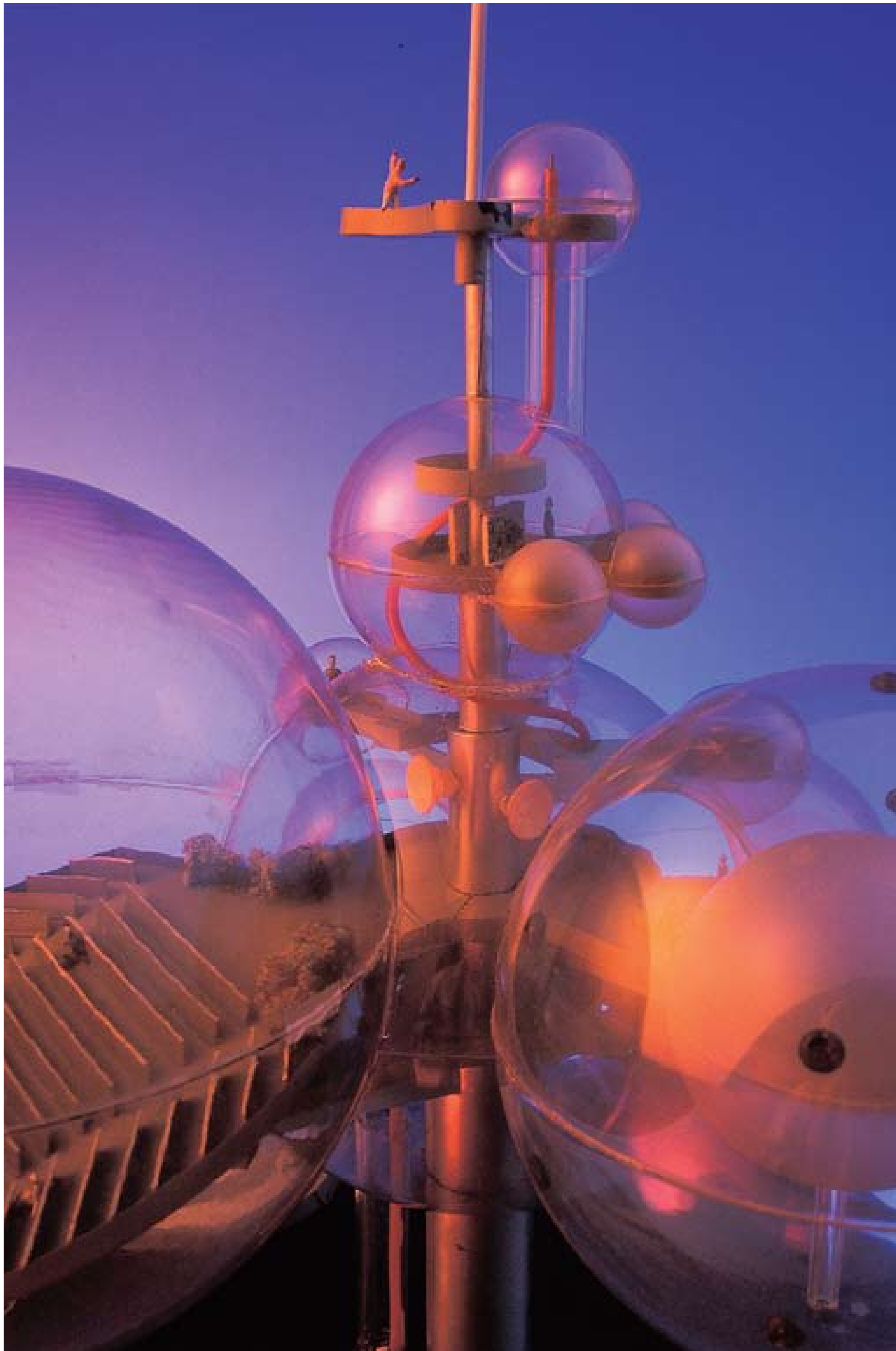


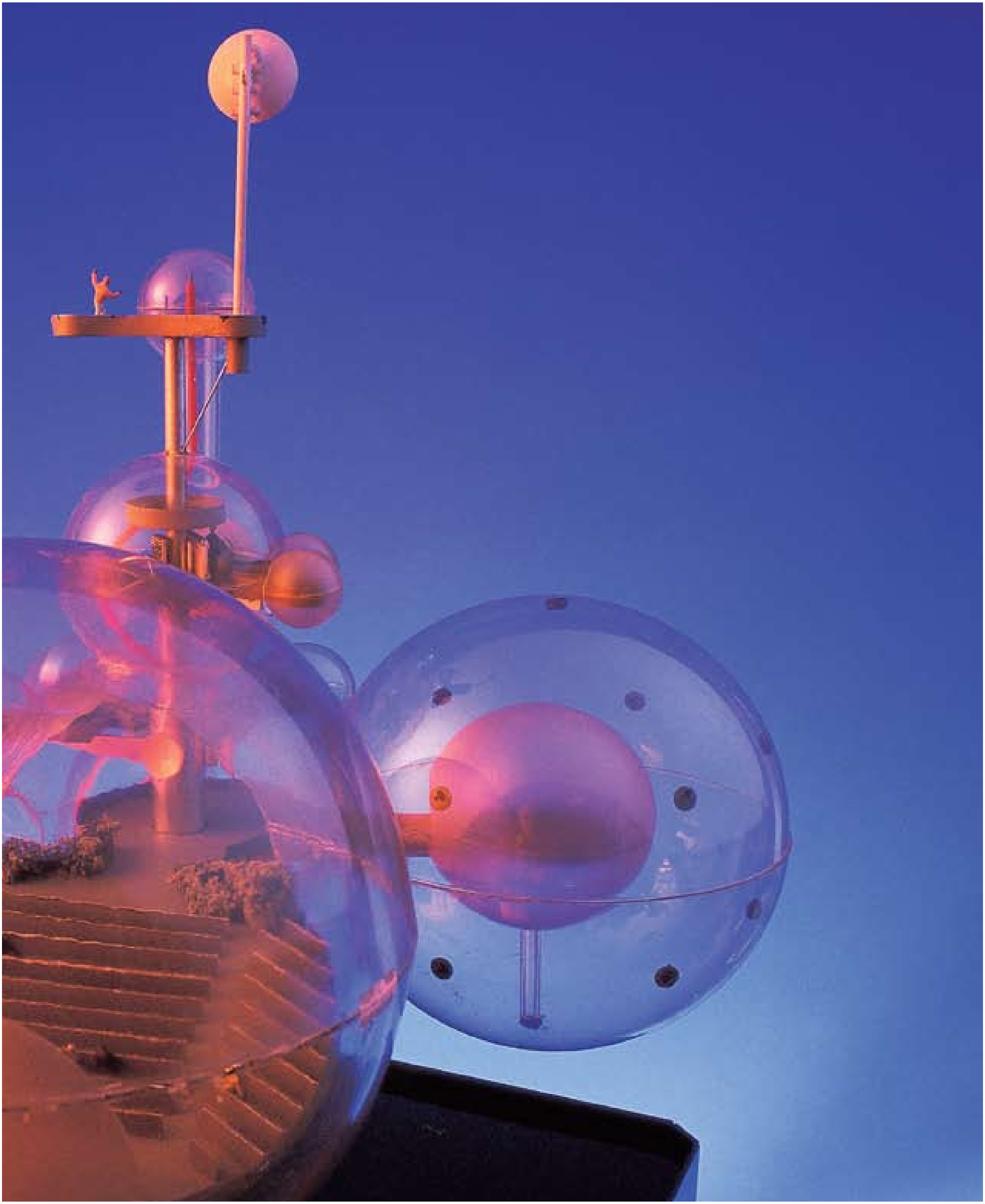


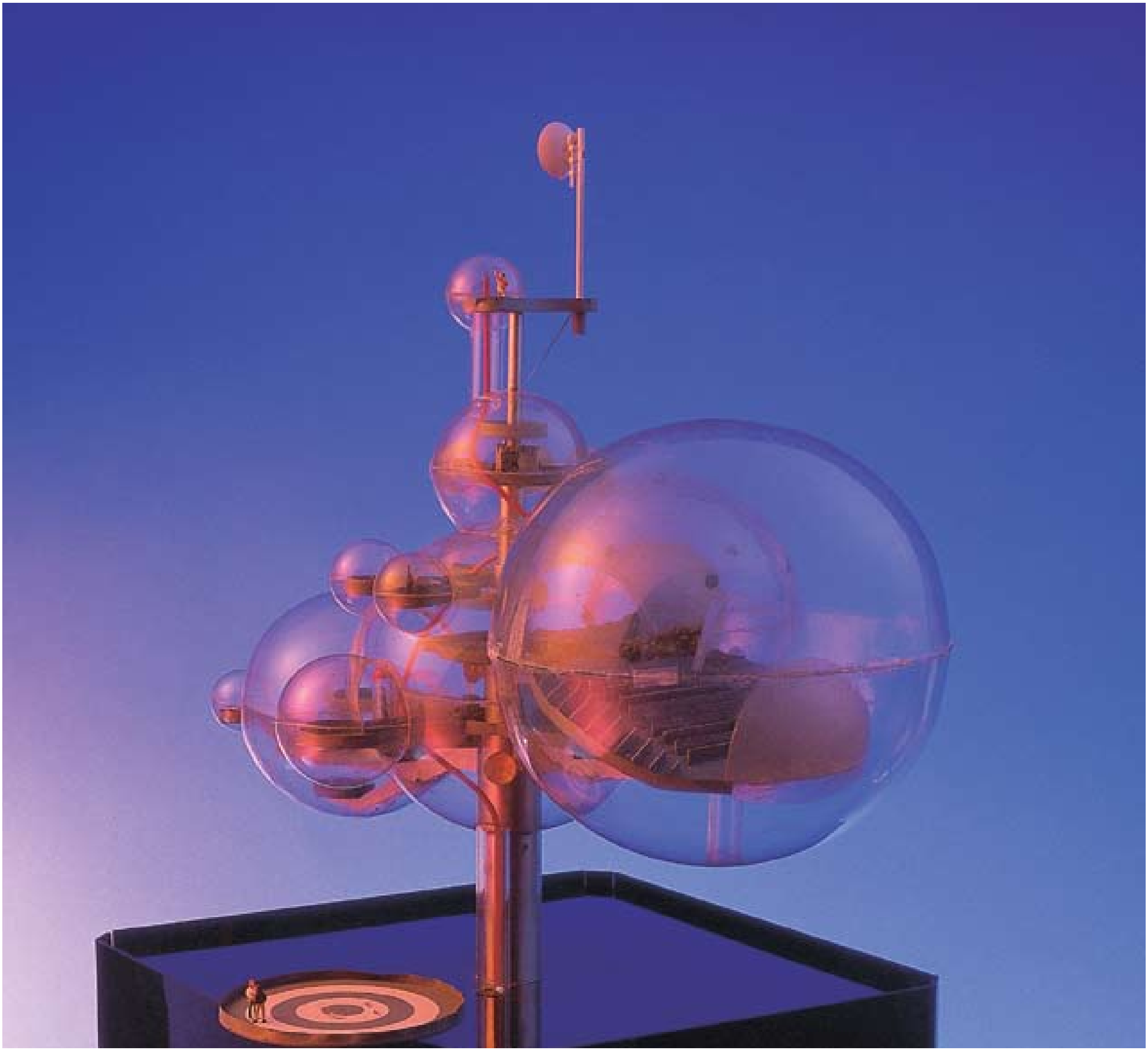


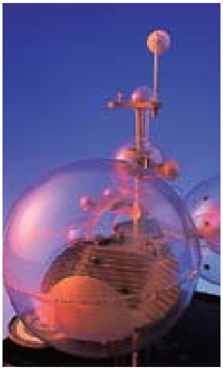


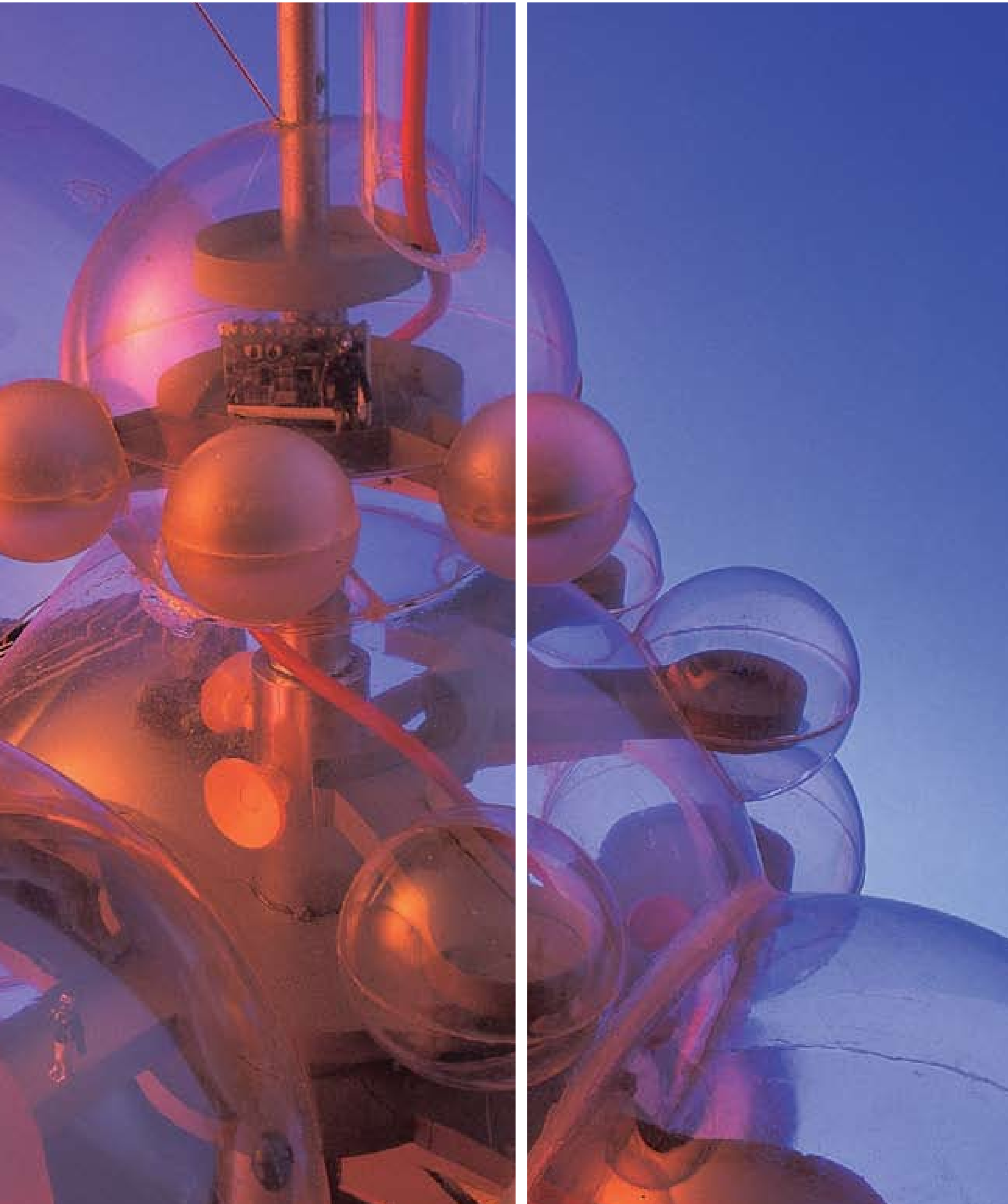


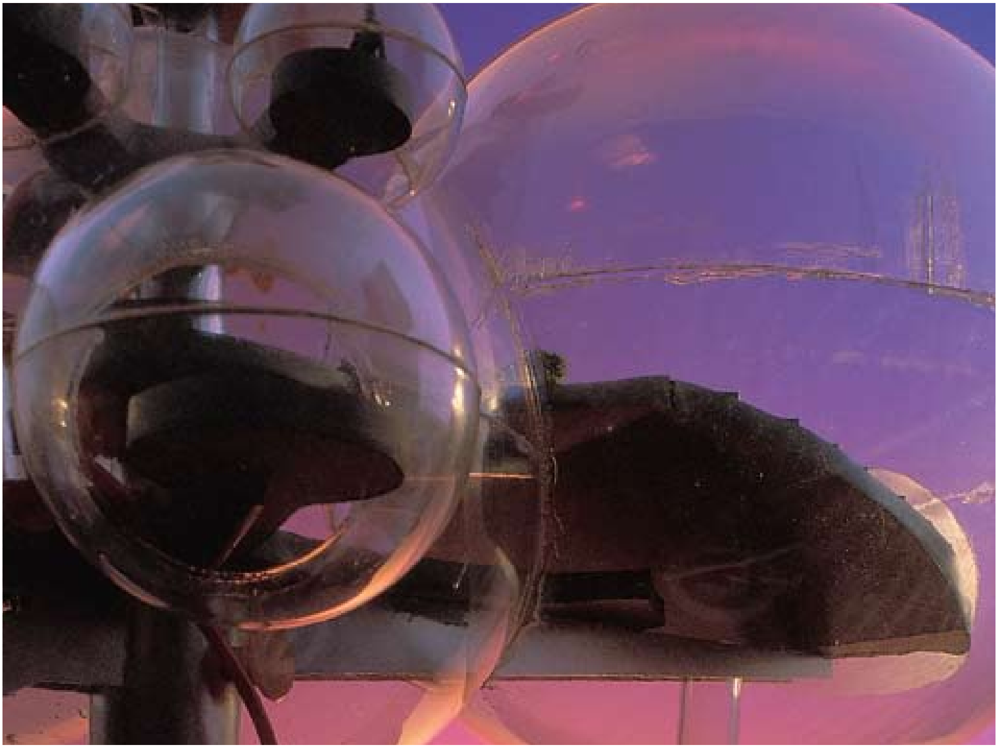


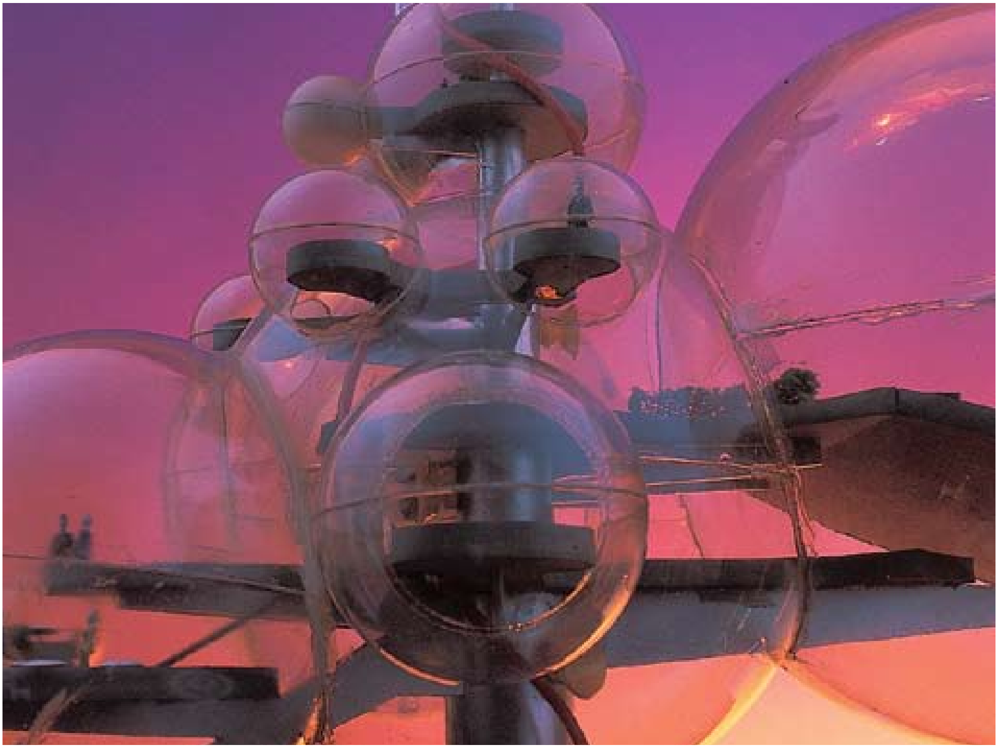


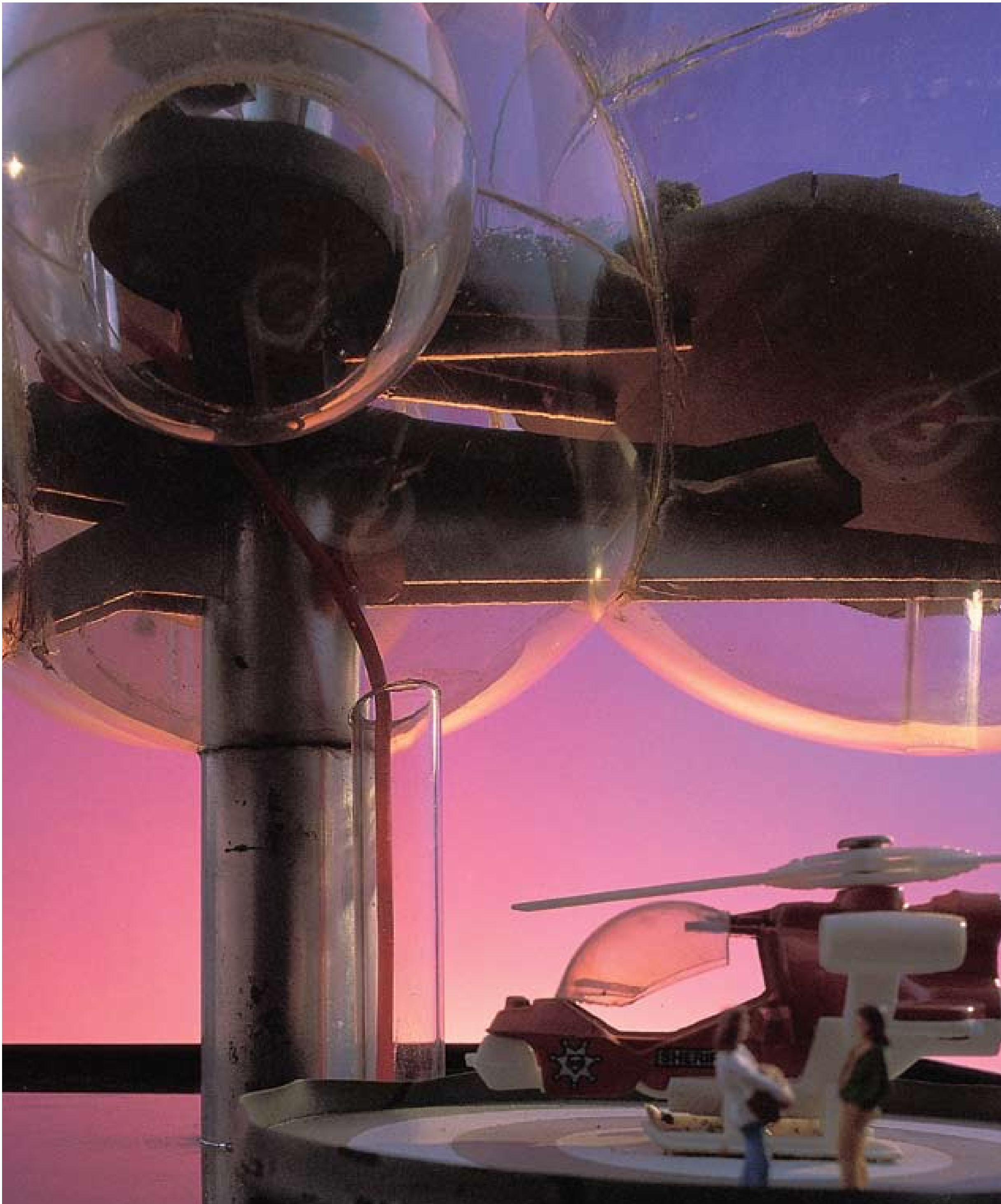


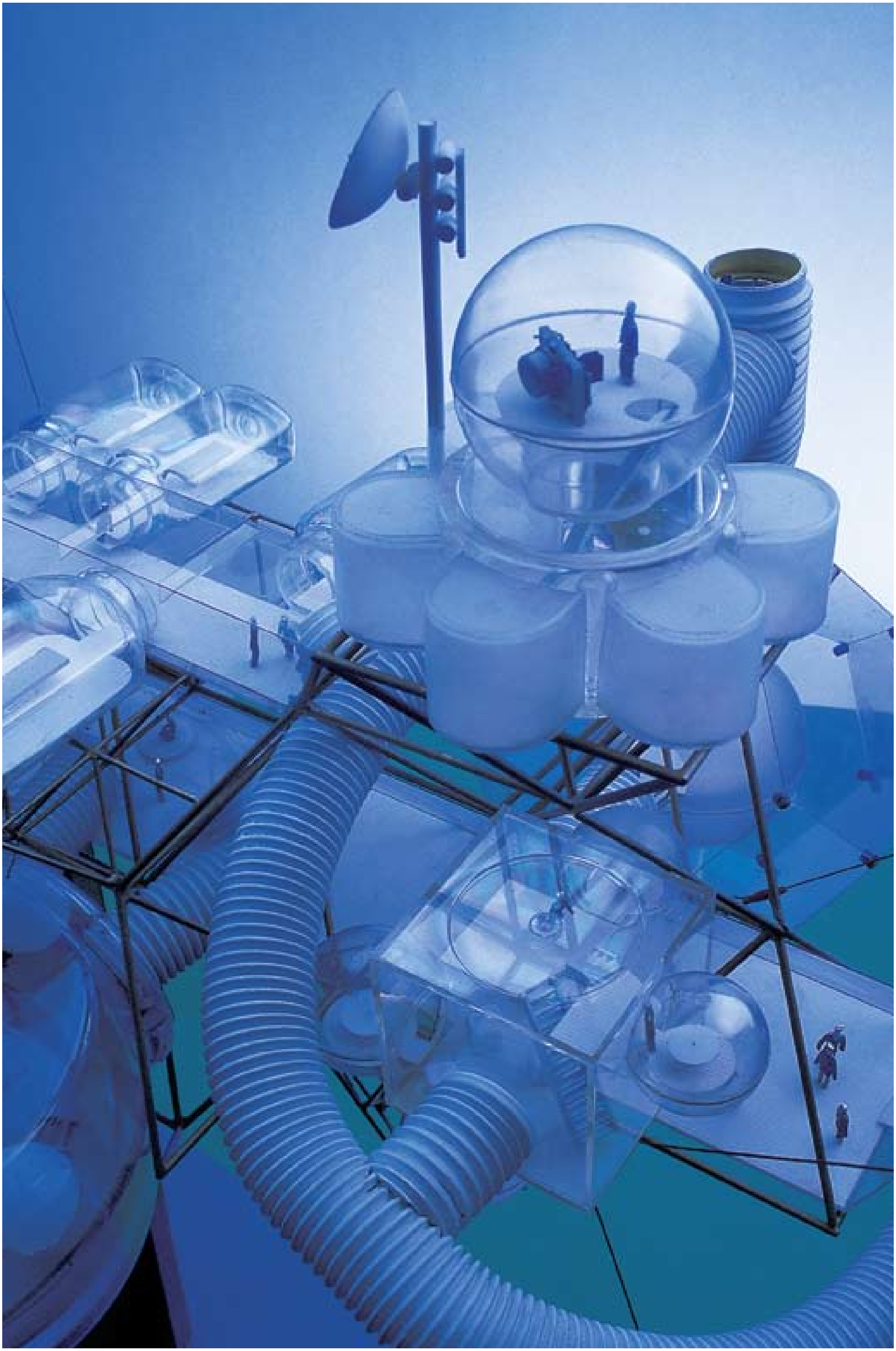












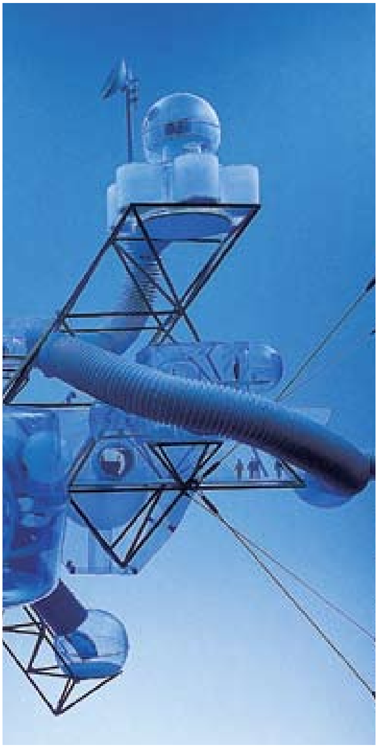
THE WEB

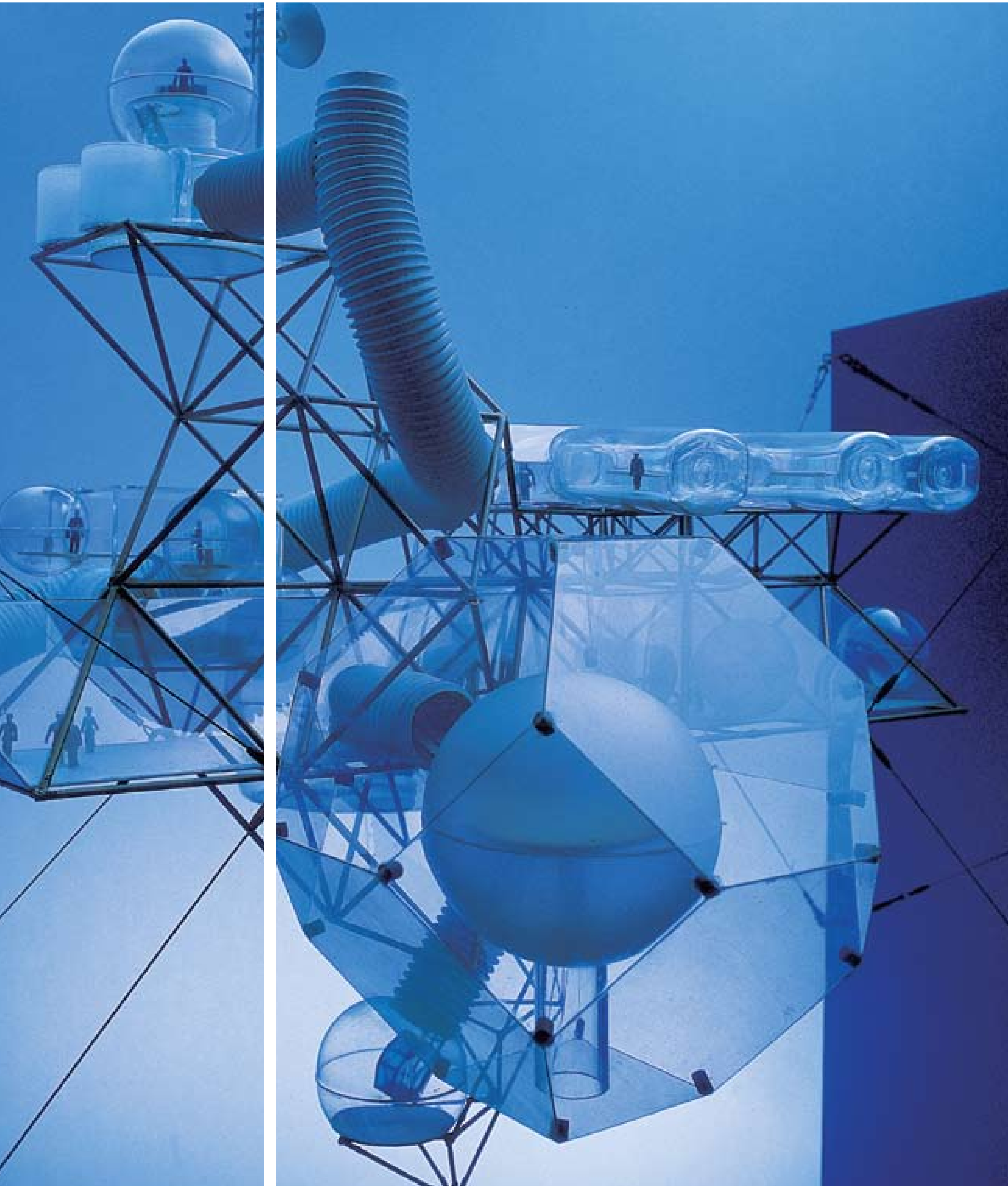
Also a conference center, this project would have been suspended between the twin towers of New York's World Trade Center. A similar design could be suspended beneath bridges designed to withstand concentrated loads.

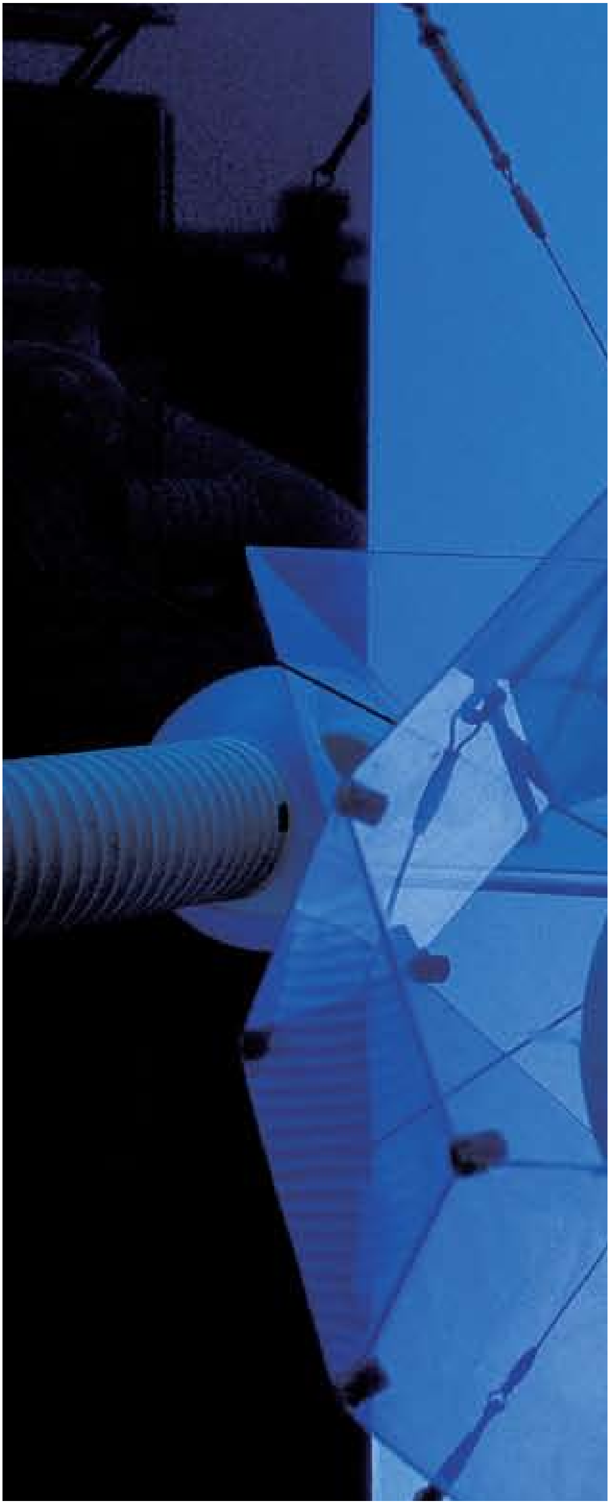
The triangulated structural frame can be assembled on the ground, lifted, and leveled with ease—later to be completed as additional struts are attached as standardized nodes. Such a structure will require a self-balancing system. Strategically placed sensors will monitor any destabilizing forces, such as horizontal wind loads, snow loads, or shifting live loads. The habitable enclosures of plastic will be molded in appropriate forms, just as yacht hulls are produced of fiberglass-reinforced resin. Forces are transferred throughout the shell, eliminating the conventional frame.

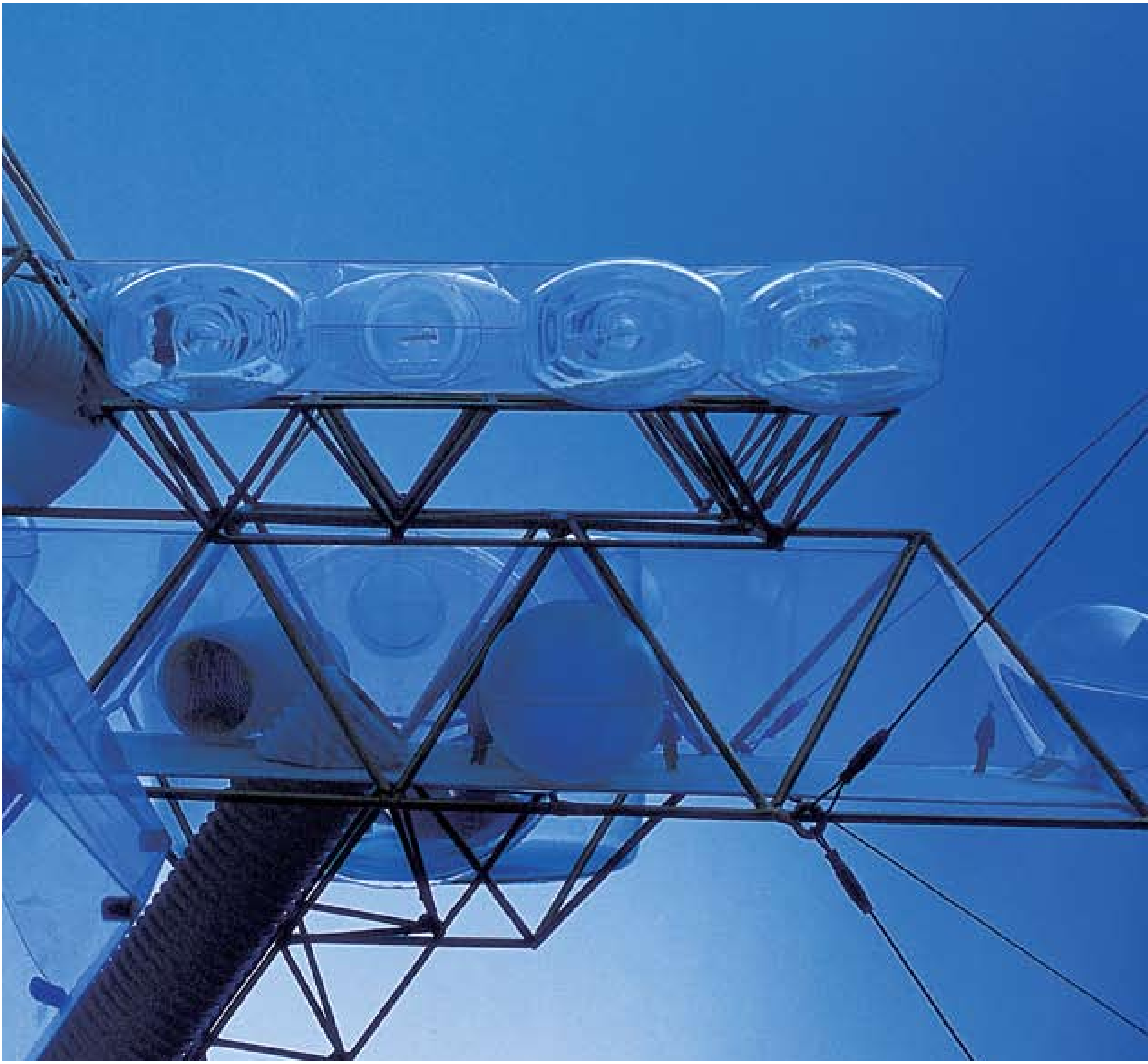
Other features of this design are the serpentine tubes that house people-moving "levitators," a helipad, the central concourse from which access is made to the auditorium, simulation chamber, meeting rooms, restaurant, and computer center surrounded by a cluster of work stations.

Symbolically as well as practically, the Web holds together a company of people in common cause or intellectual pursuit. (1989)

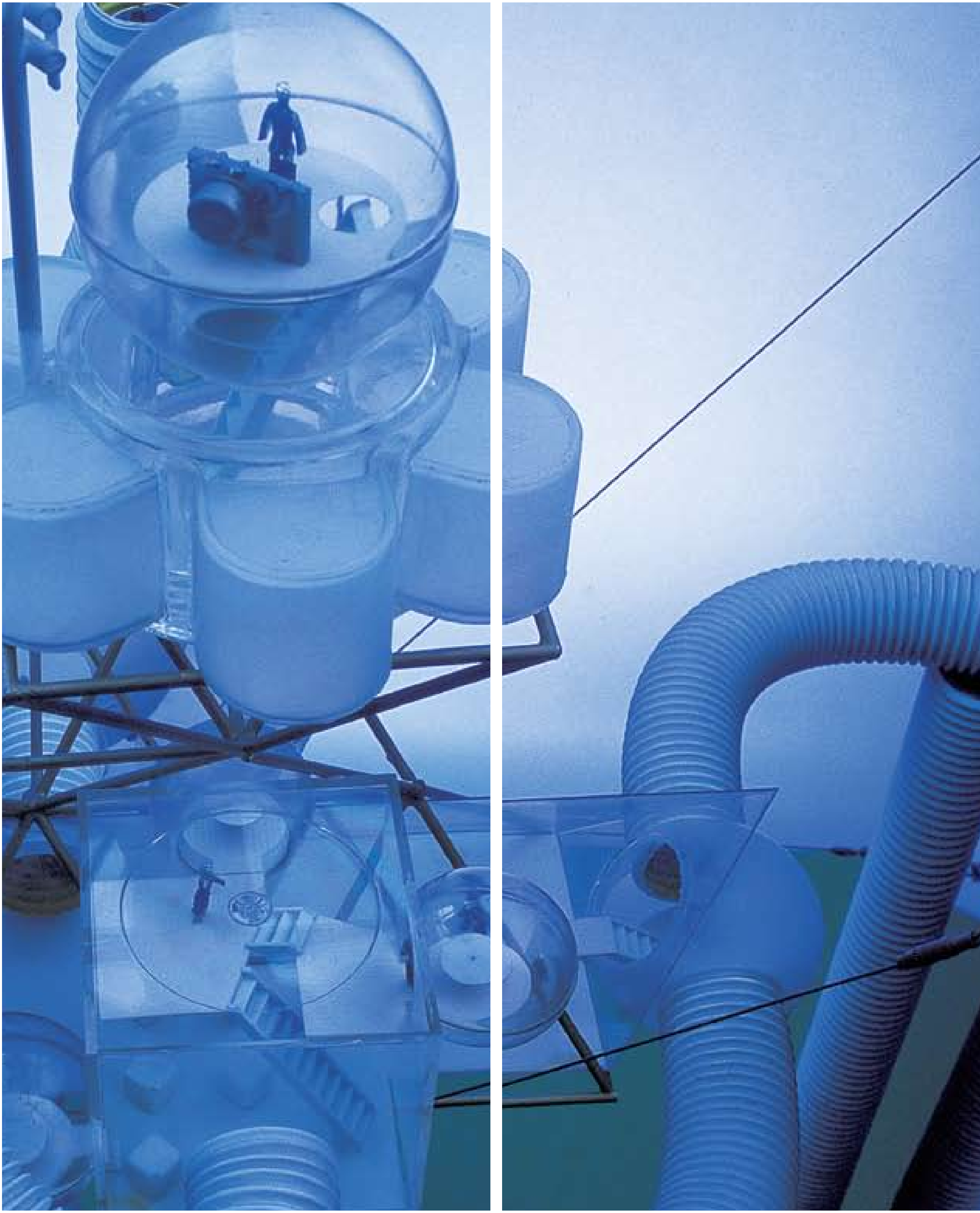


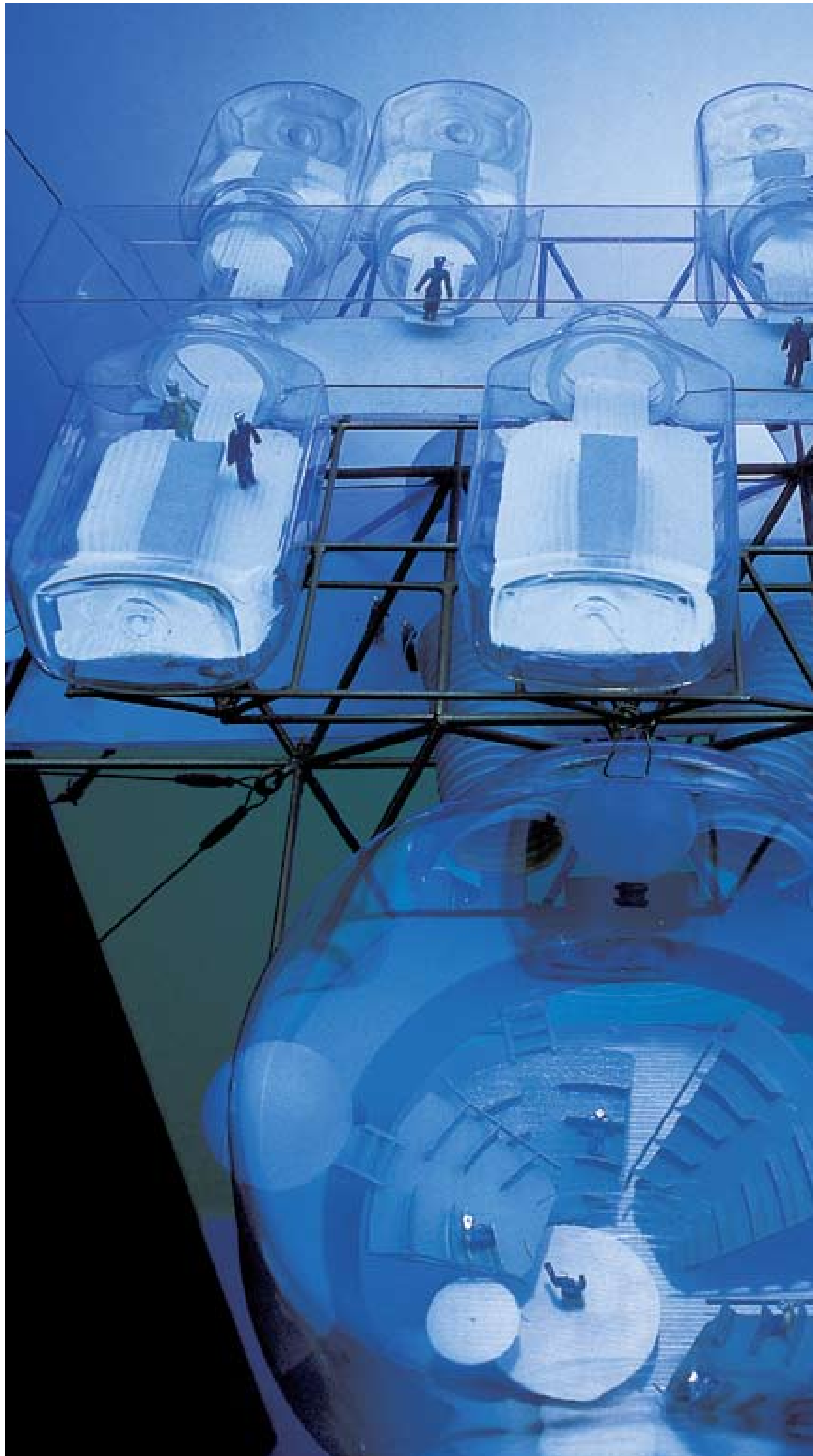


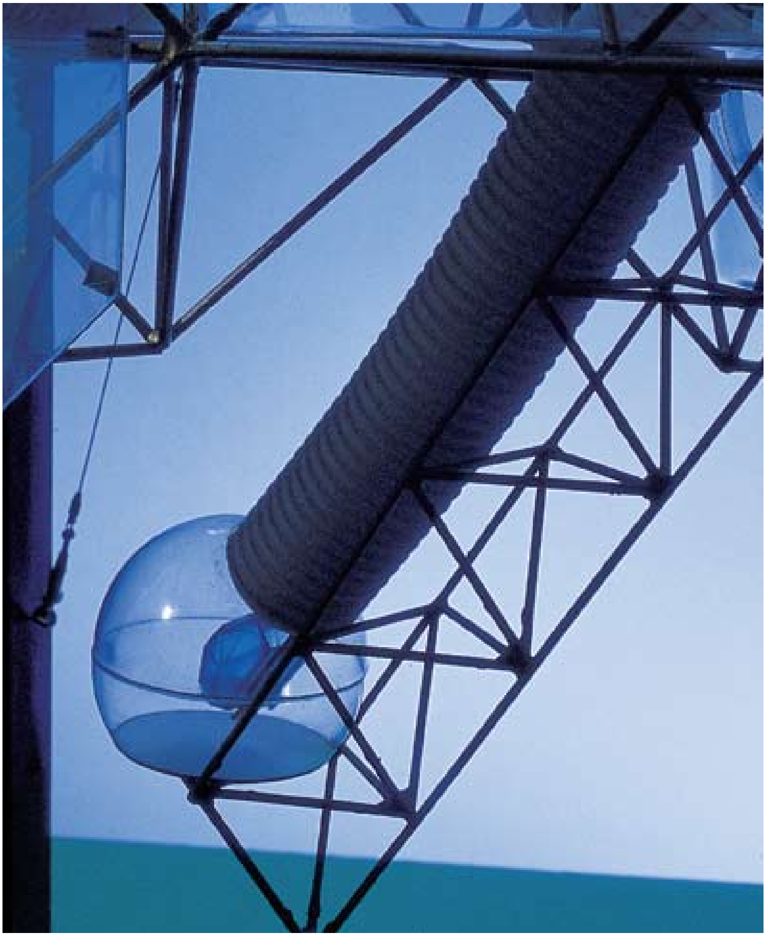


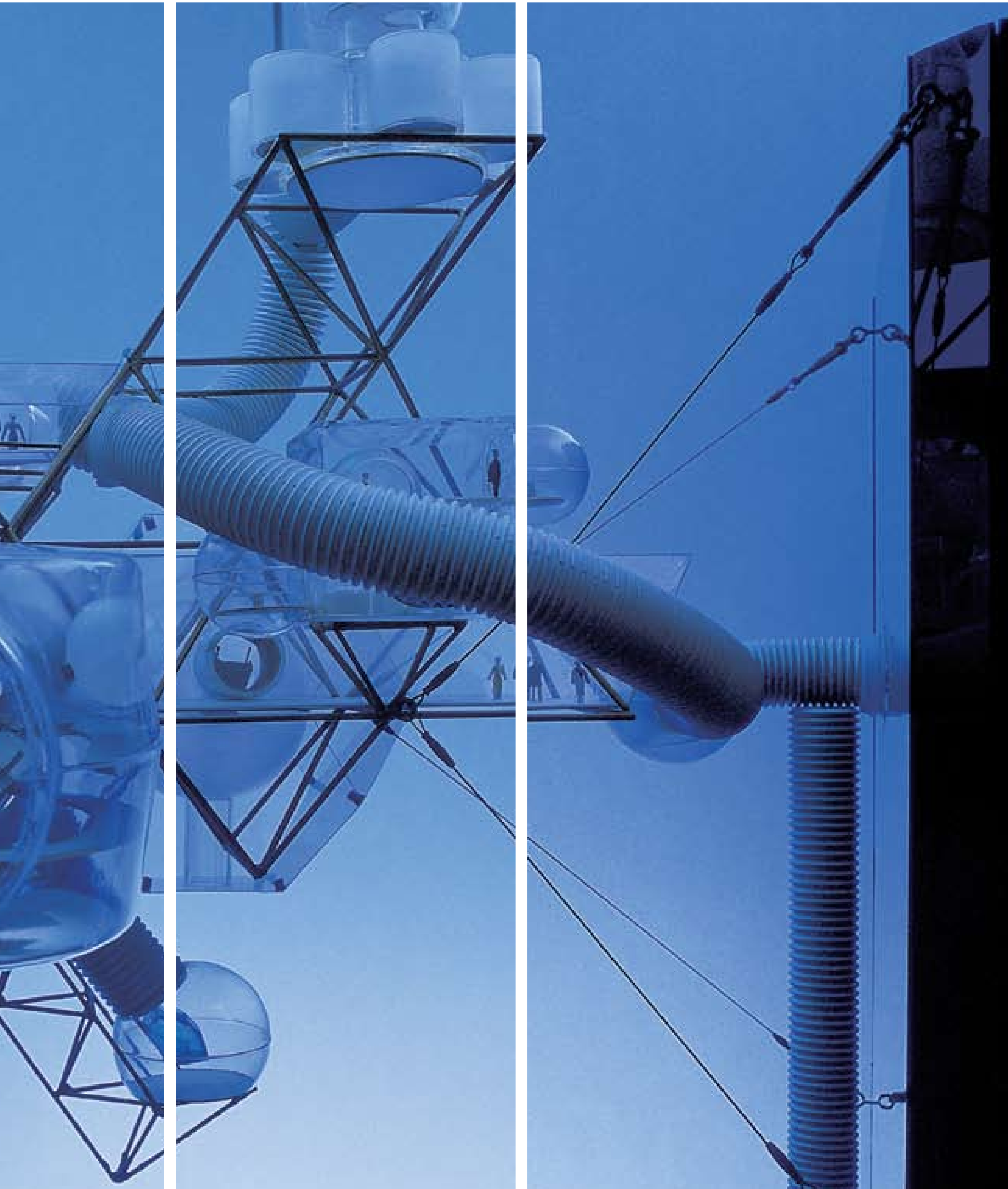


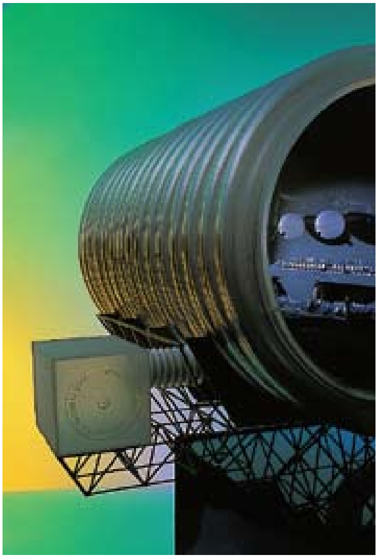


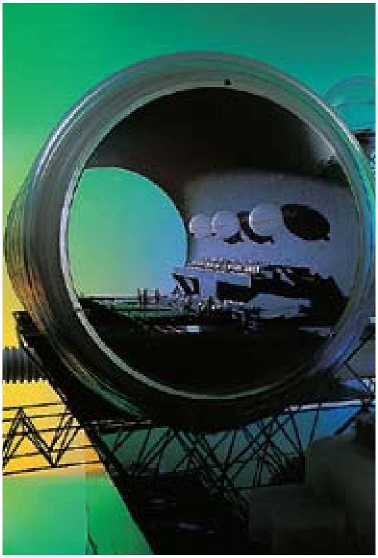



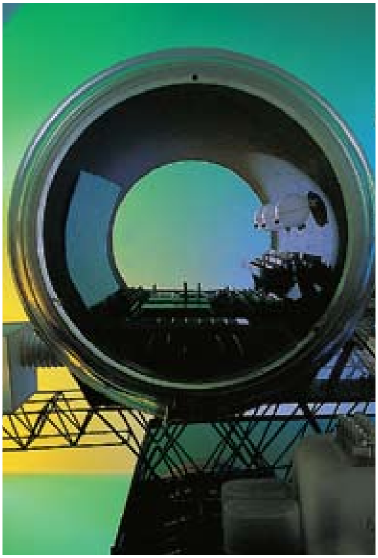













THE MAG-LEV THEATER

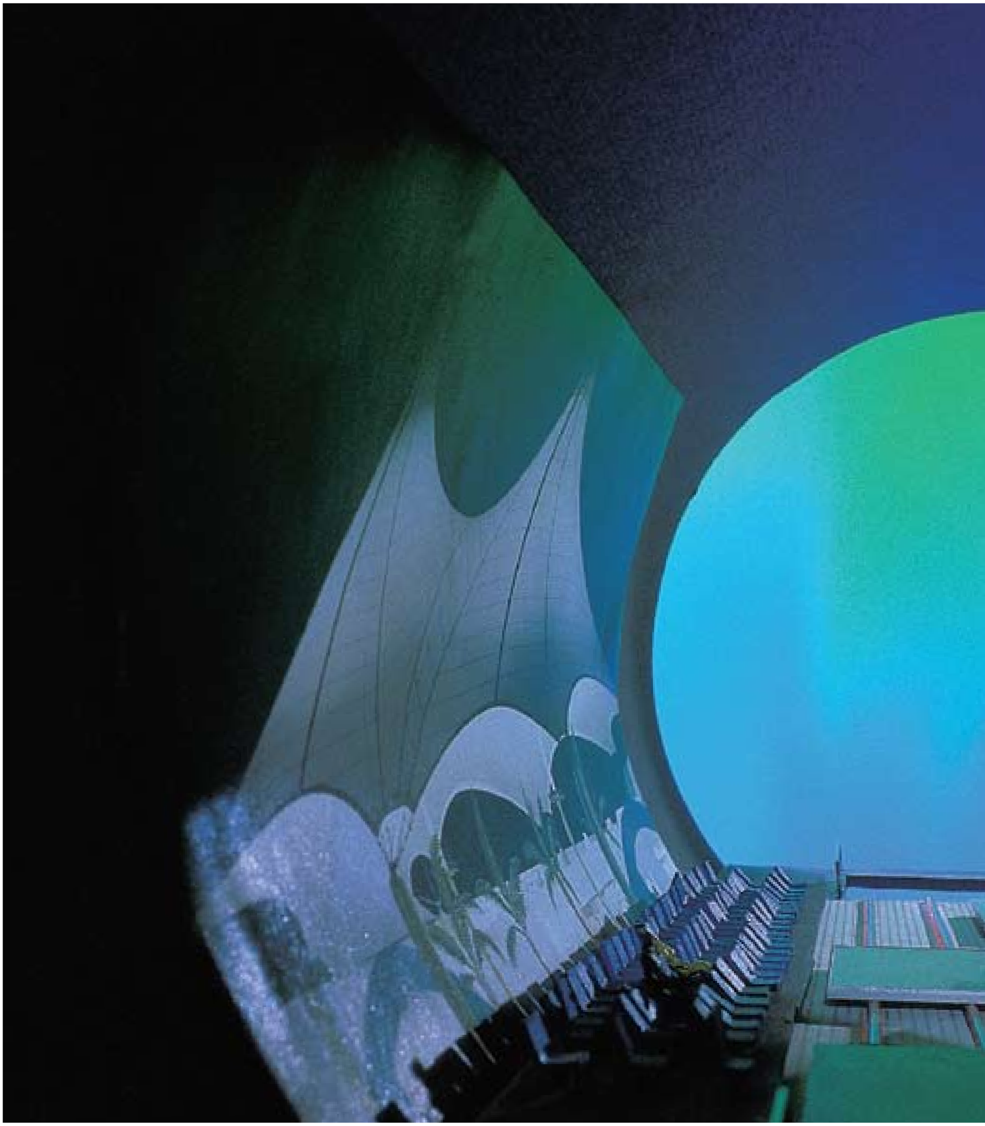
This theater complex takes advantage of the developing technology of electromagnetic levitation ("mag-lev"). The complex is comprised of three lightweight, inflated structures supported in a steel frame basket that rests upon the roof of another building. People-moving tubes convey the theater audience up from the street along the existing building facade and on to a central lobby that accesses the three theaters and a restaurant at the top.

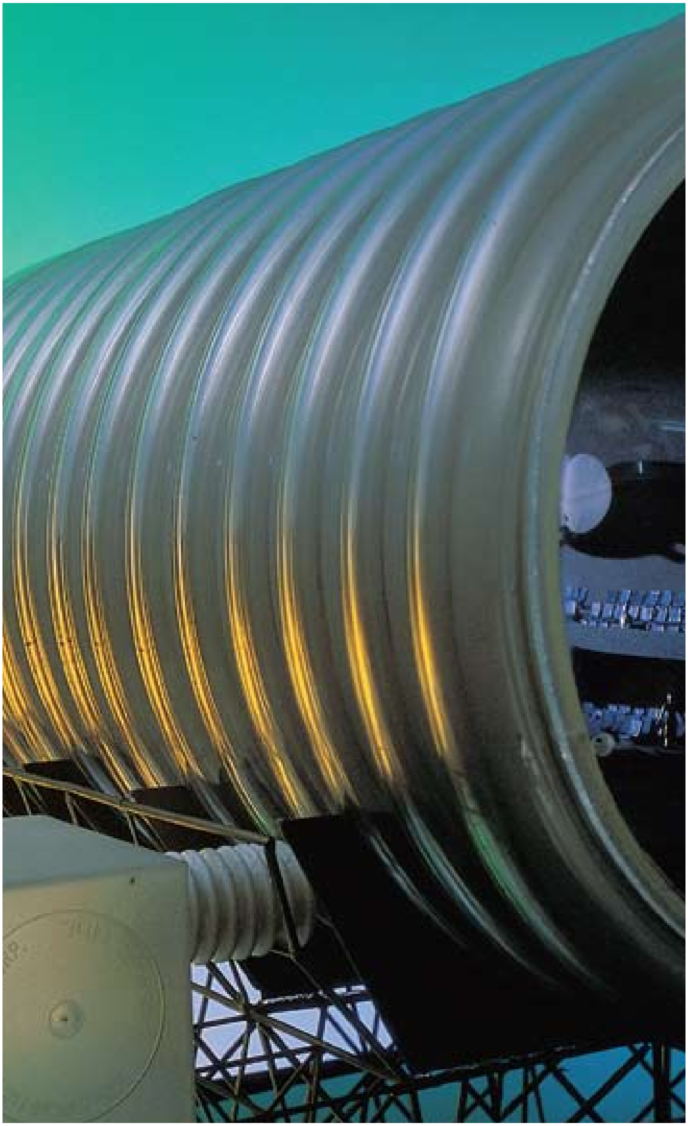
Each of these experimental theaters has a specialized purpose. The Theater of Simultaneity is set on horizontal rails and uses linear induction motors to move performance platforms that will feature theatrical events set in times past, present, and future. Here plots can unfold with reference to any time relationship. The Theater of the Divine Comedy moves platforms vertically to accommodate dramatic events that call, for example, for descents into hell and flights upward through purgatory and then into the realms of the divine. The Theater of the Eternal Return is for theatrical events that are philosophically circular in nature: cycles of life, reincarnation, the seasons, the passing of the day.

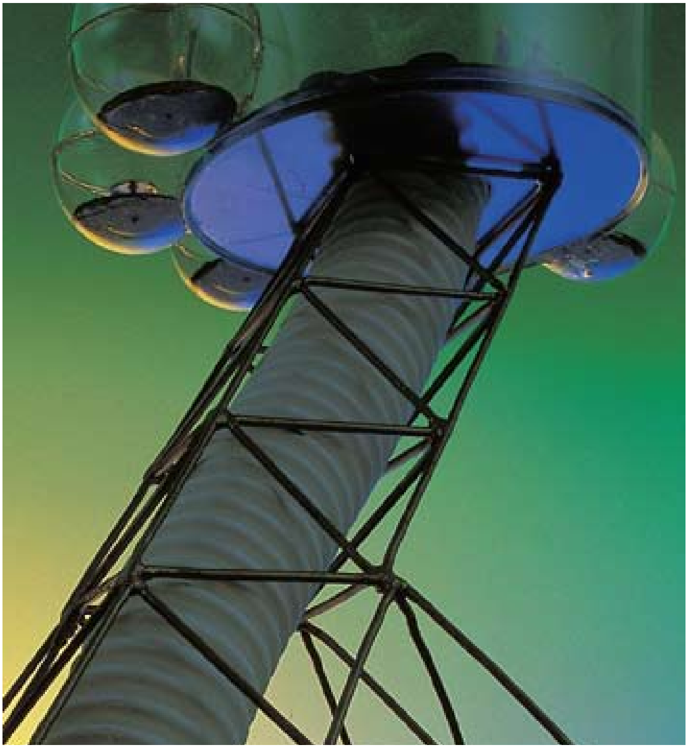
There are two mag-lev systems employed in the complex. The first is a more limited "sliding contact" or shoe-to-rail lift that is propelled by lineal induction motors. With this method, continuously changing scenic, lighting, and projection positions can be achieved. The second, more complex, system is not yet possible but is theoretically realistic. Here, a free-floating platform is moved and stabilized through the application of electromagnetic forces—attraction and repulsion. Movement is determined by the coordinated control of forces emanating from walls, floors, ceiling, and platform. The platform is maneuvered either by a handheld video selector, a remote panel, or a computer program. With this technology a stationary audience can witness a levitated performance, or vice-versa. As an educational demonstration, for example, a levitated audience might travel through a large model of the human brain.

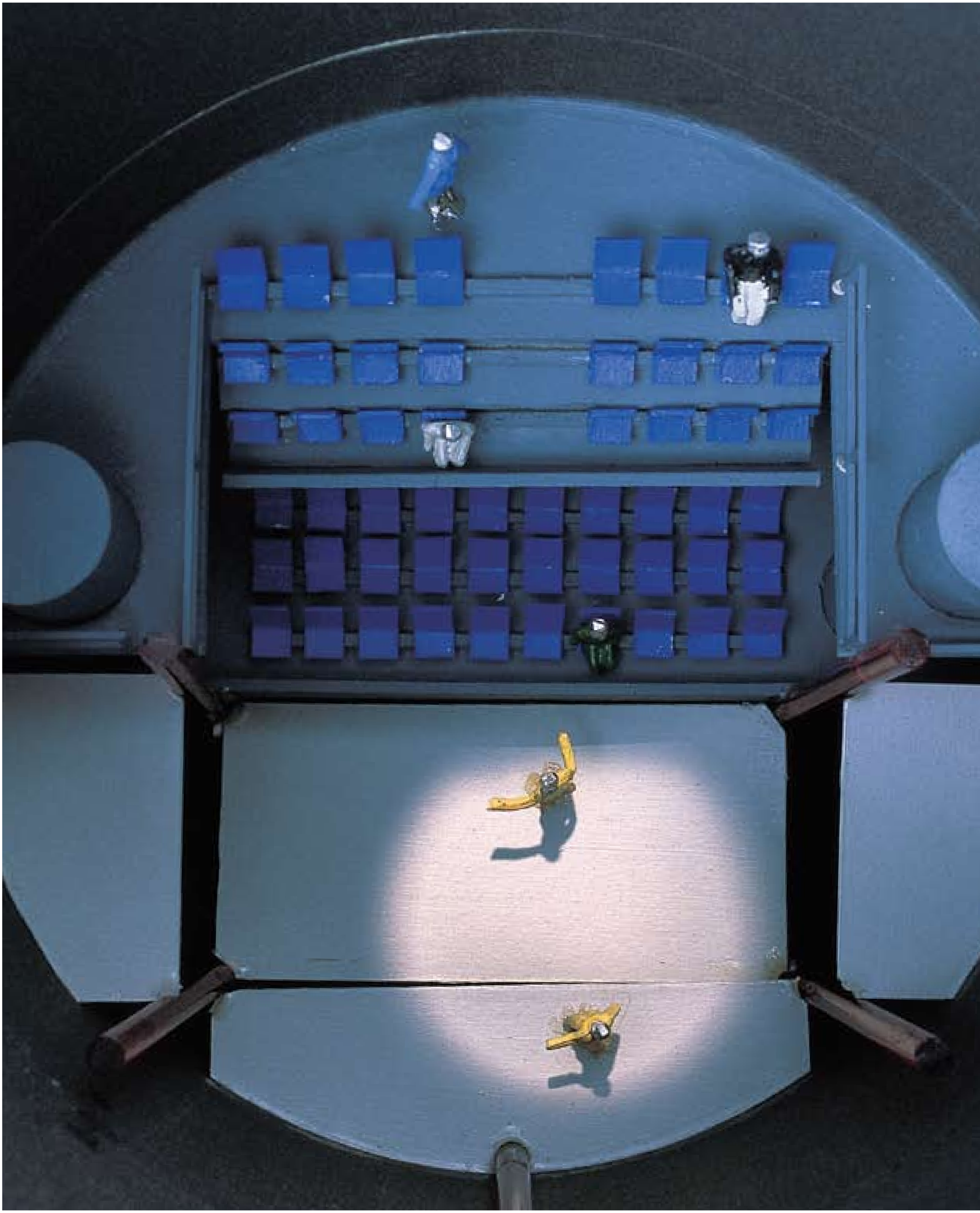
Each theater structure can be interpreted as a chrysalis; each holds, for a time, audiences under a spell that might be understood as conditioning for the theatrical event. Meanwhile, the steel-frame basket binds together a company of people in common cause or adventure. (1990)

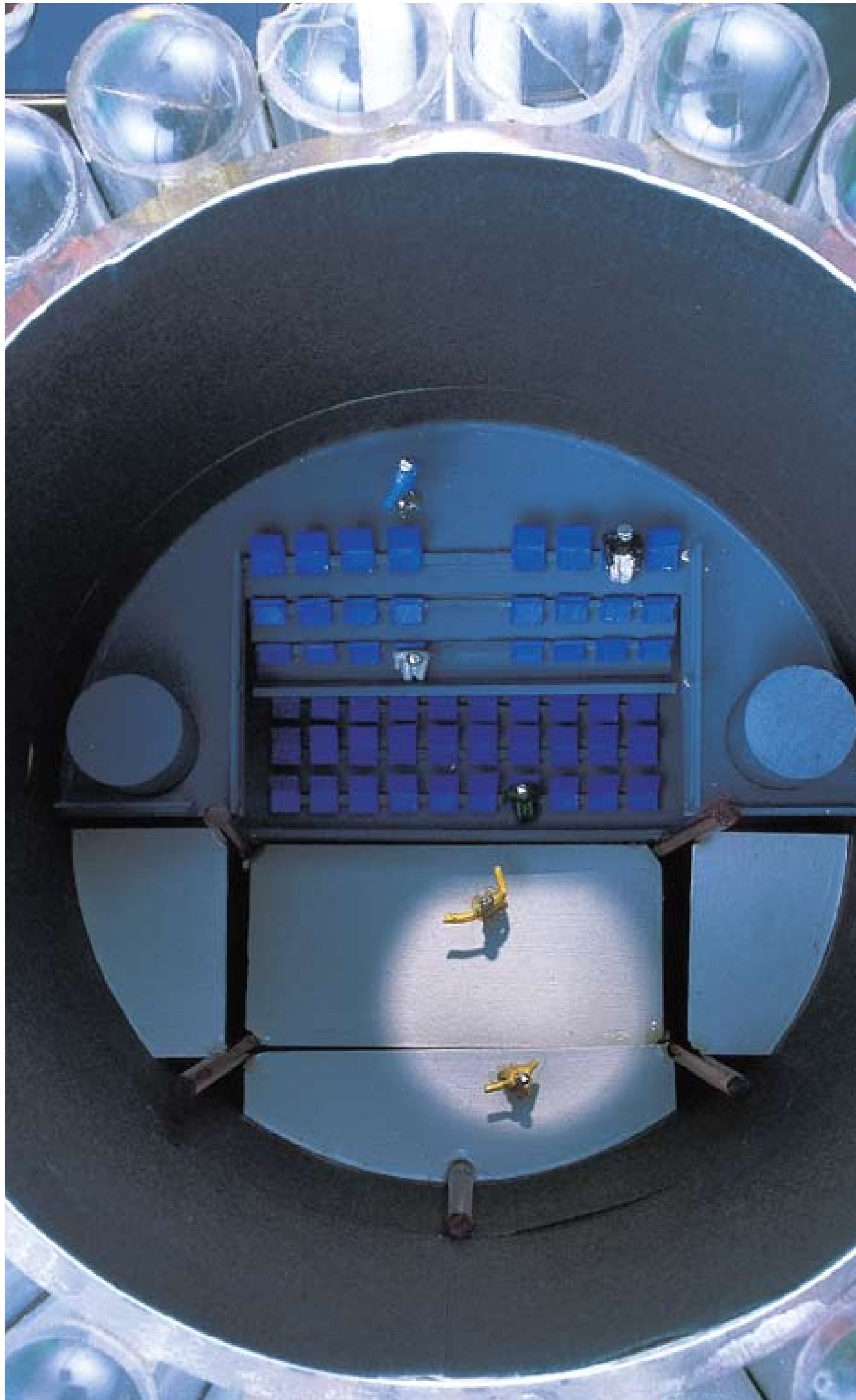
This project was supported by a grant from the Graham Foundation for Advanced Studies in the Fine Arts.

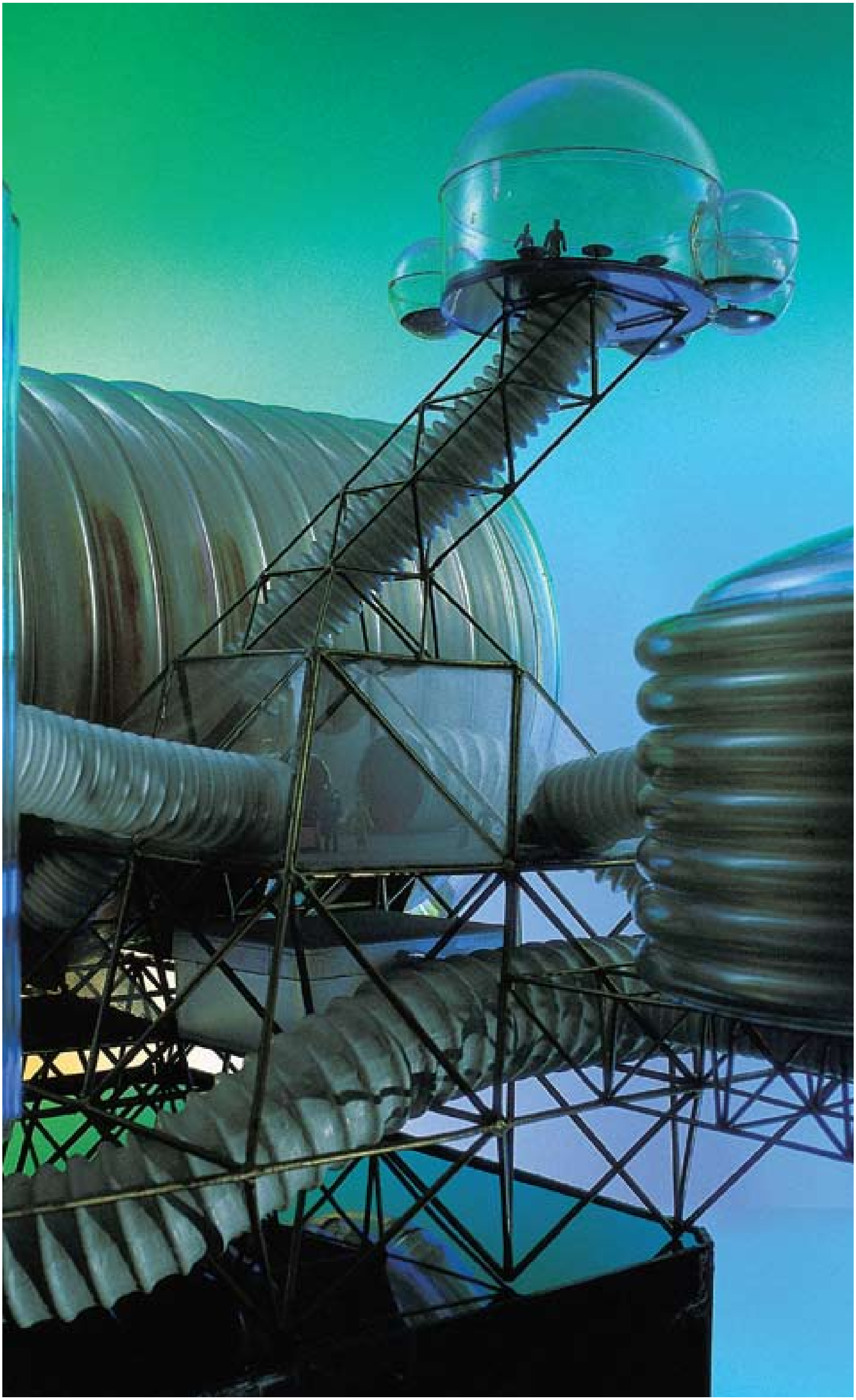


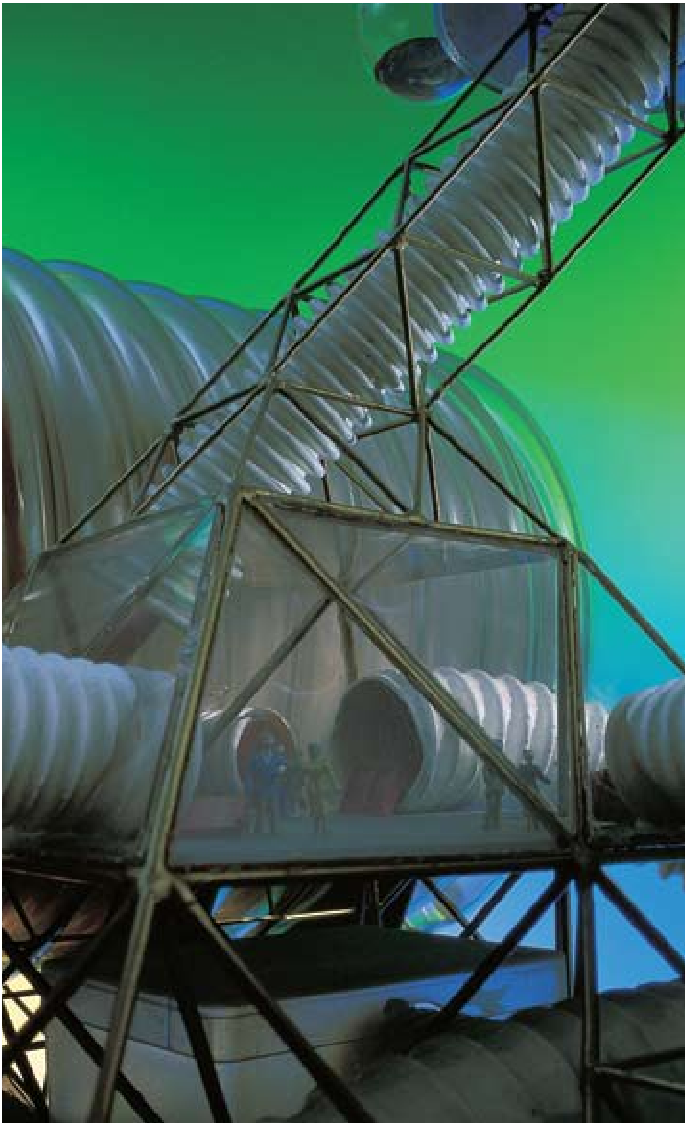


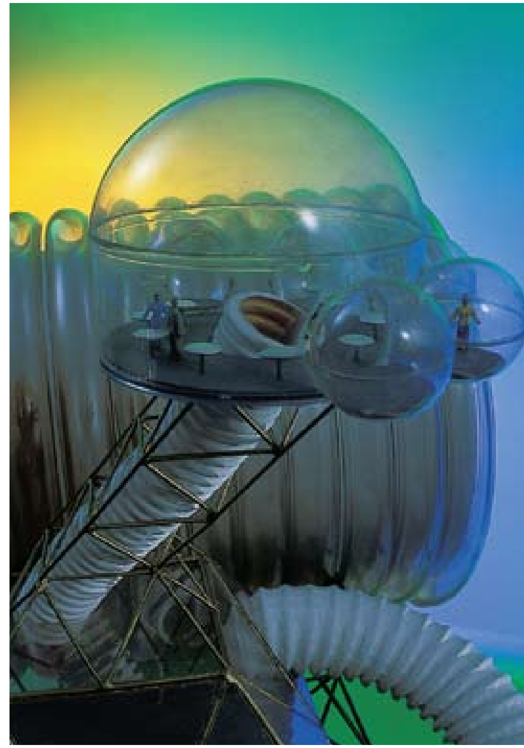


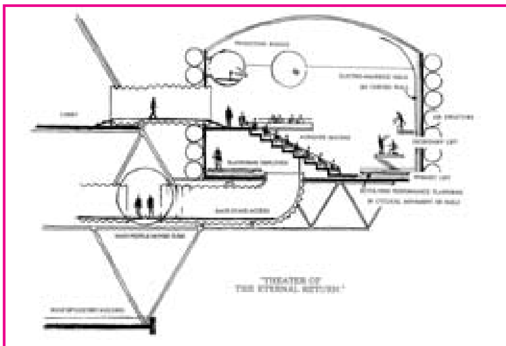


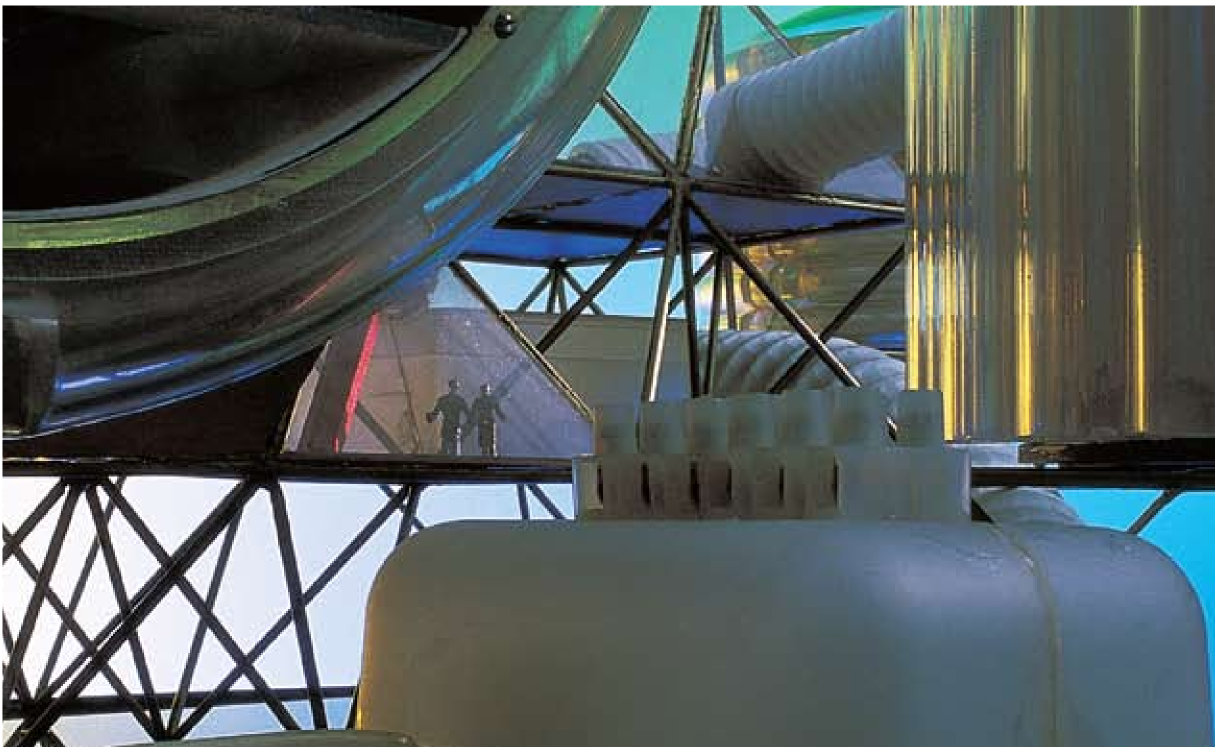


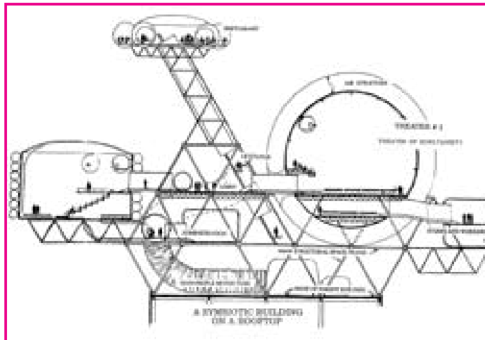



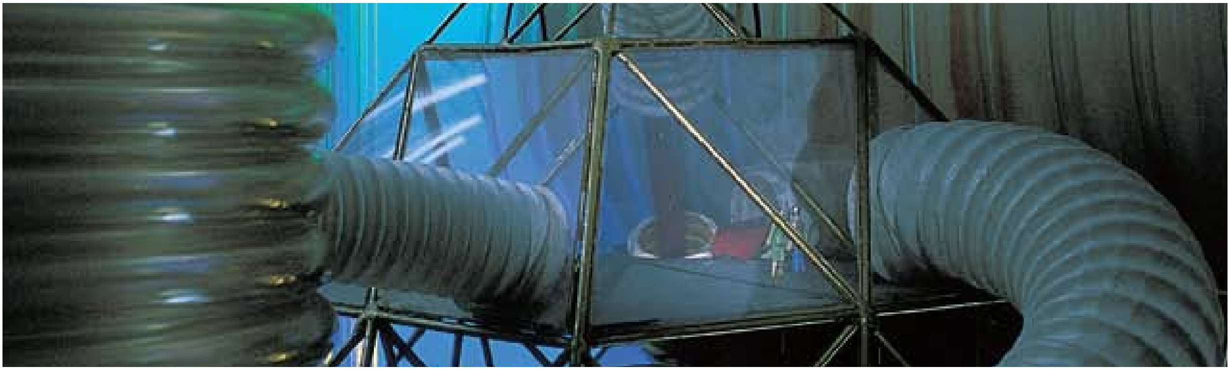


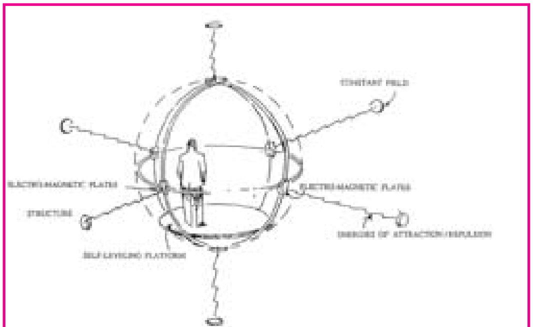



"THEATER OF
THE ETERNAL RETURN."

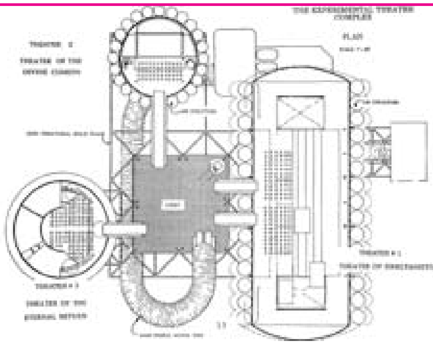



A SYMBIOTIC BUILDING
ON A ROOFTOP

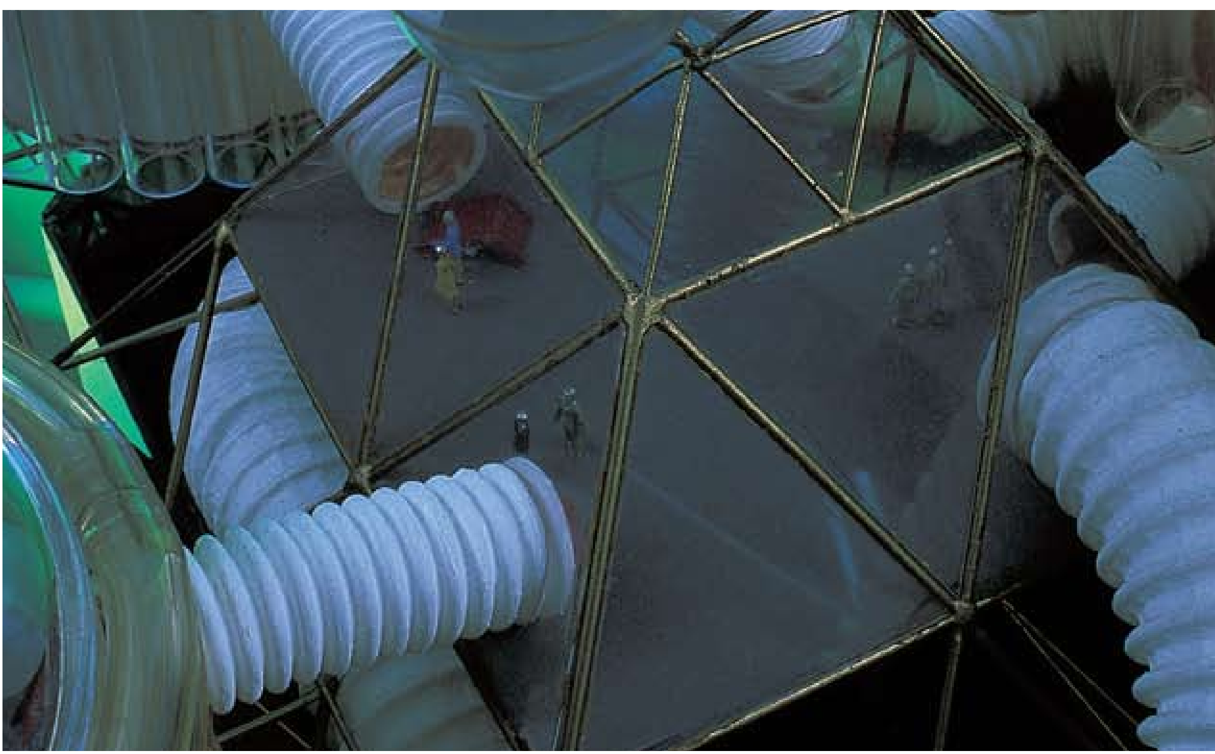


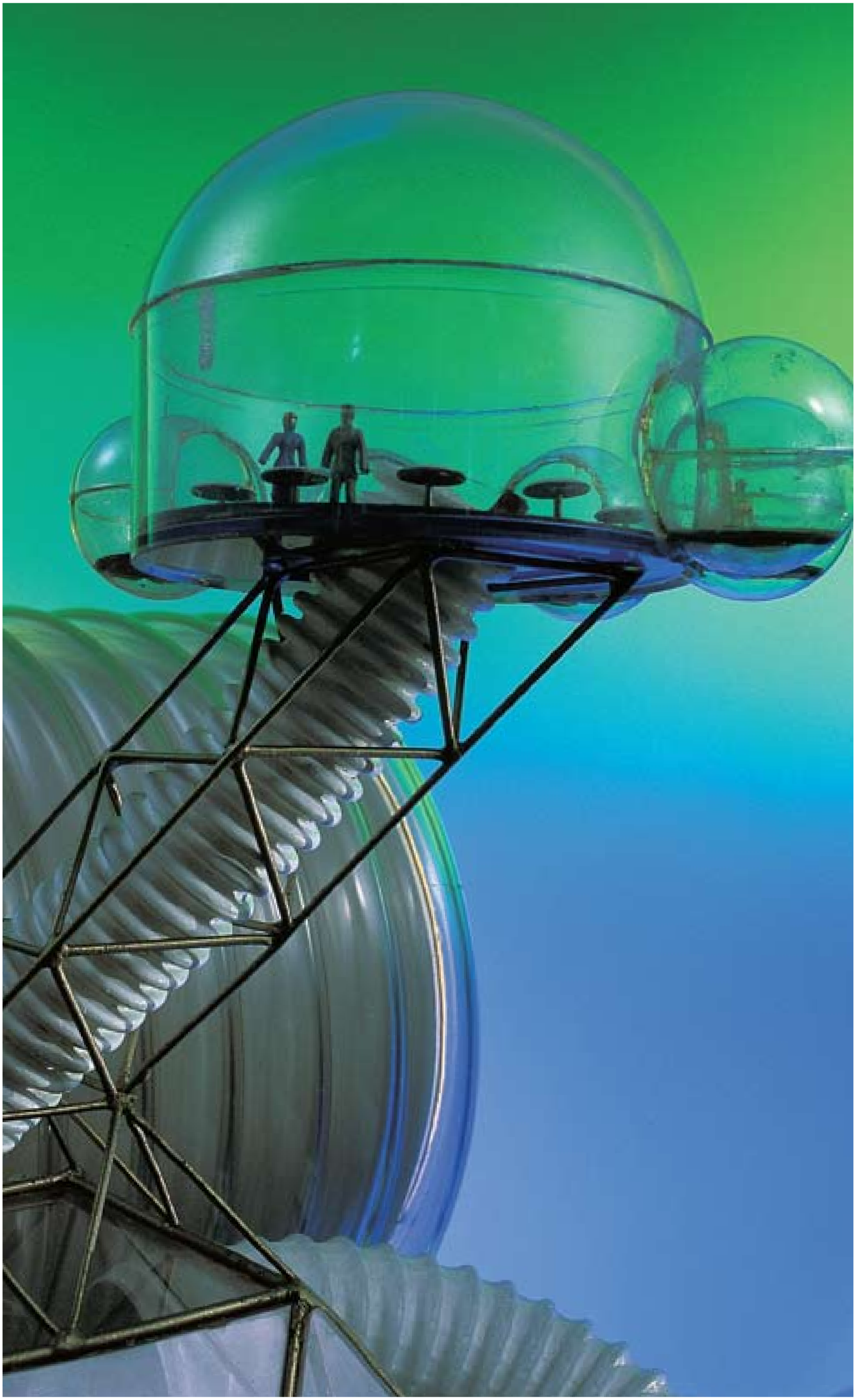


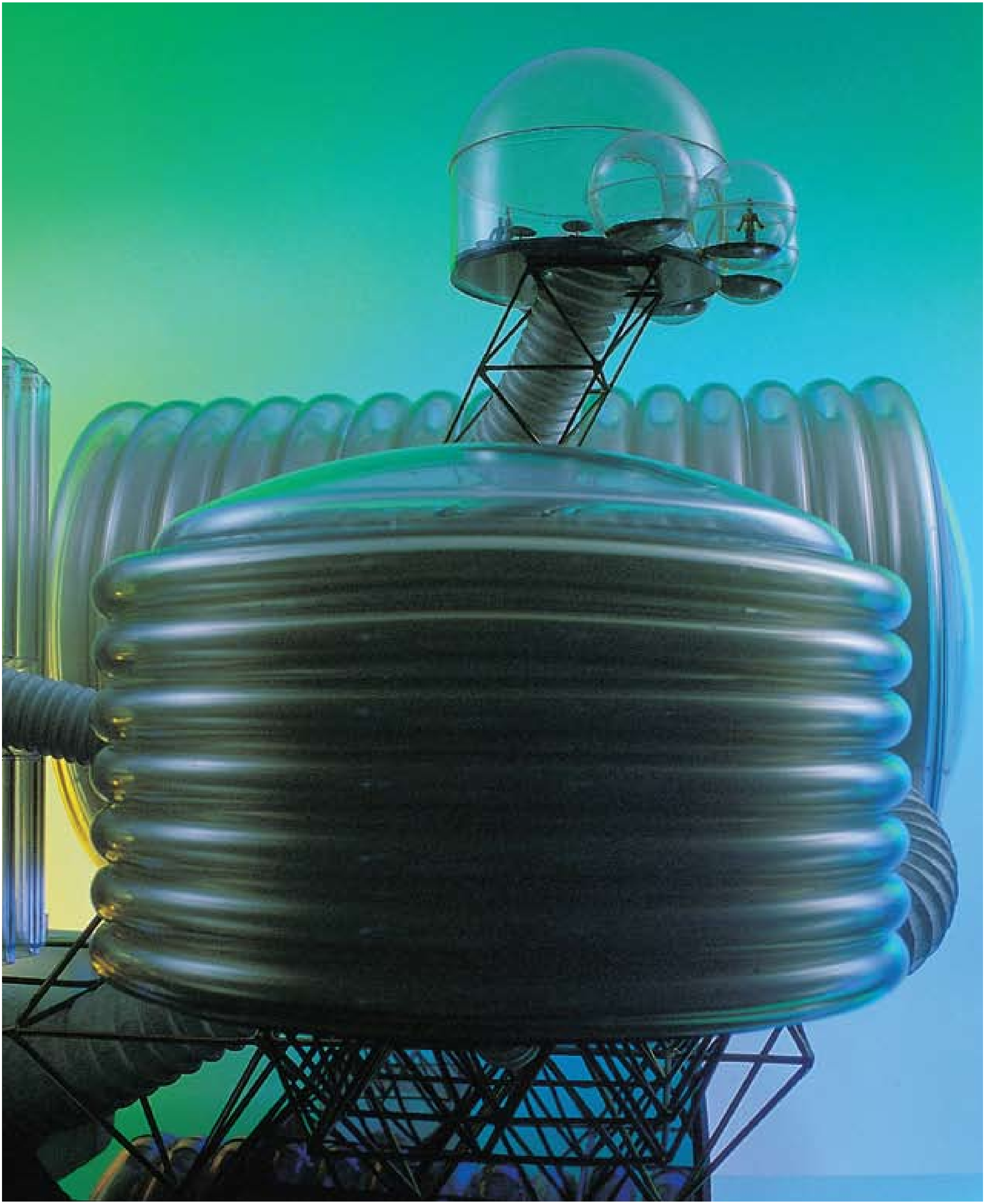
CONSTANT FIELD
ELECTRO-MAGNETIC PLATES
ELECTRO-MAGNETIC PLATES
STRUCTURE
ENERGIES OF ATTRACTION-REPULSION
SELF-LEVELING PLATFORM

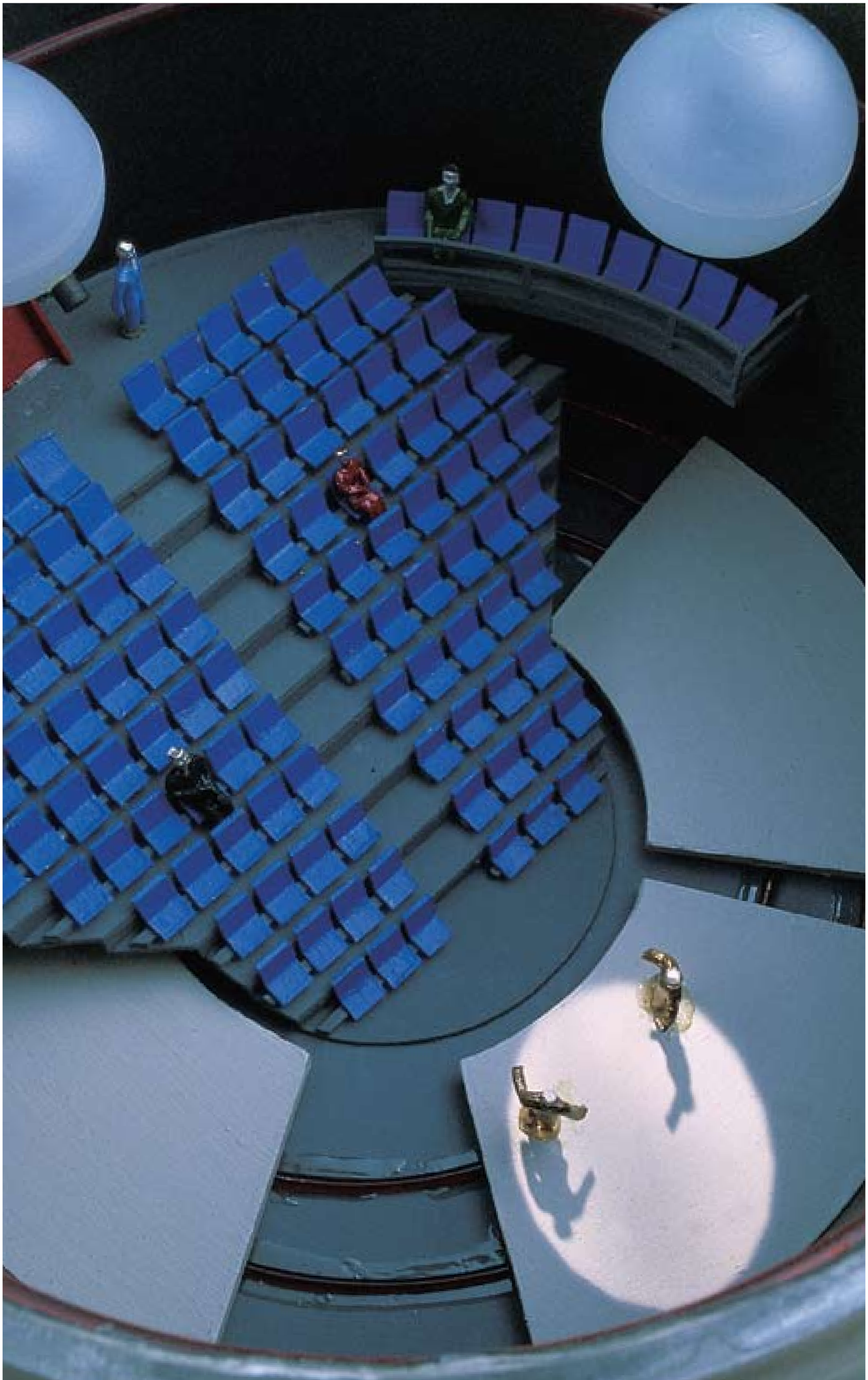


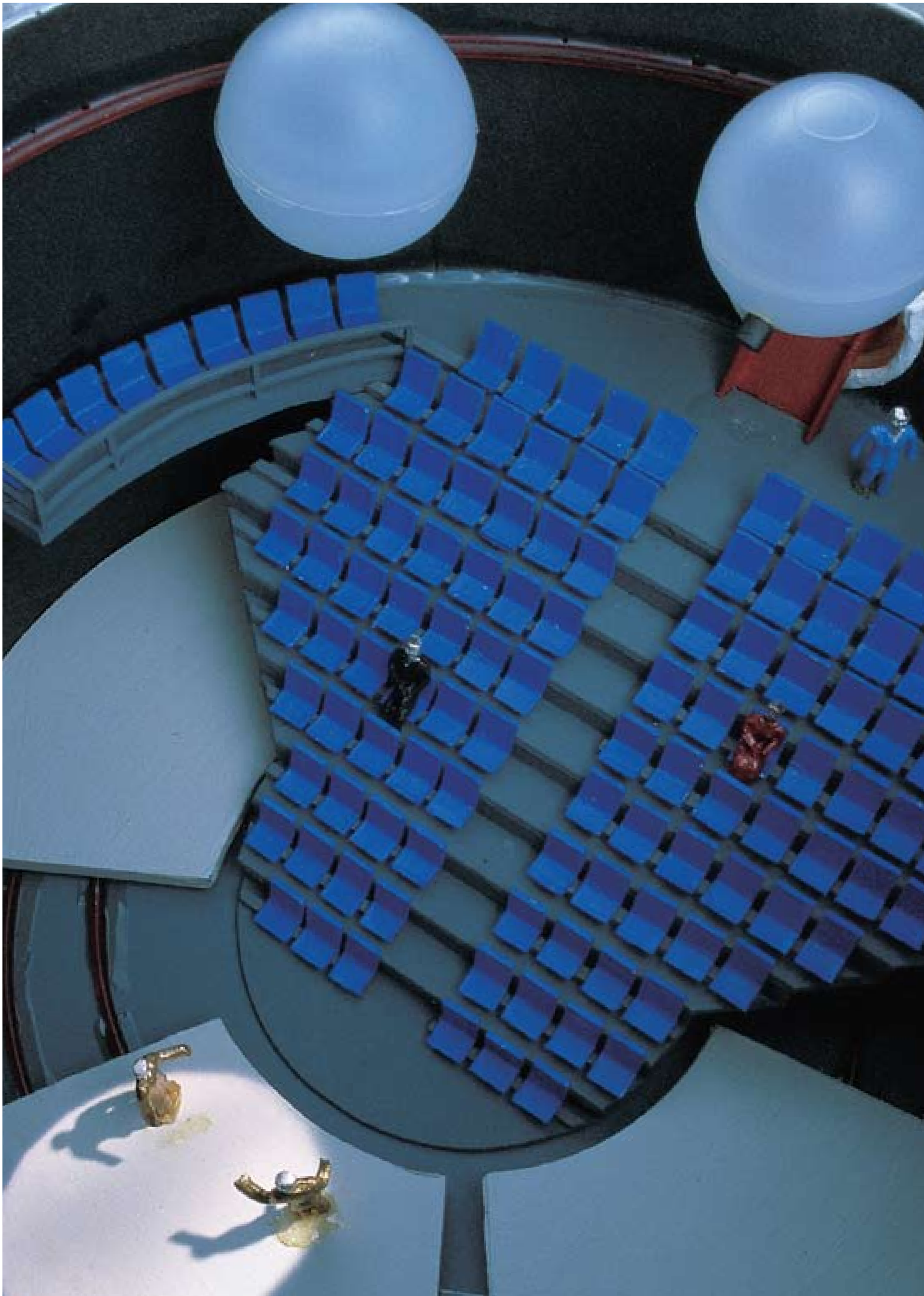
THE EXPERIMENTAL THEATER COMPLEX
PLAN

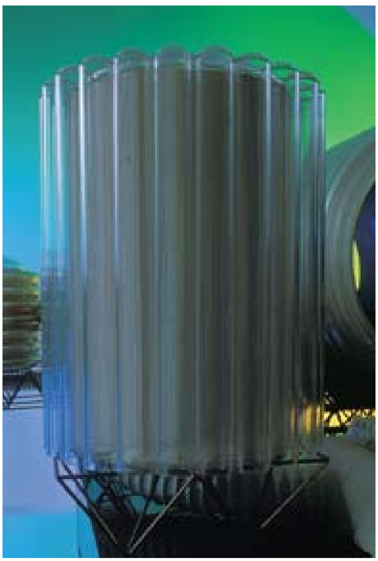


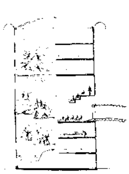


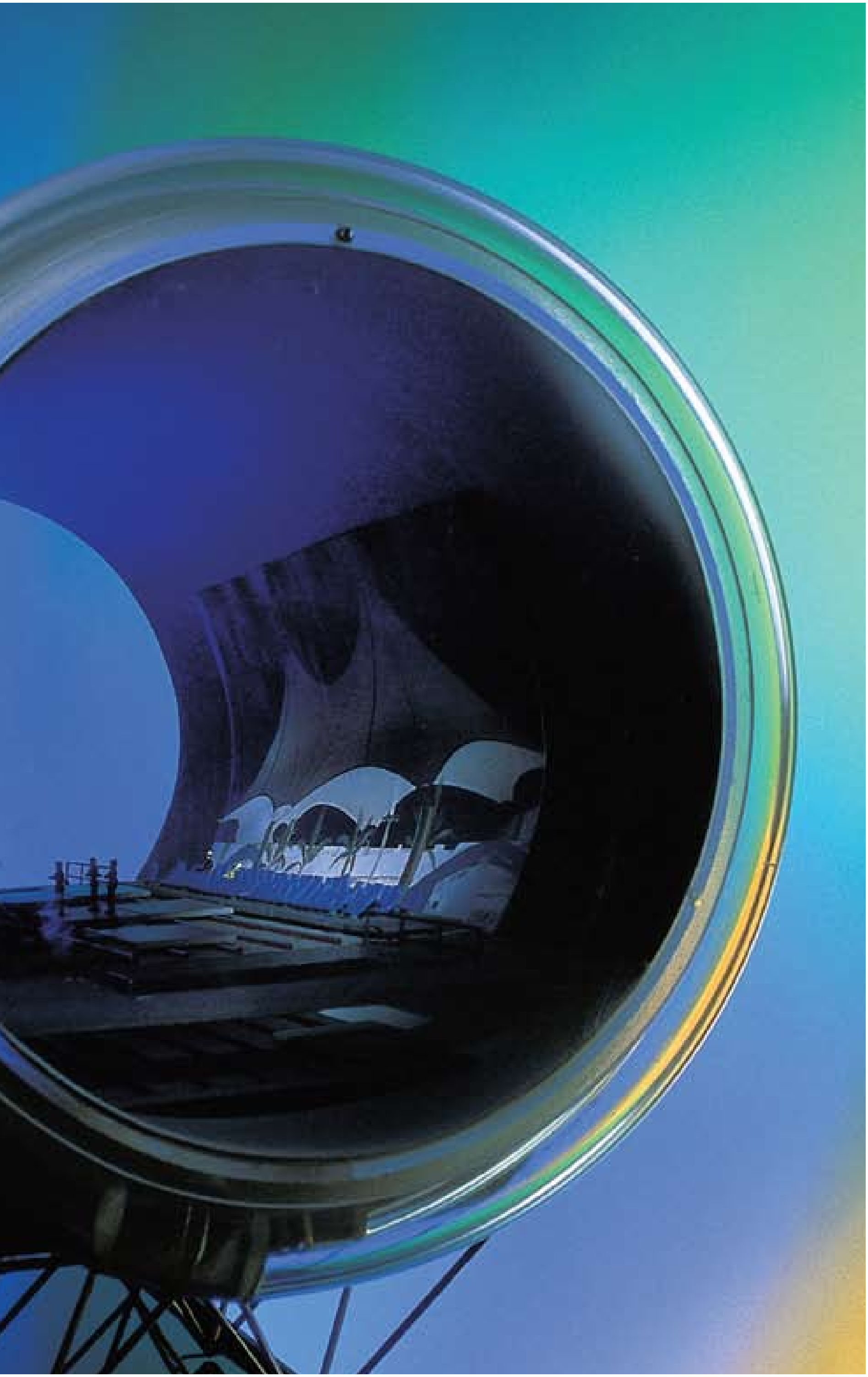



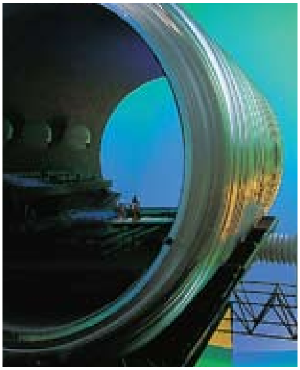


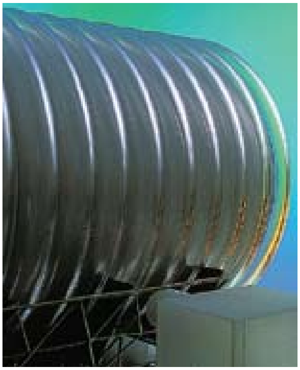









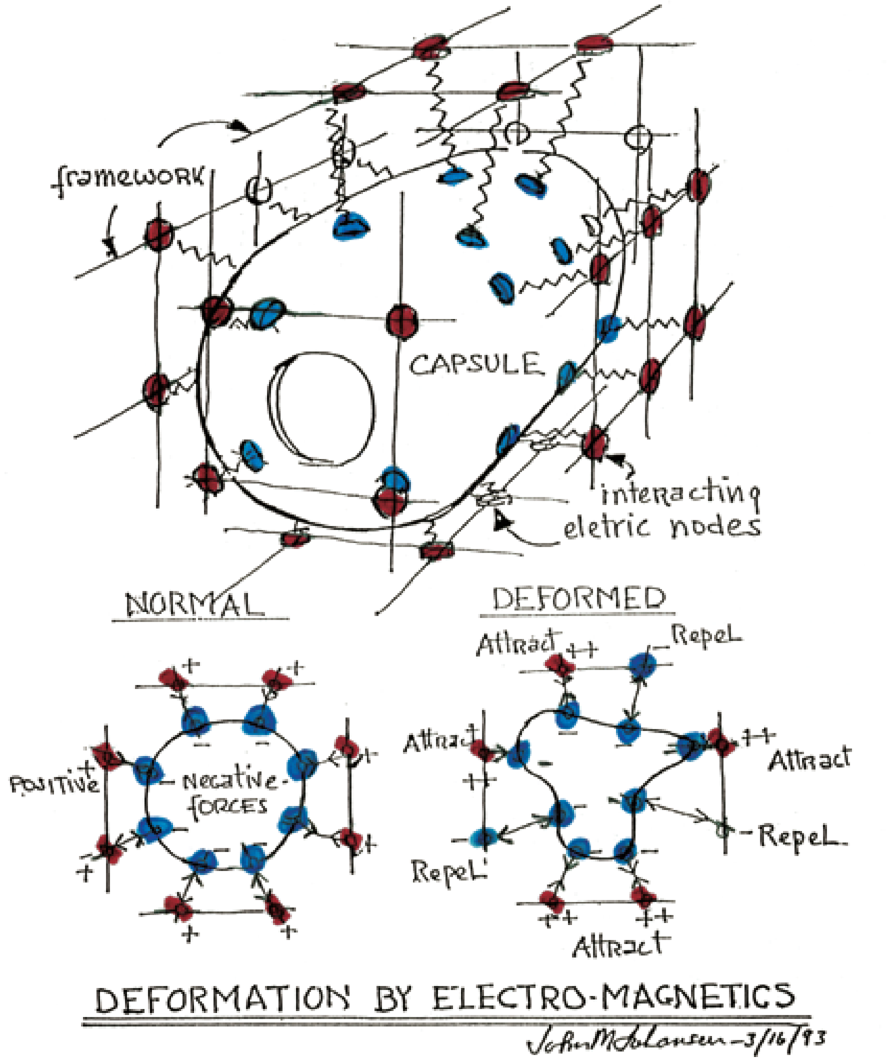




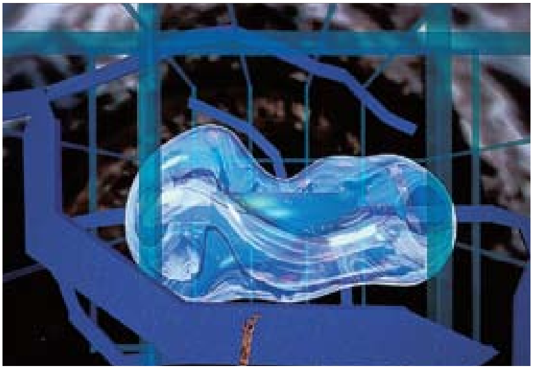
THE SPACE LABYRINTH

The Space Labyrinth is an educational and recreational tool that takes visitors on an exploratory journey through a dynamic field of three-dimensional geometrical structures. The labyrinth, which is roughly 150 feet wide and of equal height, can be installed indoors or out. Its spaces are deployed so that, as visitors travel through, shifting facets open and close in frameworks, forming perspectives that blur spatial continuities between inside and outside. Various line patterns extending through the labyrinth intertwine but never touch as they extend toward infinity. Visitors are carried through the labyrinth in a small carriage that moves along a serpentine track system, or rail, and is propelled by a linear induction motor. The carriage is self-leveling regardless of the incline of the rail on which it travels. (1991)

This project was completed in collaboration with Haresh Lalvani. Project assistant: Sean Murphy; Computer modeling: Eyeball on the Floor



framework
CAPSULE
interacting
eletric nodes
NORMAL
DEFORMED
Positive
Negative forces
Attract
Repel
Attract
Attract
Repel
Repel
Attract
DEFORMATION BY ELECTRO-MAGNETICS
3/16/93



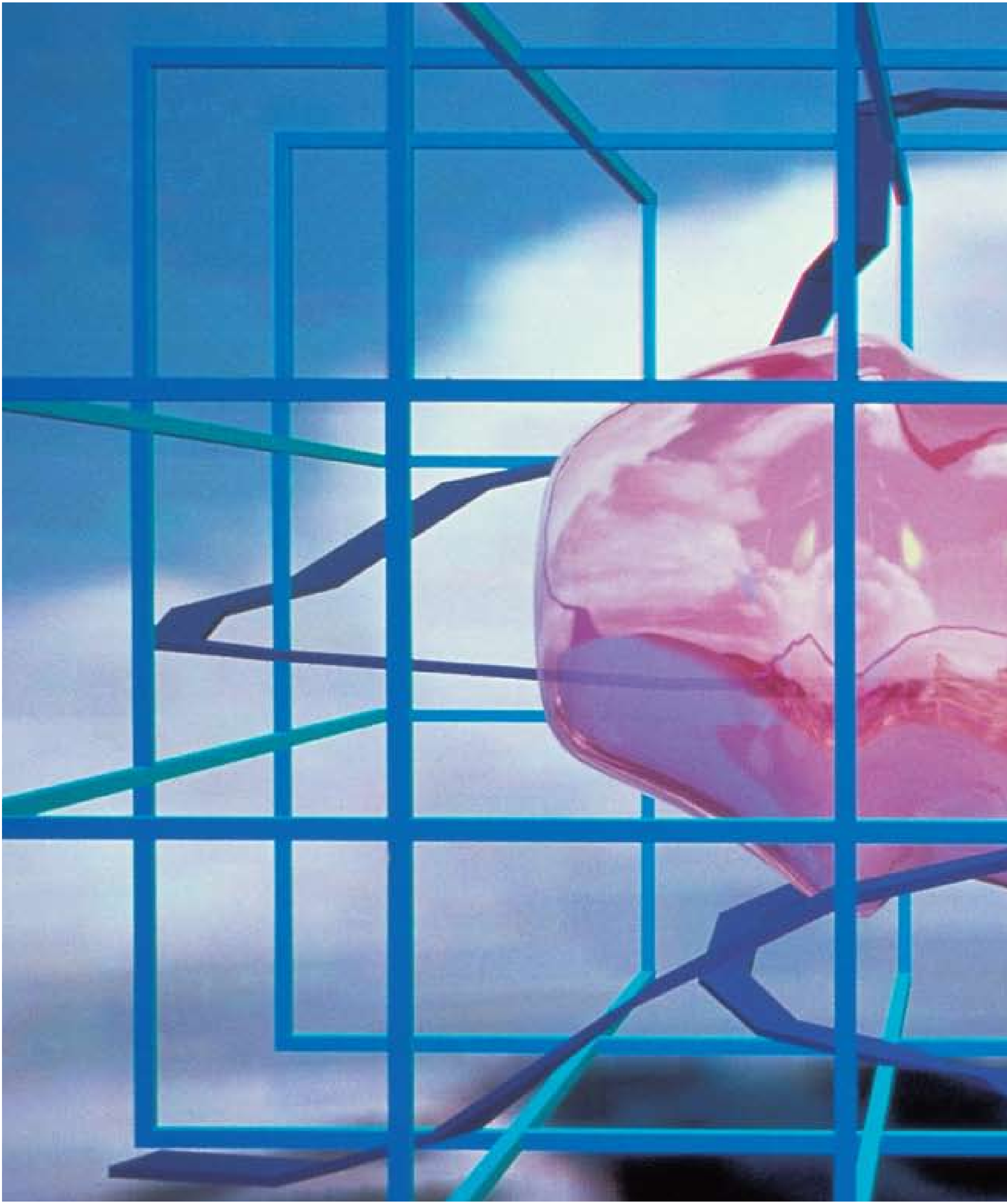
THE METAMORPHIC CAPSULE

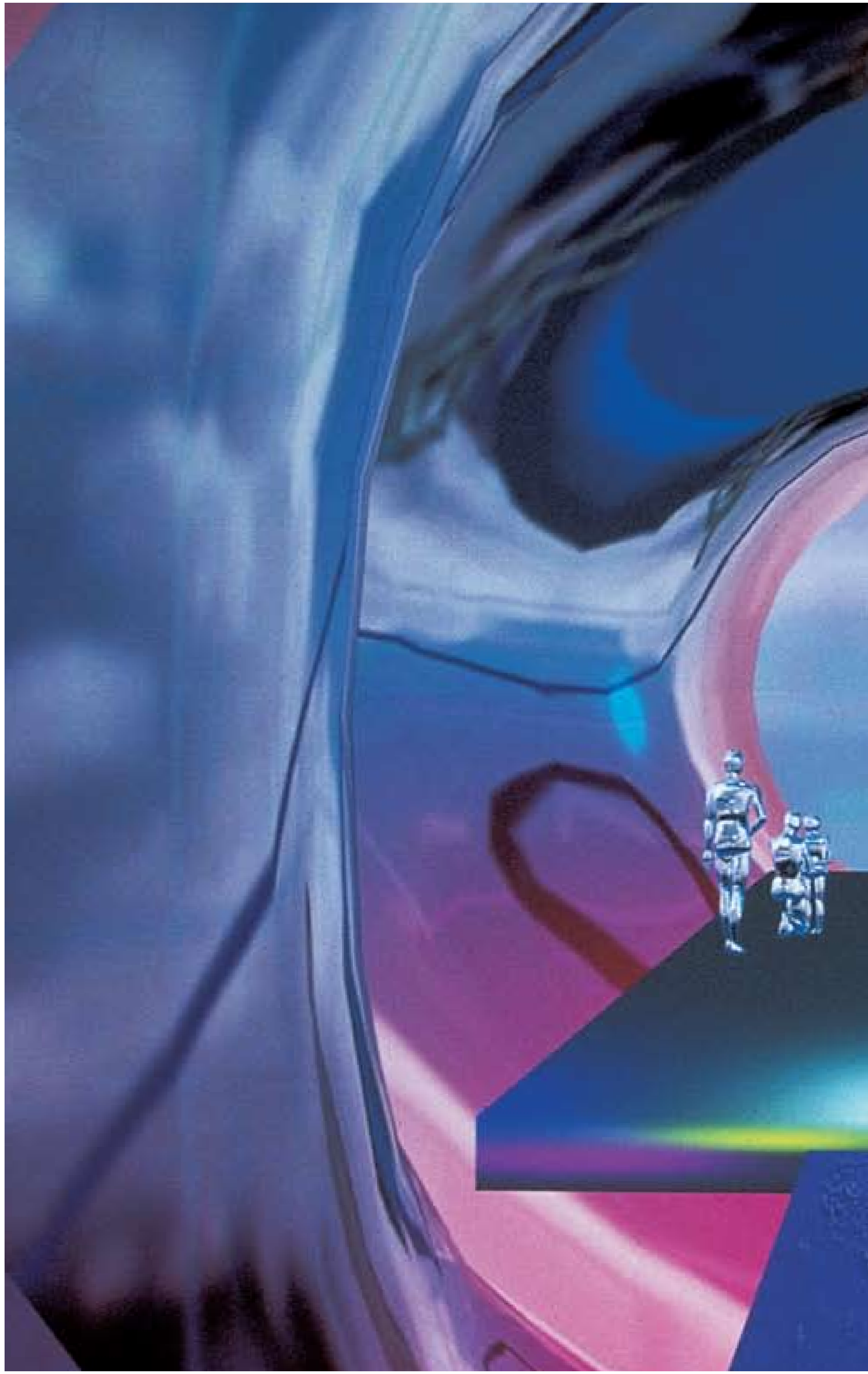
The Metamorphic Capsule is an enclosure whose form, opacity, and color is controlled by electromagnetics. The suspension of an object in space by the application of repulsive and attractive electric forces acting from nodes on the object with those of a surrounding field has already been achieved in the laboratory. Here, this surrounding field is formed by a system of nodes attached to a structural framework, with corresponding nodes placed on the outer surface of a fabric capsule placed within this field. Continuous air pressure from within is necessary to sustain the form of the capsule.

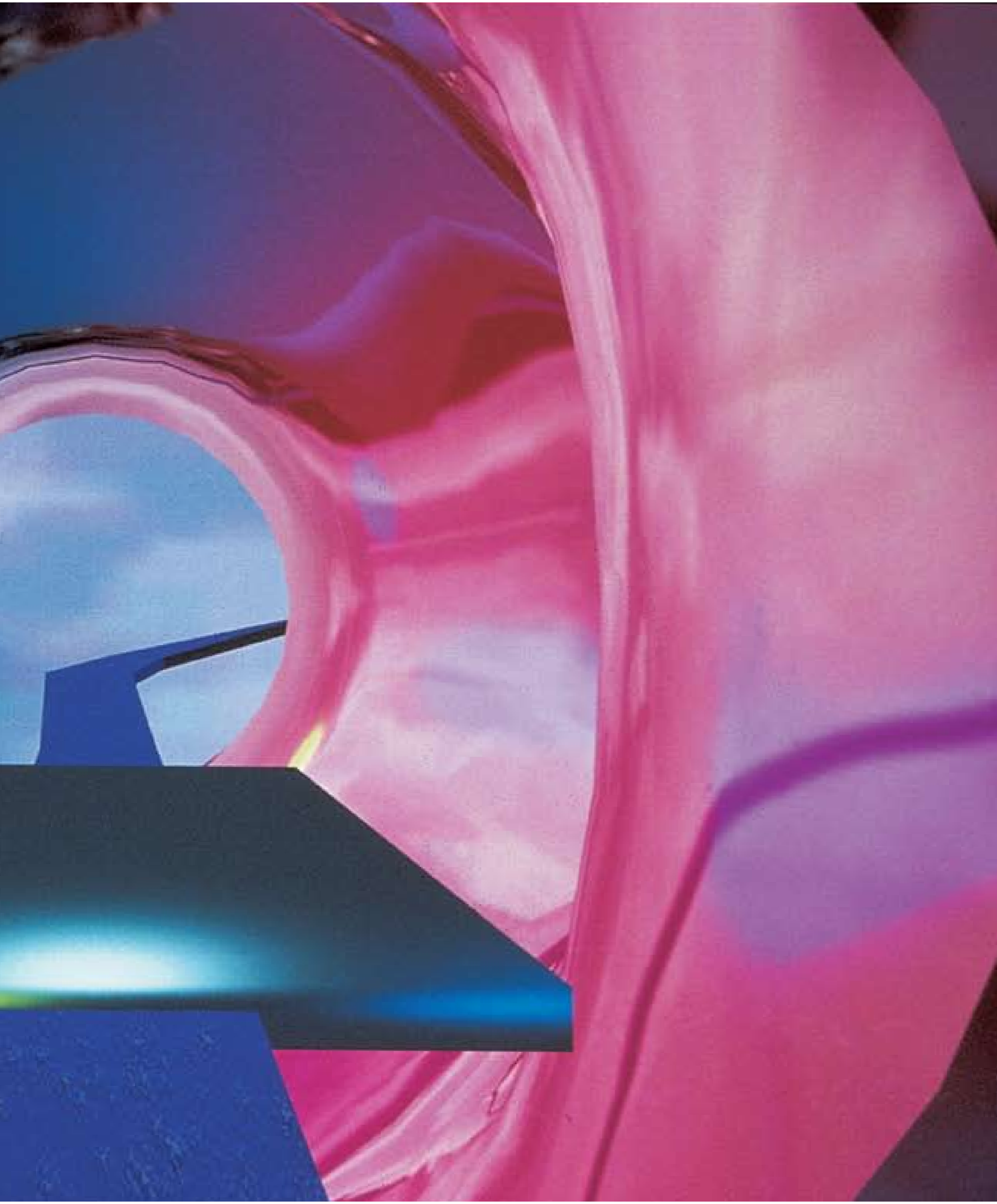
The power of the attracting and repelling forces sent to each node determine the overall shape of the capsule. Changes in the power sent to the nodes, or the relative amounts of power sent to individual nodes, cause the capsule to undulate. Color, degrees of opacity or transparency, and other visual and audible stimuli can also be controlled (governed either by handheld device from within or remotely programmed for repeated events).

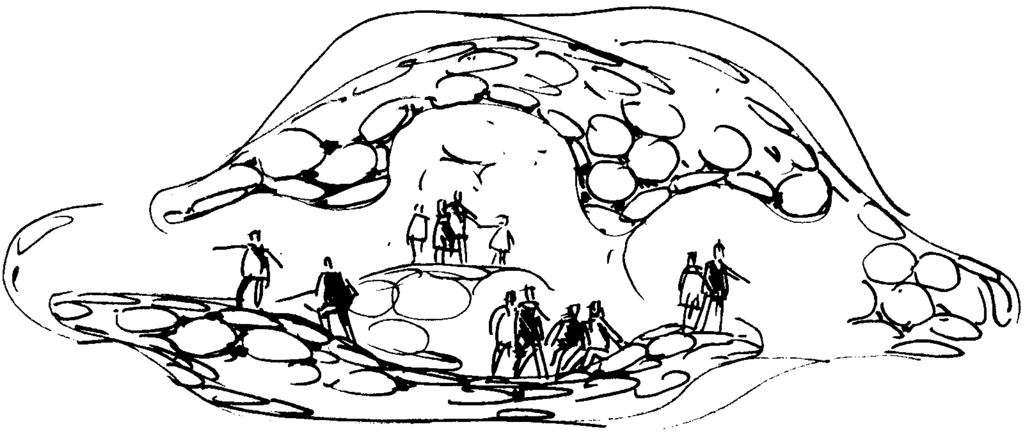
A serpentine levitator (like those used in the Mag-Lev Theater) carries visitors around and through this shifting form. Movement of the individuals passing through the capsule can itself motivate visual effects. Brain waves that indicate the various moods are recorded and harnessed to prompt changes of light and sound.

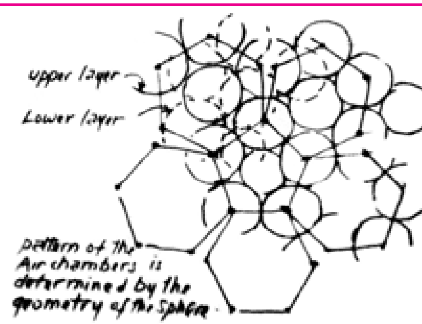
While not notably utilitarian, the capsule provides the experience of being swathed in a diaphanous, luminous, iridescent chamber in the timeless tradition of the cave or womb. (1992)









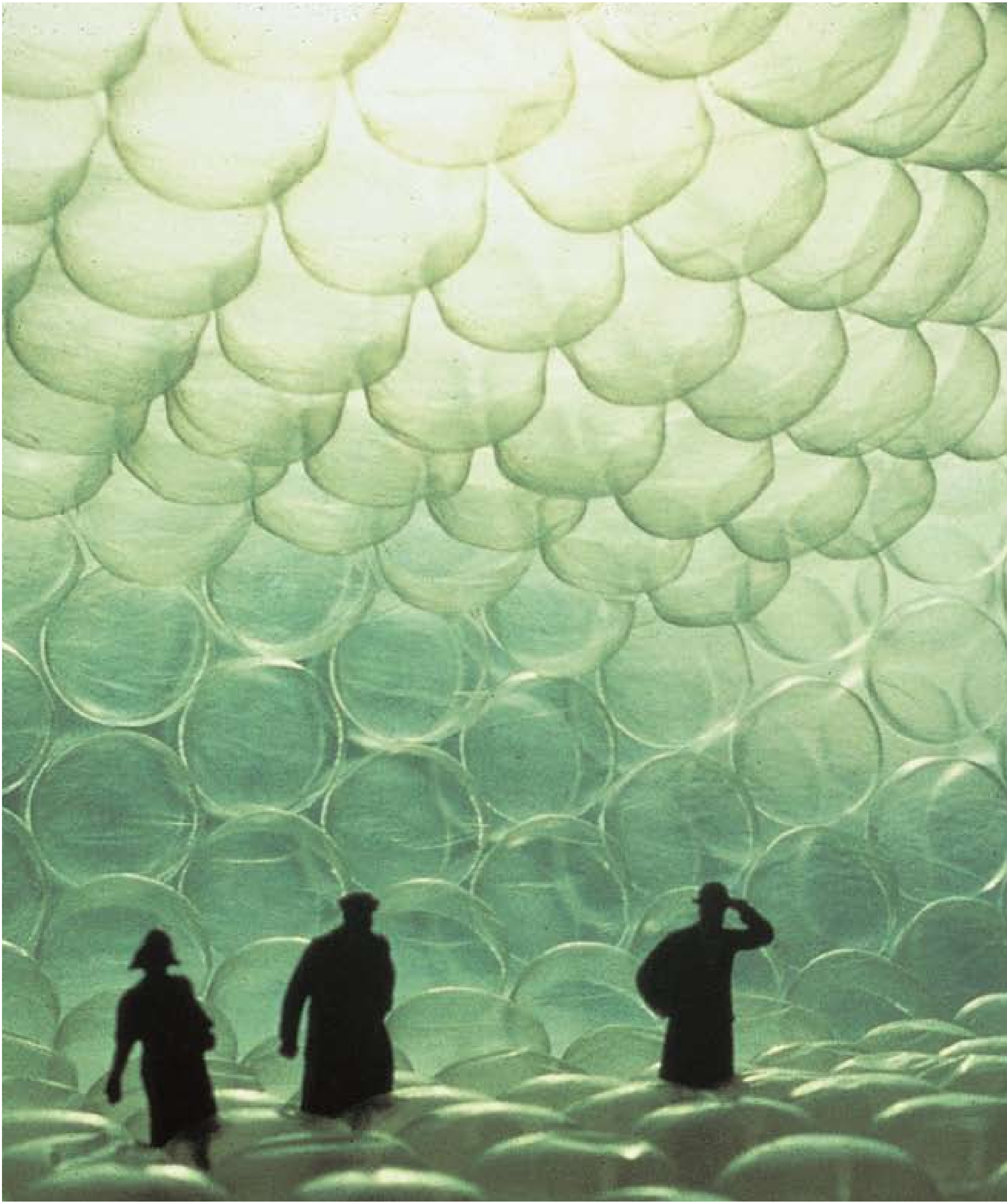

upper layer
Lower layer
pattern of the Air chambers is determined by the geometry of the Sphere.

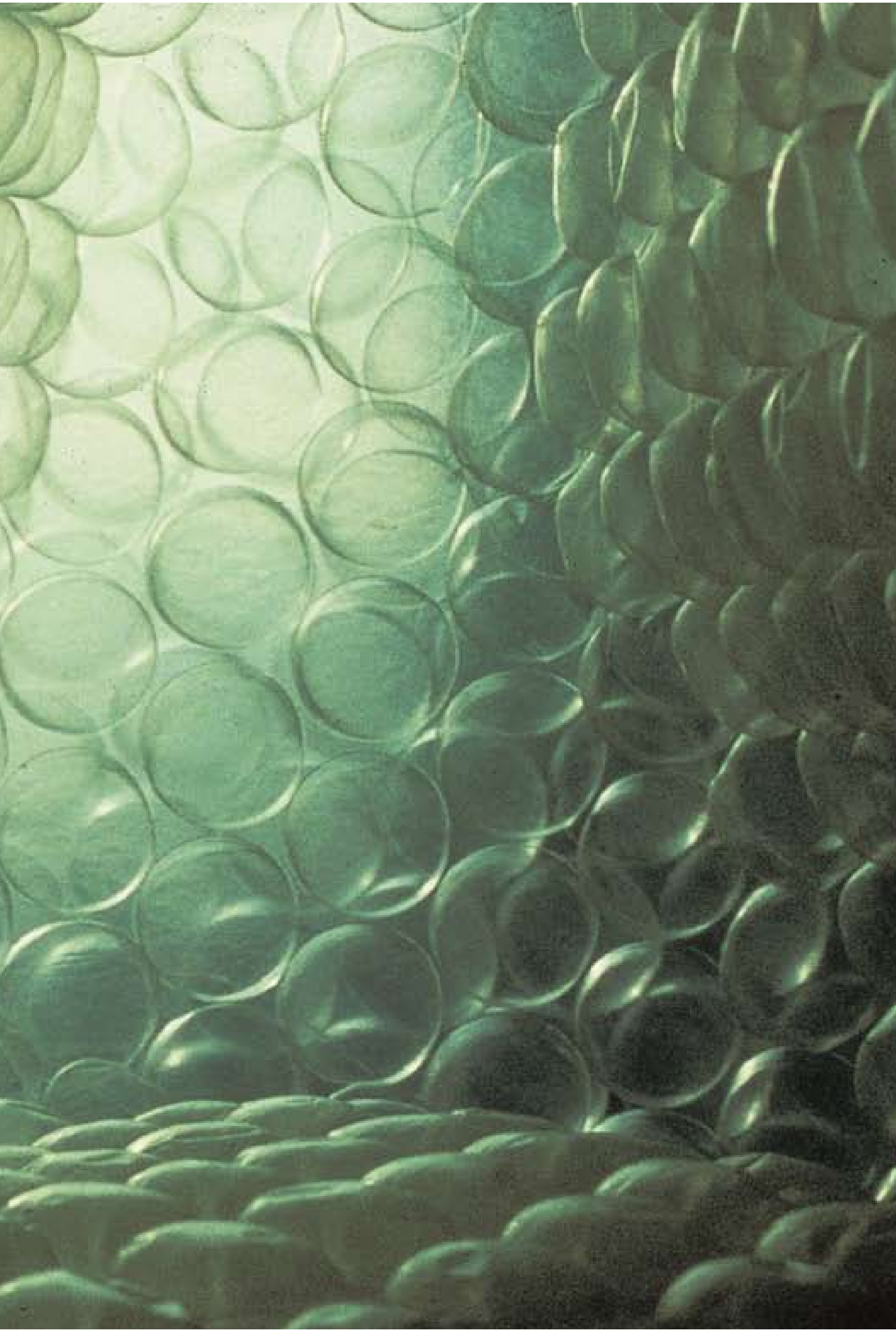
THE AIR QUILT

In this project, a quilt of spherical air chambers form malleable, habitable enclosures. These chambers are clustered in two layers in an order established by a geometric pattern of hexagons and pentagons. An "adaptive" building that can adjusts its interior volume to accommodate changing needs is created by distorting the chambers into desired configurations.

Distortions of the quilt surface are achieved by the variable expansion and contraction of the two-layered strata of air chambers. Transferring air from the chambers in the outer strata to the inner strata results in a bending action and a convex form. Conversely, air passing from the inner strata out creates a concave form as seen from the interior. As with the Metamorphic Capsule, internal air pressure sustains the envelope. Small air pumps, prompted by a computer system, power the air transference.

By substituting helium gas for air, this structure would lift off. Such a structure could be tethered by cables to the ground. It could also be equipped with jet motors to lift and lower it, stabilize it against wind, and navigate it as well. If this simulated cloud structure were used as a chapel, it would attain, quite literally, that detachment from earth and mundane matters sought after by so many religions. (1995)





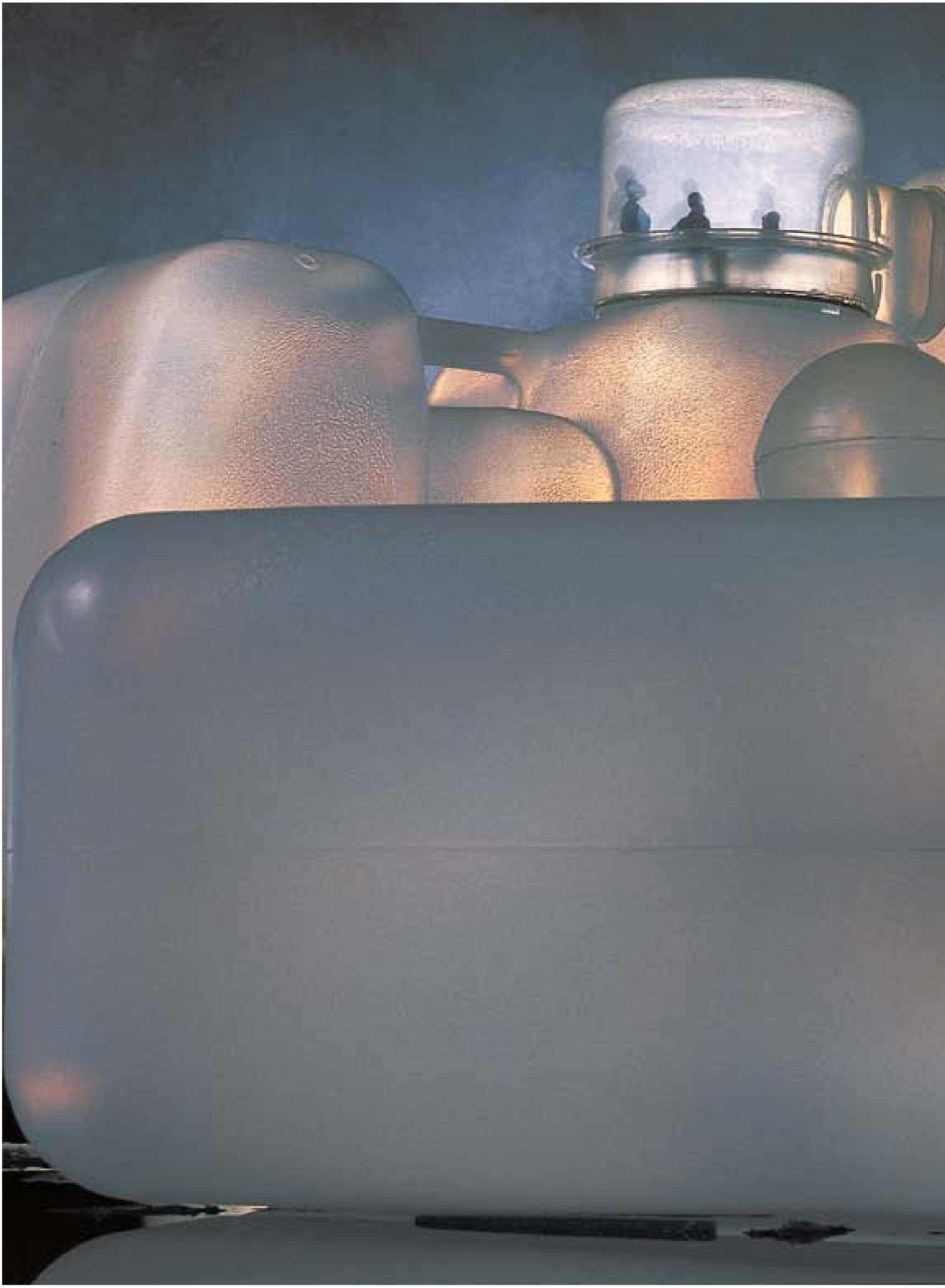
THE FLOATING CONFERENCE CENTER

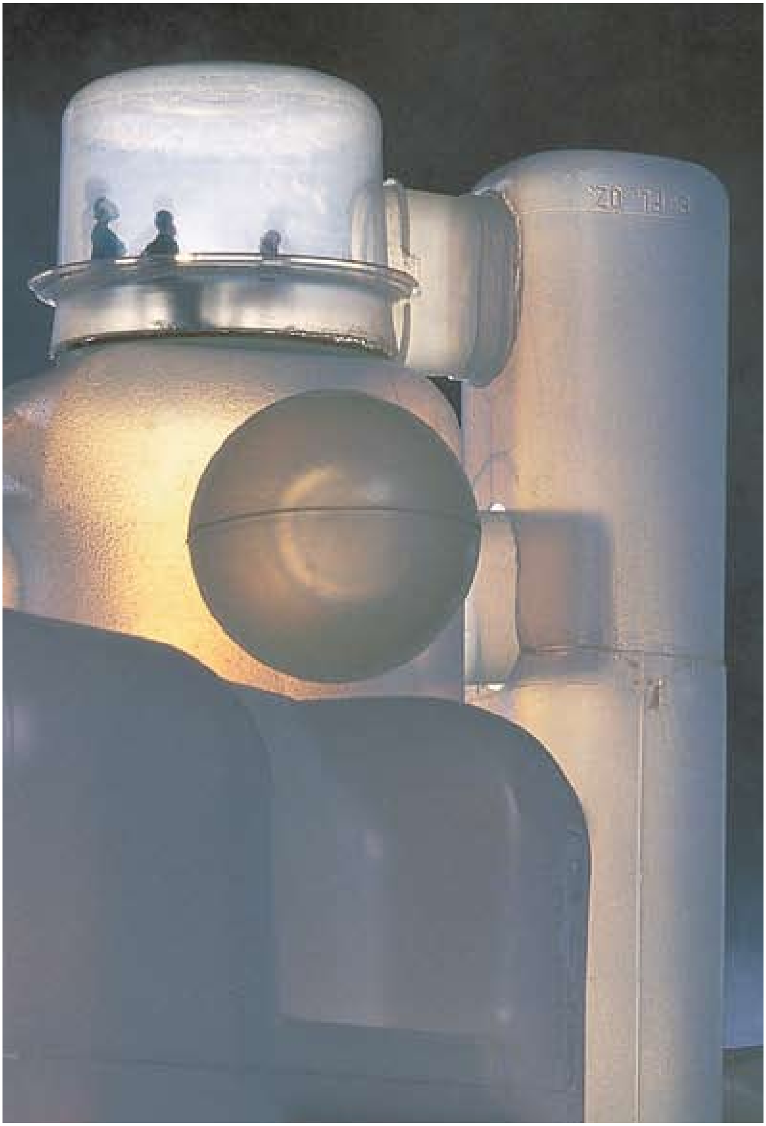
In my effort to advance the field of architecture, I often find it useful to adopt advanced technologies and construction procedures from related industries. Such is the case with my application of the thin fiberglass shell, a technology used in the construction of boat hulls, for these two projects. Fiberglass shells, which can be formed in any desired curvature, have been created in lengths ranging up to 175 feet. Set vertically, these could make eighteen-story buildings.

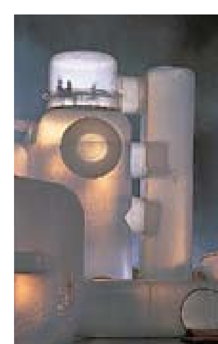
The remarkable aspect of thin shell structures is that great strength can be achieved by bending, curving, and crimping the shells. Take, for example, the plastic container used to hold water or milk (and used here in this model): though only 1/32 of an inch in thickness, they can carry some 50 pounds of water. The thin fiberglass shell exhibits similar properties.

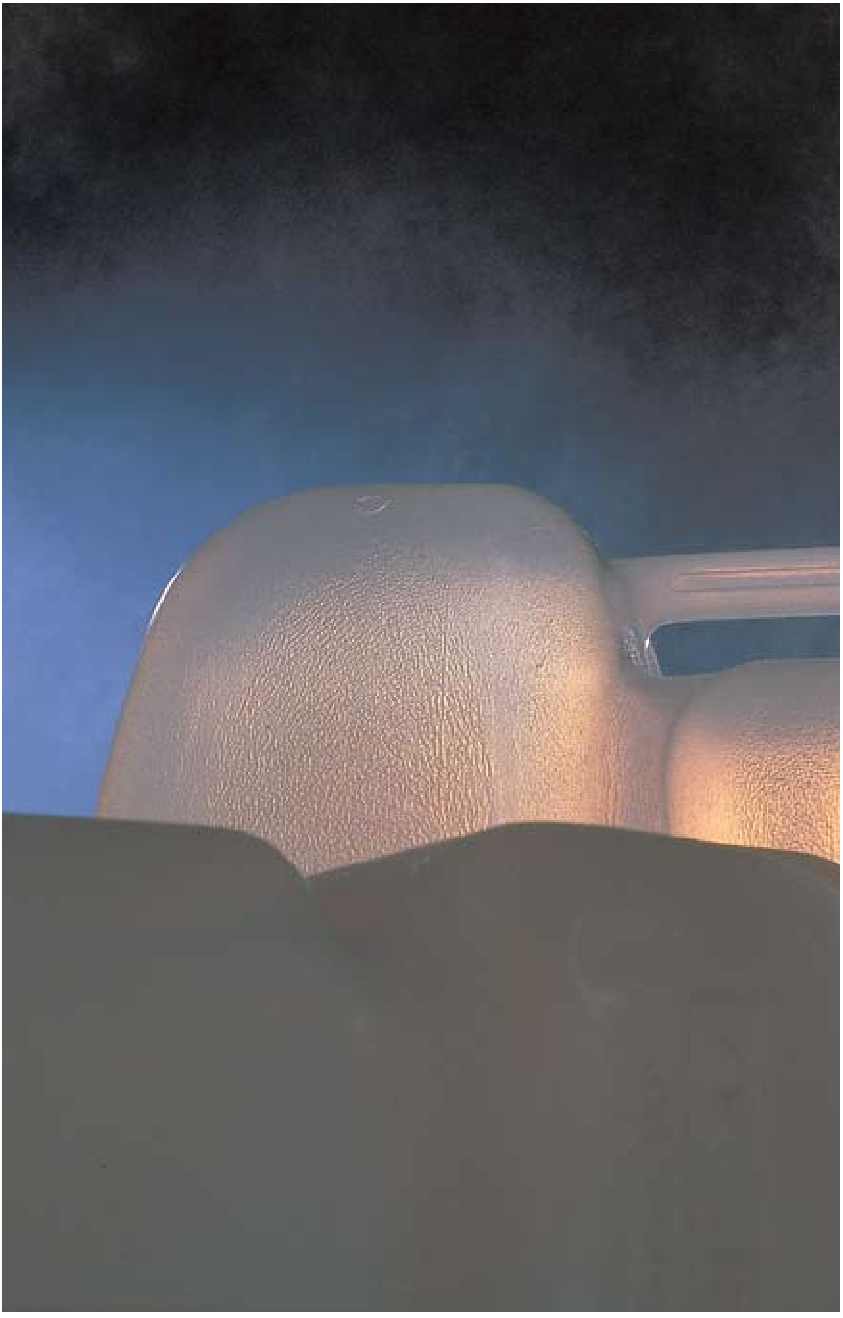
Thin shell technology will provide a unique formal and aesthetic character to a building. In the conference center, structural ribs rise from the floor, reaching upward and merging to support the arched roof. Natural light glows through these translucent shells, creating a luminous, iridescent, and ever-changing interior of gossamer character. It is an architecture of dematerialization: eerie, magical, other-worldly, somehow Gothic in spirit.

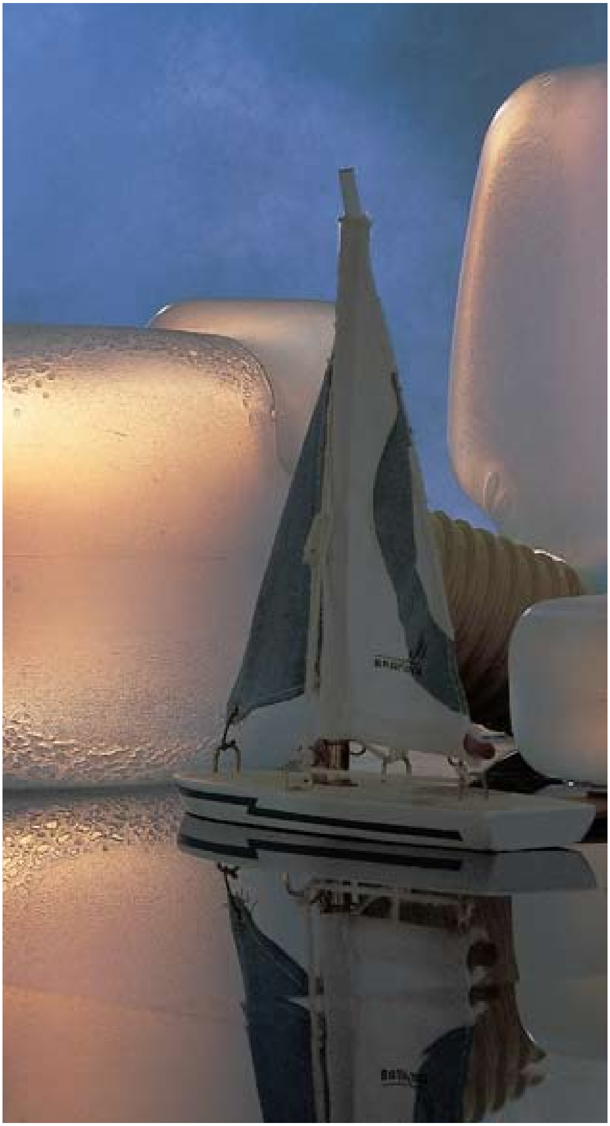
The shells would be formed at a factory and then transported and literally glued together on site, at water's edge. If boats are made to float, then why not a conference center, located away from busy surroundings, that can do so as well? (1996–97)

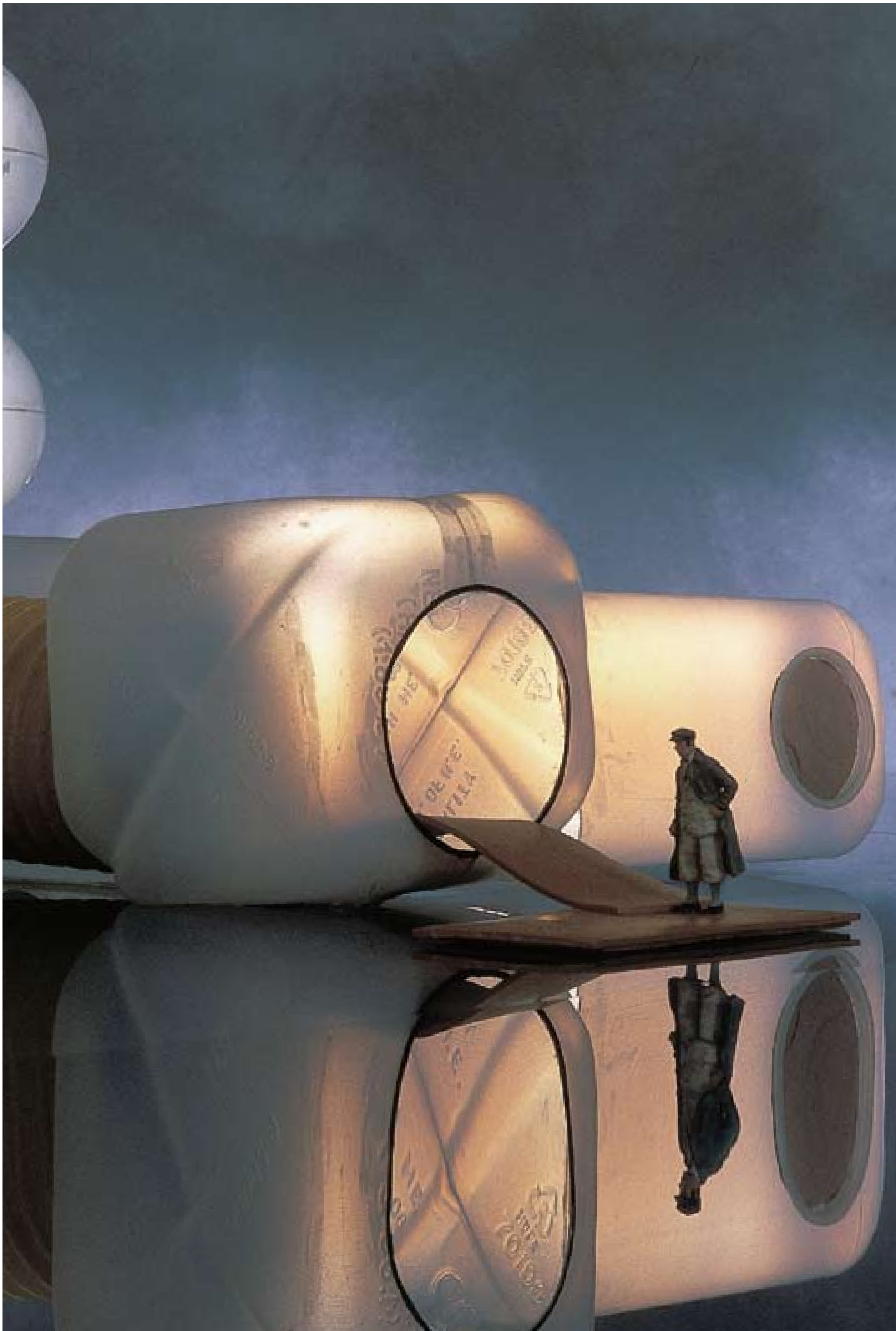


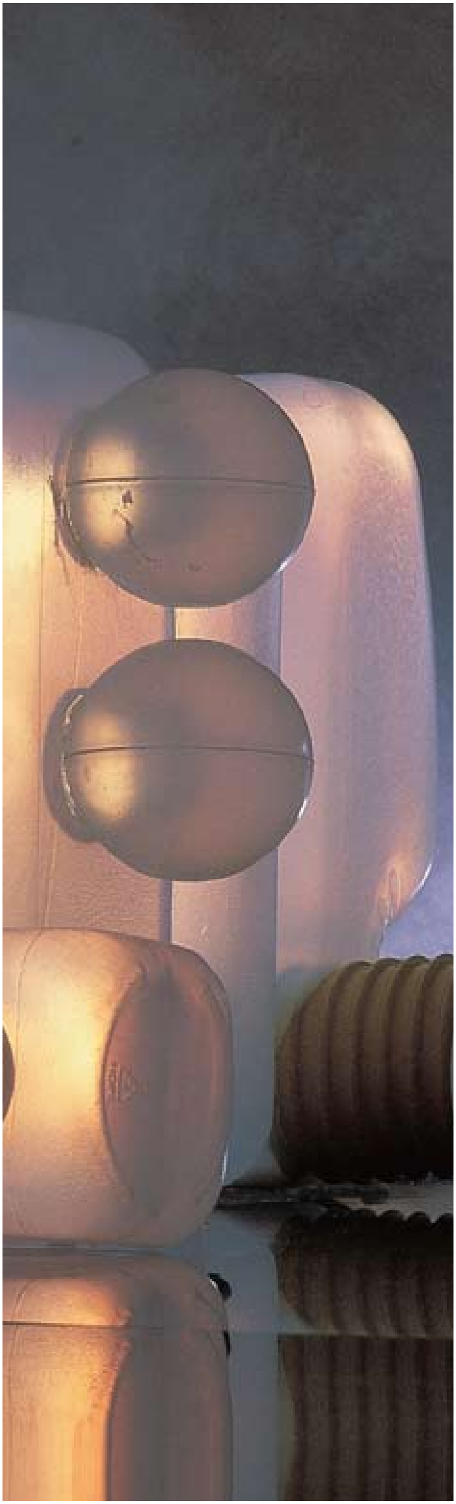


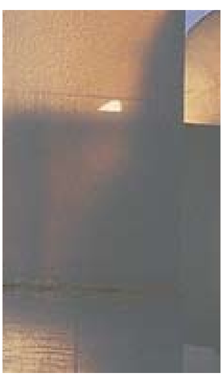


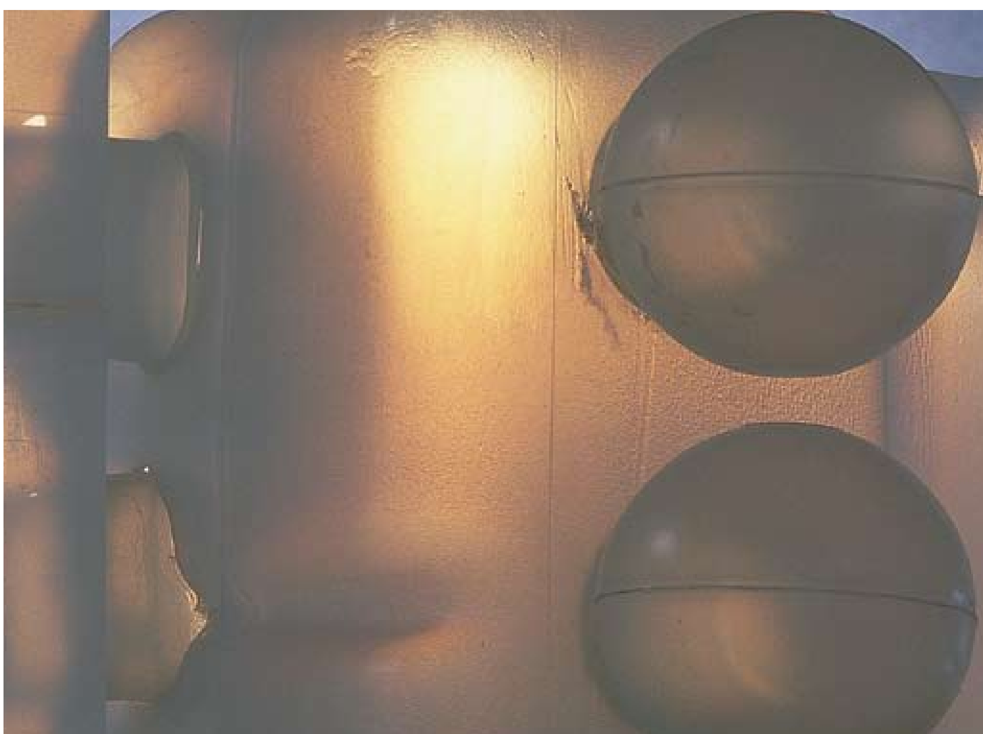


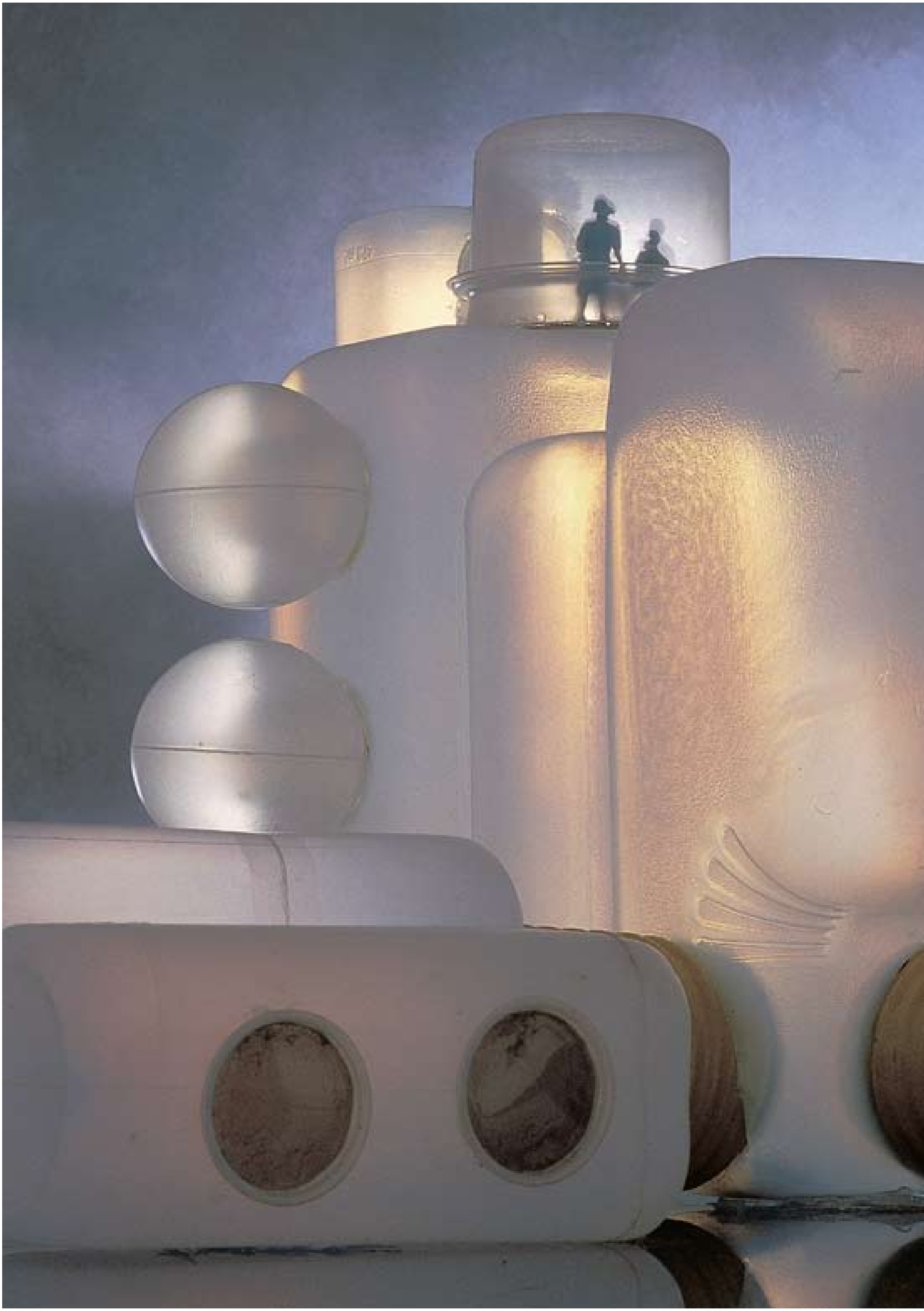






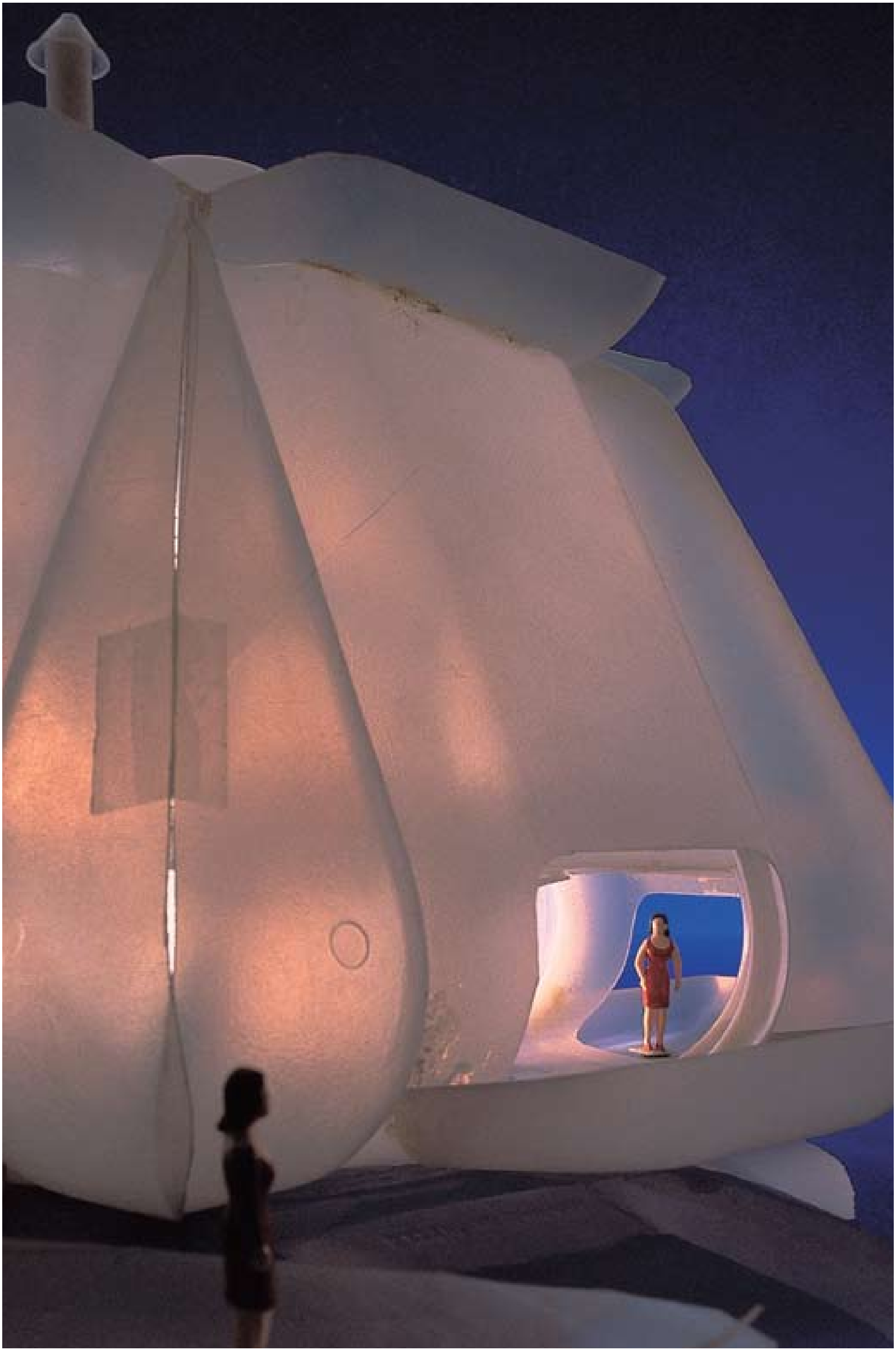


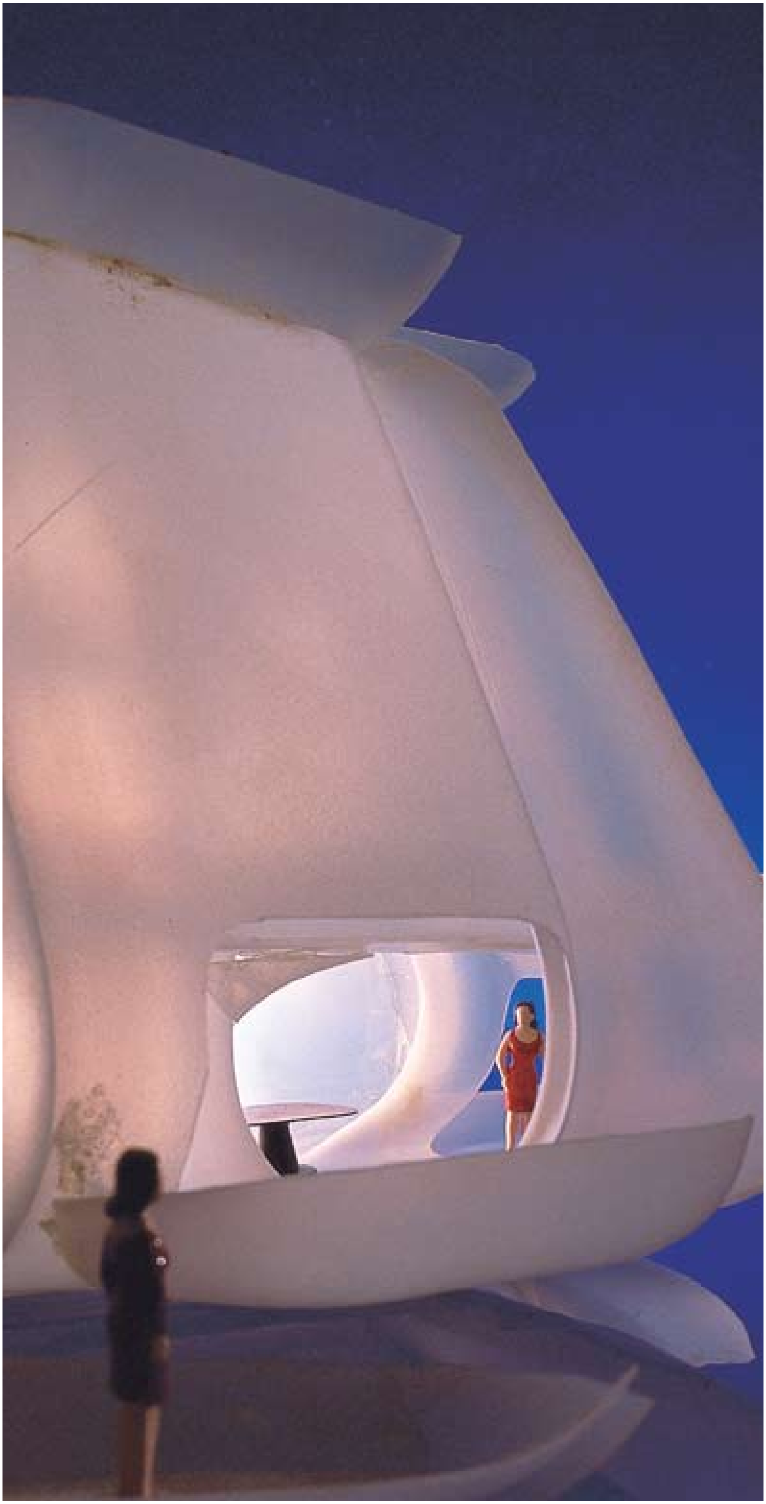


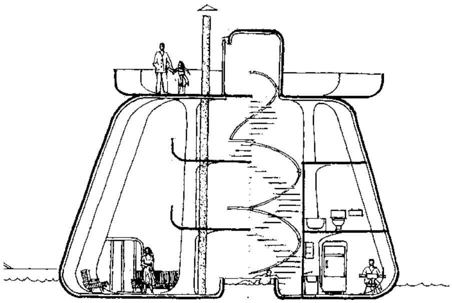

32 FL OZS

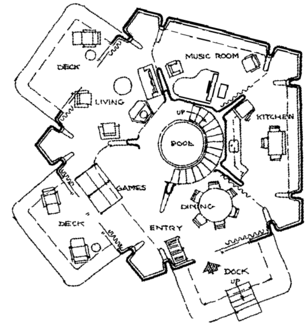

THE FLOATING HOUSE

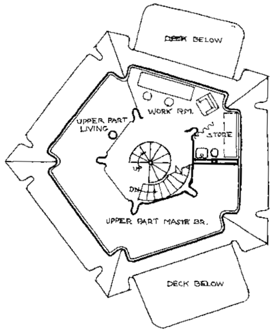
Like the Floating Conference Center, the Floating House applies thin-shell structural technology, but this time for a domestic rather than a commercial building. The three-story home has a central, spiral staircase and a roof deck above where residents might enjoy the canopy of the night sky. Public rooms are situated on the first level, as is a private dock. The entire home—its structural supports along with much of its built-in furniture—is sculpted from the same luminescent plastic material, giving it the bearing of a giant water flower. Residents moving through its inner chambers will experience a visual unfolding, as if promenading about the flower's translucent petals. (1996–97)

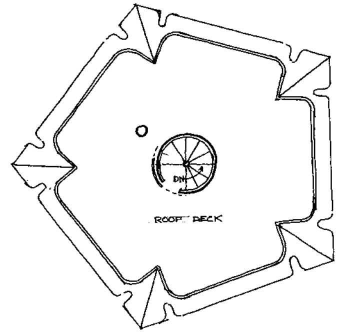



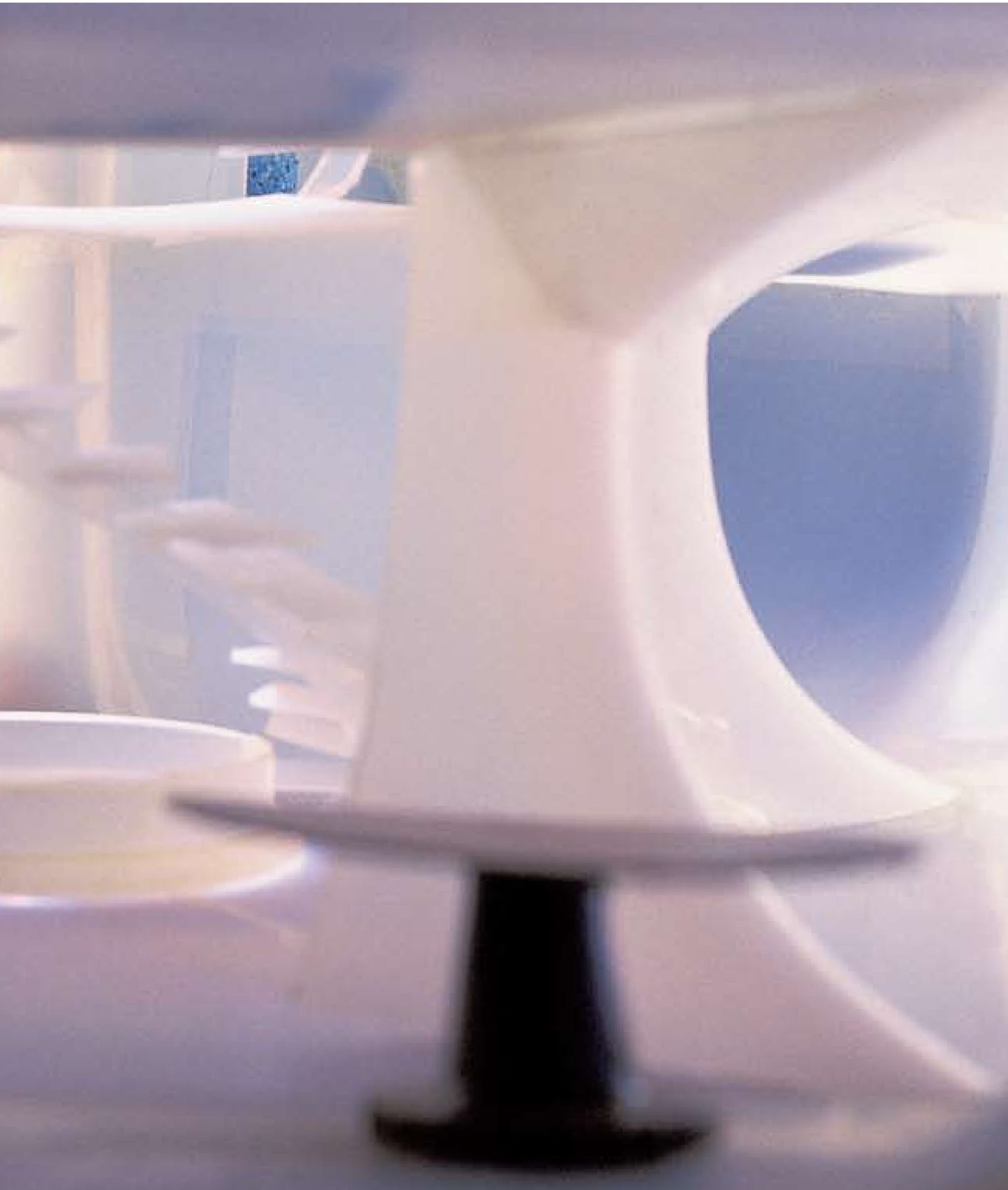


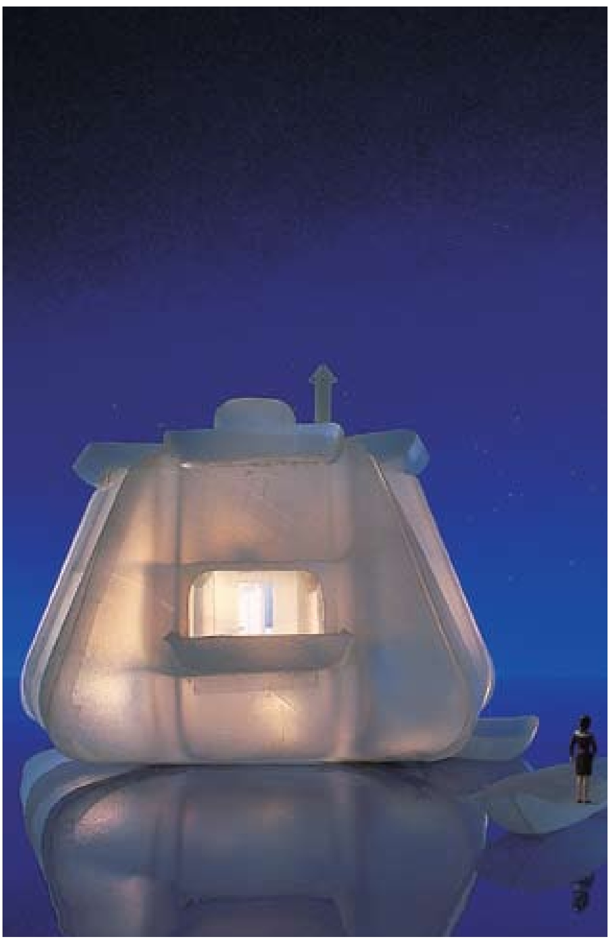


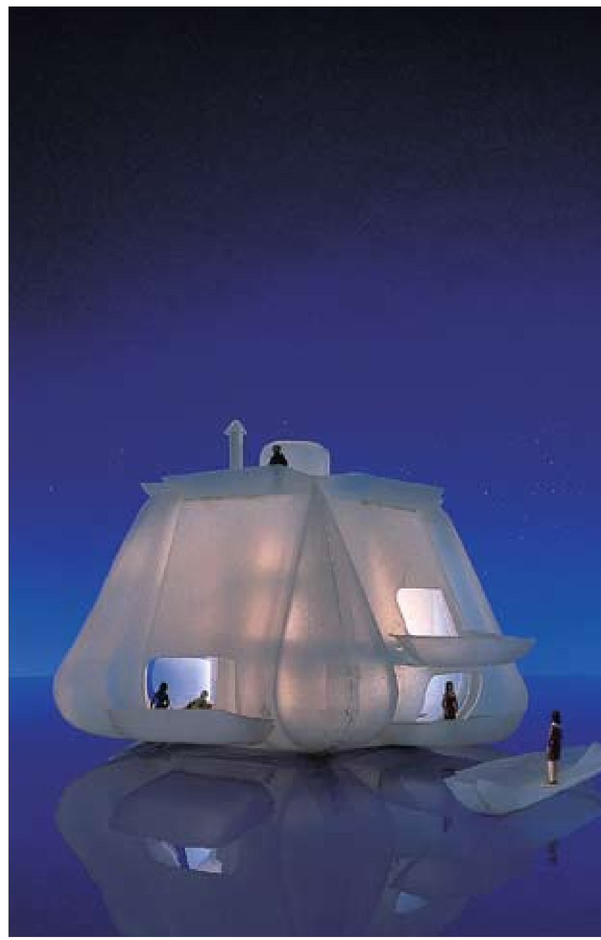

DECK
MUSIC ROOM
LIVING
KITCHEN
UP
POOL
GAMES
DINING
DECK
ENTRY
DOCK
UP

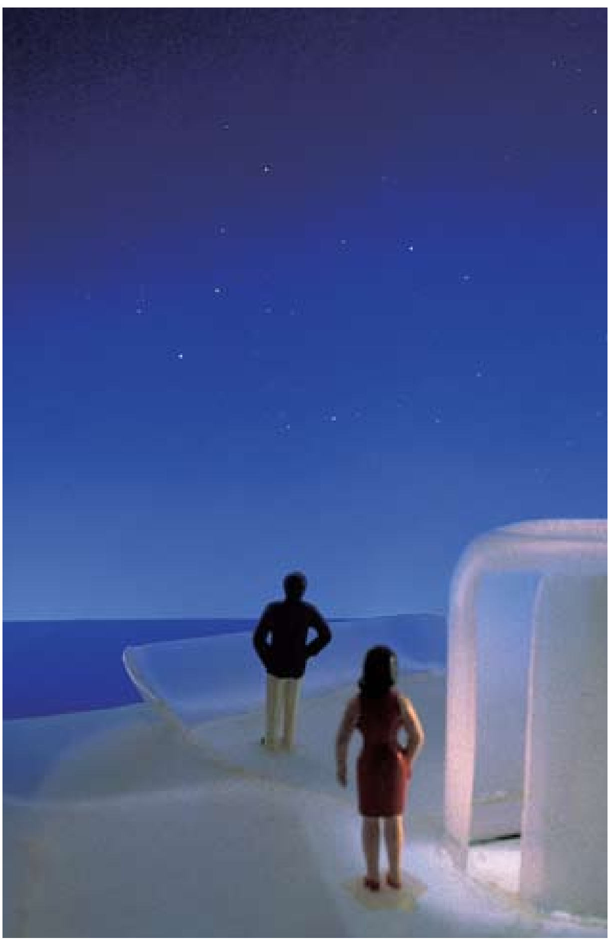

DECK BELOW
WORK RM.
UPPER PART LIVING
STORE
UP
DN
UPPER PART MASTE BR.
DECK BELOW

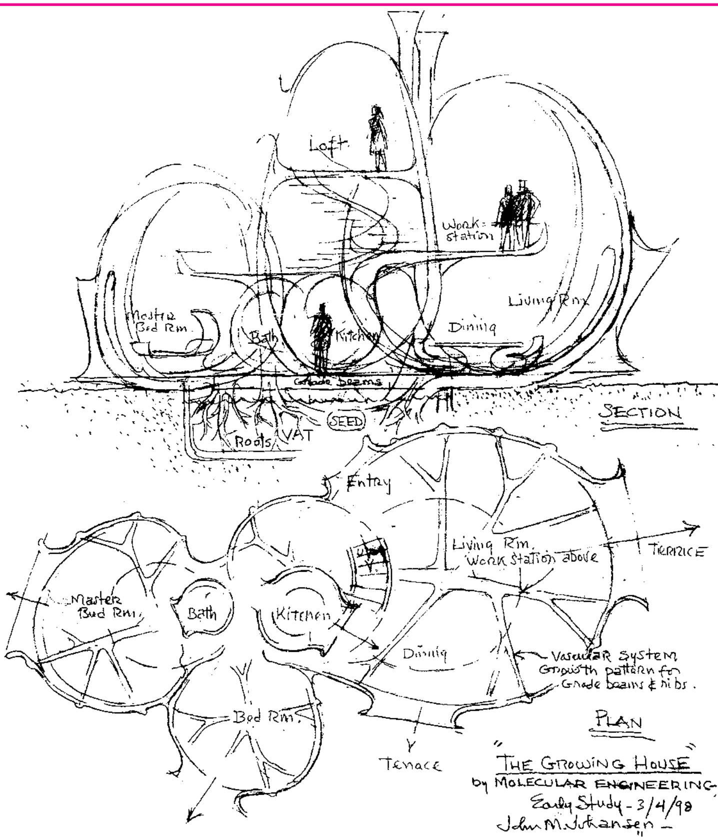

DN
ROOF DECK





Loft
Work-station
Living Rm
Master Bed Rm.
Bath
Kitchen
Dining
Grade beams
SEED
VAT
Roots
SECTION
Entry
Living Rm
Work station above
TERRACE
Master Bed Rm.
Bath
Kitchen
Dining
Vascular System Growth pattern for Grade beams & ribs.
Bed Rm.
PLAN
Terrace
"THE GROWING HOUSE"
by MOLECULAR ENGINEERING
Early Study - 3/4/98
John M. Johansen

MOLECULAR-ENGINEERED HOUSE (FOR THE YEAR 2200)

The following is a diary created by the owner of a molecular-engineered house written during its construction. It is set in the year 2200.

Day 1: Excavation begins on site where assembly vats will be placed.

Day 2: Vats delivered to the building site, along with selected chemicals and bulk materials in liquid form. The various materials are then pumped into the vats.

Day 3: The code, developed from an architect's designs and then engineered and molecularly modeled, is ceremonially placed in the vat. We are amused that this code represents what long ago were the drawings, specifications, and strategies of construction management.

Day 4: Molecular growth, in the form of a vascular system, begins. This starts with roots stemming from the chemical composite. Reaching up and out of the vat to ground level, the roots form rudimentary "grade beams" extending horizontally to the edge of the house, where they curve upward to support the superstructure. Cross ribs connect the grade beams and form the ground-floor platform.

Day 5: The growth of the superstructure starts with the development of primary exterior and interior vertical ribs. The infill of minor connecting ribs—"the lattice"— also begins to develop. The lattices are of varied densities, and are programmed to meet stress requirements—being less dense and more open in pattern where door openings are specified, for example. Fine web work and membranes appear as protective enclosures and interior partitioning. A neural network communicating via transmissions—and not preprogrammed—couples to the vascular system and begins operation.

Day 6: The upper platforms, supported by lateral brackets stemming from some of the major structural ribs, are accessible by a sprouting central spiral staircase. Exterior protective membranes conceal the interior. The molecules of the membranes link to create an unbroken fabric. The membranes provide openings for access that are prompted by two molecular activities. First, the membranes are infused with electric current by a manual selector that induces the molecules to disengage and form the openings. Second, other molecules, acting as muscles at the opening edge, flex to draw the exterior membrane apart. We enter our house.

Day 7: For the first time, we experience the space, ample for a small house. Ethereal light glows through the translucent membranes. With a signal, these membranes change from translucent to opaque to transparent, providing a view anywhere at any time desired. Our house is self-sufficient, functioning without dependence upon any outside public services. Solar power activates heating, cooling, recycling of wastes, and purifying of water. The vats and vascular system, vital to the growth of our house, remain and will convey additional materials when repair or replacement is required.

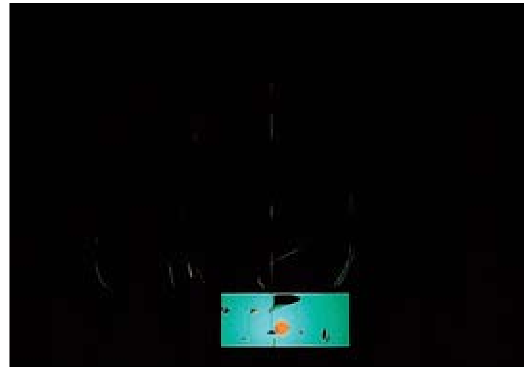
Interior finishes grow around us. “Body support,” known previously as sofas, chairs, tables, and beds, are springing up from the floor, out from the wall ribs, and hanging from the arched vault—furniture as an extension of the structure itself. The floor, a “morphable topographic carpet,” consists of a resilient, molecular, spongy substance that is responsive to our every comfort, whim, or tactile experience.

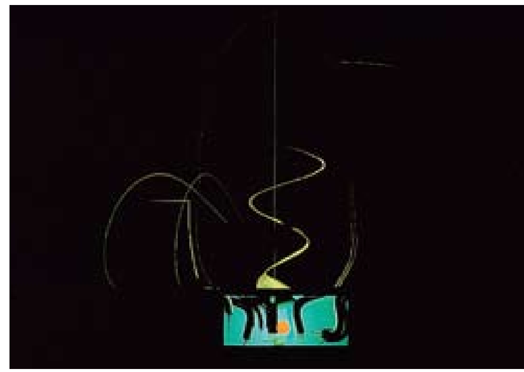
Day 8: We return the next day to find our house more familiar. As a “light modulator,” the membrane responds to the ever-changing conditions of the immediate environment to appear as cloudy, opalescent, gossamer, iridescent, opaque. We have created an artificial, organic, protective cocoon.

Day 9: After six days of molecular growth, we move in. The house anticipates our changing needs, expanding the living space to form a small study, repartitioning the master bedrooms, rearranging and redesigning the “body supports,” and extending the wheeled legs to a new site. These shape changes demonstrate the flexibility of the molecular engineering.

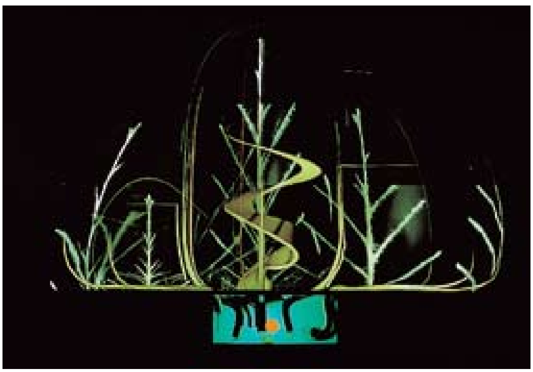
In future years, if we cannot find a buyer for our house, we will demolish it, or more correctly, the house will demolish itself. The building growth operations will be recycled for future buildings. (2000)

This project was completed in collaboration with Mohamad Alkhayer.

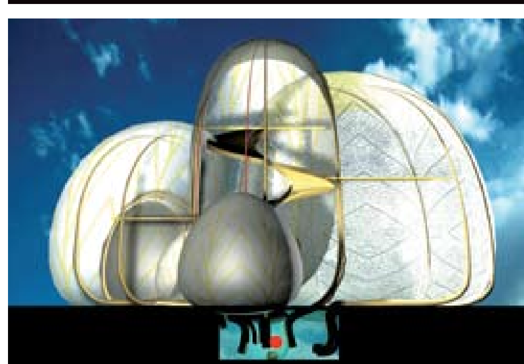


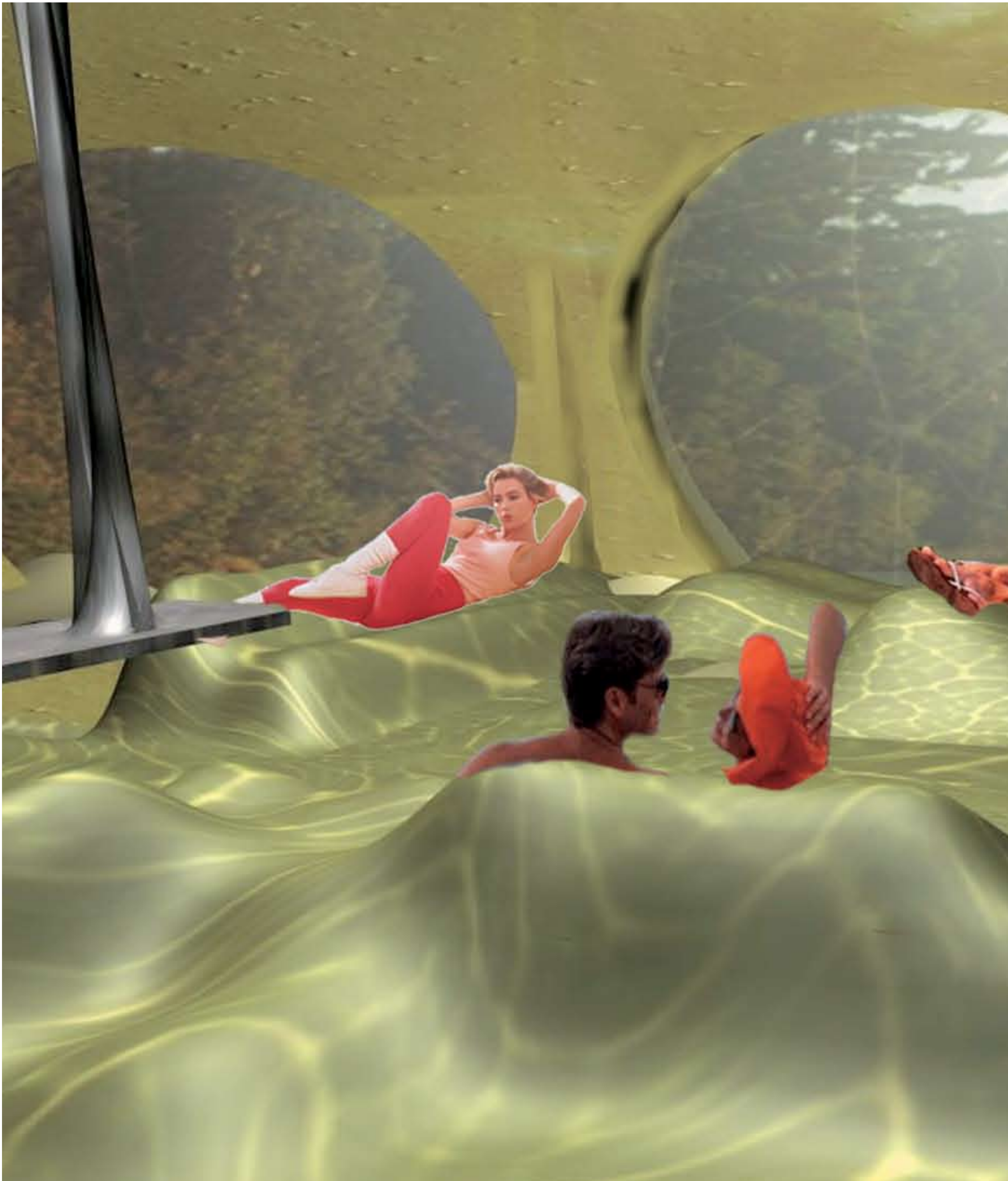


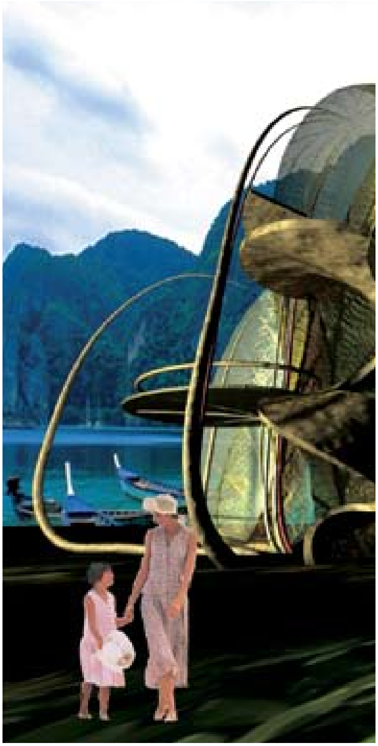


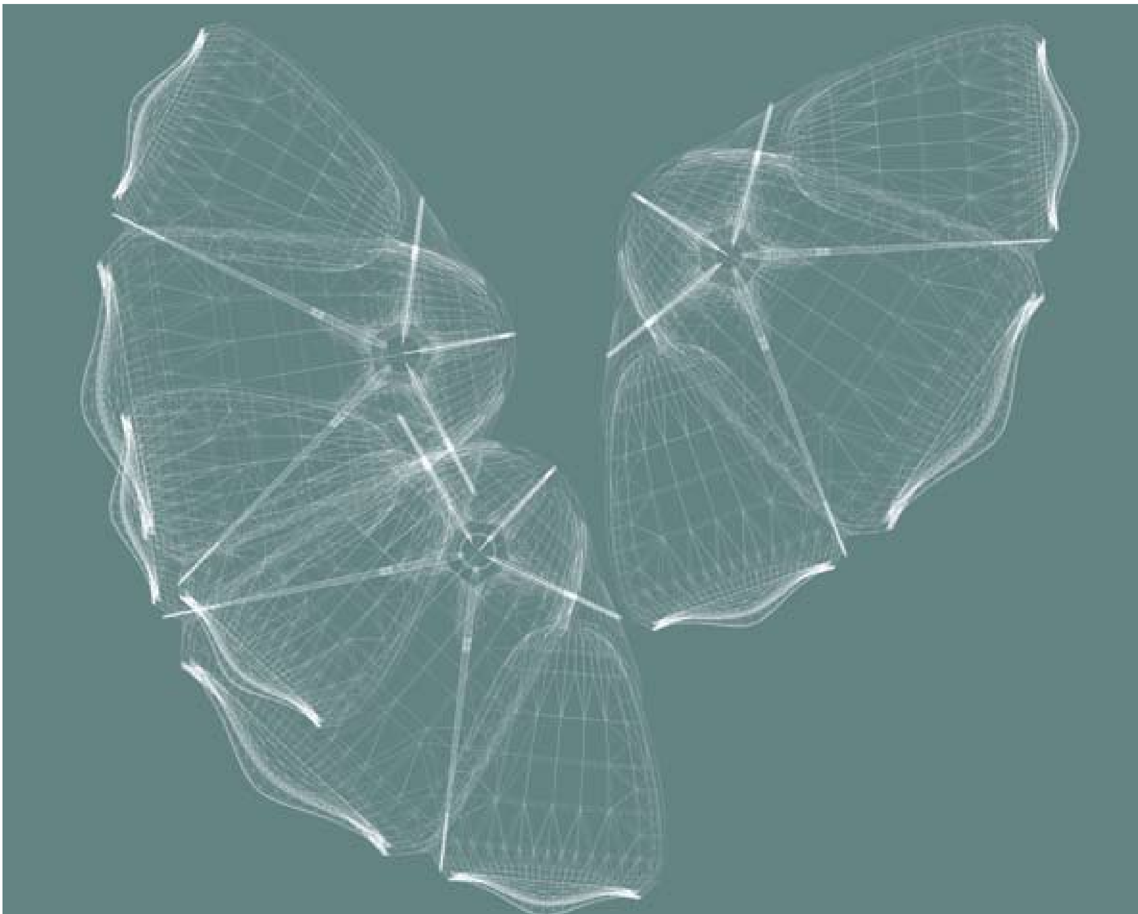










MULTISTORY APARTMENT BUILDING

For further demonstration of molecular engineering in more complicated building types, other than houses, I propose this project, a multistory apartment. In this case we consider a more sophisticated structure, grown in stages, controlled by more intricate coding strategies.

First, we may fairly assume that the molecular growth processes, though more extensive in this case, are the same as for the Molecular-Engineered House. From vats at the building site, root, stalk, branch, platform, lattice, membrane, and openings develop. Light control, self-cleaning, repairs and demolition systems also emerge.

As a structure of this size requires a larger layout of supporting columns, it would be required that a number of vats be assembled and filled together at the site, each to feed a cluster of stalks or columns, each supplied with the same or different codes, which must be strictly coordinated.

Growth of the structure would then be in stages; say, in four- or six-story increments in accordance with rental and marketing analysis; when necessary, growth could be arrested, to be activated at another time. Replenishing the bulk material in liquid form in the original vats would fuel subsequent stages.

Looking back from our future time, we would remember uniformly designed dwelling units in which there was little latitude for personal expression, and consider them inhuman. Intricate coding systems will facilitate a greater diversity, particularly in interior design. Suppose the basic building structure proceeds in growth according to the directives of a central, all-inclusive code to achieve the entire structure, dwelling units and all common basic services. But suppose then that each dwelling unit is provided a separate local vat, and within it a separate code that could prompt growth of personalized interior design—growth within growth, as it were. Such specific codes could be readily acquired from the local rental agent, or custom designs could be produced by designers of the tenant's choice—offering any interior, from styles past to contemporary to something imagined. Remodelling partition layout, lighting, surface materials, and furniture within the dwelling unit would be of little complication. However, the basic form and character of both the house and apartment exterior and interior will, or honestly should, express the growth process. (2001)

Images created with Marcel de Winter and Dan Stoica

NANOARCHITECTURE: A DISCOURSE

From the outset, it should be understood that molecular-engineered buildings are still theoretical in nature. Though the projects that I have developed over the past decade are indeed based upon technologies that, before long, will be realized, the applications of molecular engineering, architectural included, remain speculative.

Molecular Nanotechnology (MNT) represents a new phase in the evolution of manmade structures. The central thesis that nanotechnology is “capable of producing almost any chemically stable structure that can be specified” was first advanced by the physicist Richard Feynman in 1945. Prompted by Feynman, physicist-designer William Katavolos expanded the study of MNT to the growth of architecture, foreseeing the production of a large floating city. Katavolos remarks, “We are rapidly gaining the necessary knowledge of the molecular structure of these chemicals with the necessary techniques that will lead to the productions of materials that will have a specific program of behavior built into them.”

Advanced studies link the processes of DNA with molecular growth. James Watson and Francis Crick discovered that DNA governs the continuity and growth of all living things. In nature, DNA directs ribosomal machinery to build other machines. Physicist K. Eric Drexler, considered the founding father of nanotechnology, has advanced realistic procedures for designing simulated molecular structures. Accordingly, Drexler proposes that artificial DNA, or coding devices, be developed and employed in structuring matter to the service of mankind. Within the molecular structure, atoms of various chemical make-up are selected, assembled in particular patterns, and programmed to replicate themselves thus enabling immense workforces to produce products of almost any design. The molecular structure harnesses the energies from chemicals and electricity, rather than conventional human labor and current major power sources.

Progress to Date

Notable advances have been made in the allied field of biochemistry. Genetic engineers have programmed bacteria to make proteins used in human growth hormone and insulin. In the field of computer-aided design, the National Science Foundation has supported research for developing molecular computers, and the Japanese government has launched a program to develop microscopic, self-assembling molecular motors. These instruments are essential elements in the nanotechnological enterprise.

At the forefront of research and development is the Palo Alto-based Foresight Institute and its affiliate, the Institute of Molecular Manufacturing, which were formed specifically to develop molecular assemblers—robots programmed to build. The Nanotechnology Development Corporation of NASA has also invested extensively in the research of MNT and its applications for construction in space. Though a self-assembling molecule has yet to be produced, its development seems inevitable.

This research has lead scientists to develop products based on MNT for future consumption by ordinary people. At the Ames laboratory at NASA, J. Storrs Hall has designed a simulated "Air Car" that can be controlled remotely and with little human input. Hall's "Air Car" is designed specifically to prompt further experimentation in aeronautics. Likewise, it is my intention that the projects in this book stimulate advances in the building industry.

Implications for the Future

The implications of this new technology are vast. As Kai Wu has written: "Imagine a technology so powerful that it will allow such feats as desktop manufacturing, cellular repair, artificial intelligence, inexpensive space travel, clean abundant energy, environmental restoration; a technology so portable that everyone can reap its benefits—which will radically change our economic and political systems—and so imminent that most of us will see its impact within our lifetimes."

Nanotechnology will soon change industrial production by introducing labor-free manufacturing. This will directly influence our health, welfare, comfort, and prosperity. The molecular assembler breakthrough will transform our entire manufacturing process; for this, we must prepare. As with previous technological revolutions, MNT will present new ways of thinking about society and ourselves, and exact the same moral responsibilities.

Feasibility

Time, as a factor of molecular growth, is of crucial importance. The slow pace of cellular growth in nature is not comparable to the demands of modern manufacturing, marketing, and consumption. However, it is predicted that artificial growth by MNT will greatly outpace both that of nature and present manufacturing. Drexler remarks that with MNT, "a vast number of replicators will produce assemblers by the ton," which will in turn allow for rapid production. The replicators, when grouped in what theorist Ralph Merkle has called a "Convergent Assembly," form molecular building parts, or "bricks," that can be assembled into larger parts. Groups of these could then be assembled into still larger parts. Within a few minutes, a thirty stage convergent assembly could produce a final product of one meter from material initially one nanometer in size.

Another consideration is cost. Merkle states, “Common elements like hydrogen, carbon, nitrogen, oxygen, aluminum, and silicone are best sources for constituting the bulk of most structures, and because these elements can be taken in abundance from earth, water, and air, raw materials will be dirt cheap.” The cost of molecular engineering—minus licensing fees, insurance, and business expenses—is comparable to the cost of creating plastic or industrial chemicals. Labor constitutes a minor factor within MNT; excepting costs for the development of computer software, MNT is labor-free.

Drexler continues, “it seems that the feasibility of nanotechnology and molecular assemblers is to be taken seriously—for one, existing molecular machines already serve us as basic functions, and two, that parts serving these basic functions can be combined to build complex machines—since chemical reactions can bond atoms together in diverse ways, and molecular machines can direct chemical reactions according to programmed instructions.” He adds that “assemblers are definitely feasible. It may take some years for the assemblers to emerge, but their emergence seems almost inevitable.”

Proposal

I have, up to this point, presented basic research. Subsequently, it is my challenge and responsibility to address matters of applied science; matters of technology by which inventions, devices, and useful products might be produced. In doing so, I express my reverence for pure science, but from here on, I am my own man.

Is the production of a building-size product through MNT possible? To what extent is this new building method applicable to habitable structures? Processes of molecular growth within a sealed factory vat are quite possible. However, increasing the vats to accommodate buildings the size of ships is not a practical solution. We have little choice but to turn out building elements of a standard dimension to be transported and assembled in the most conventional way.

The essence of my proposal is molecular “growth” out of and beyond the confines of the vat. In the early stages of molecular growth processes, small molecules survive only in a sealed vat where an entactic environment is assured. However, it is likely that these perishable protein molecules will build larger, more durable molecules that will withstand and survive in the external environment. This growth, development from simple to complex molecules, from inside to outside the vat, is the critical and essential assumption of my proposal. It is only in this way that the production of large products can be realized.

Molecular Building Process

The molecular building process is not biological, but mechanical; living cells are replicated by dividing, assemblers replicate mechanically, by building others. As Drexler has written: "The great difference is that nanotech use not living ribosomes but robotic assemblers, not veins but conveyor belts, not muscles but motors, not genes but computers, not cells dividing but small factories producing products and additional factories."

Assemblers are robots, or "nanobots," with communicative powers that in collaboration can build anything they are programmed to build. They are organized by their "foreman," the seed computer, into specialized building crafts that operate as part of a vast construction project. Mechanical assemblers are expected to employ a greater variety of tools and use them with greater force, control, and precision than ribosomes can in nature

Growth at the Building Site

The notion of growing architecture was proposed in 1961 by Katavolos and expanded by Vittorio Giorgini, in "Early Experiments in Architecture Using Natures Building Technology," in 1997. However, only recently have we come to understand the specifics of molecular growth.

The process begins as the hardy molecules position their roots in the vats. Growth emerges, growing upward and outward as their code directs. For larger, out-of-vat products, growth is dependant on the linear, vertical delivery of nourishment. It is noted that "large plants and animals have 'vascular systems' and intricate channels to carry materials to molecular machinery working through their systems. In similar fashion, artificial assembly systems could also employ this strategy…to build a scaffold, then working through its volume incorporating materials from the central source, in this case, the vat."

Vat growth may be described through the process of "accretion," with atoms adhering to a base—as rock candy is the crystallization of liquid sugar adhering to a stick or string. For growth out of vat, at the scale of a building, there must be a linear or directional growth pattern: root, stem, rib, lattice or branches, nourished by a "fibro-vascular" distribution.

There are numerous questions that an experimental architect like myself would ask when confronted by a new building technology such as this. How will this building method aid in designing better buildings? What alternatives will it provide? What are its potentials and limitations? What defines its character? How will this molecular growth process express itself?

Coding

Artificial DNA, or coding, is essential to the process of molecular nanotechnology. If molecular structures are to reproduce and build products, they must be given directions as to what to build, how, when, and where. "It is important to know that molecular

assemblers cannot build anything by themselves," writes Bill Spence. "All products familiar today and inventions of future products to be built by MNT, must be re-designed, engineered, molecularly modeled...and translated into functional software."

It is possible, at this time, to transfer the exact pattern of DNA to an artificial code. Architect-morphologist Haresh Lavani states, "Coupled with biological (DNA based) or other (chemical-physical) building processes, the artificial genetic code enables, growth, adaptation, evolution, and replication of buildings permitting architecture to design itself." Regarding evolution, recent research by Lipson and Prilock of Brandeis University's Deno-Lab has revealed that robot evolution is close to realization. They have designed robots that reproduce according to performance, simulating natural selection and the process of evolution in nature.

In his book, *An Evolutionary Architecture*, the British computer technician and visionary John Frazier states that "our description of an architectural concept encoded is analogous to the genetic code DNA script in nature—we go beyond present blueprints and specifications to a coded set of genetic instructions called a 'genetic language of Architecture.'" He describes his project, Universal Constructor (1990), as a "tool for the explanation and demonstration of a radically new design process." Certain buildings familiar to us have already been coded as to schema, plan, section, mass, dimension, material, detail, and construction strategy. Newly designed building concepts can be easily coded as well.

Environmental Considerations

The "seed," or coding device, will replace conventional blueprints, specifications, and construction procedures. In regard to ecological relationships, the seed contains instructions with feedback allowing the new building to respond to its immediate surroundings. So far, the most extraordinary proposal put forth is that of coordinating the artificial coding of a building with the DNA of a living environment. That is to say, the building would be programmed to monitor its environment and adjust or alter its design so as to be in harmony, or symbiotic relationship, with nature.

Frazier addresses the emerging field of "architectural genesis." He approaches coding for architecture at a far more advanced state than I have discussed. The building as artifact is designed to interact and evolve with natural forces. Frazier offers, "a new, computer-based technology for developing design models, not in physical form at this stage, but rather of inner logic." He continues, "Our computer model will be the expression of the equilibrium between the androgynous development of the architectural concept and the exogenous influences exerted by the environment." These buildings may be considered self-organizing. Such buildings, he states, "will maintain stability by negative feedback interactions and promote their evolution in their employment of positive feedback." The building knows its coding for development, and in this sense, can be considered an organism of artificial life and intelligence. Frazier envisions an architecture developed to this state as "literally part of nature, in which manmade and natural environments are to be considered each as parts of a global ecosystem."

Frazier's projections leave us with a view of how mankind may, if guided by its higher instincts and moral principles, reestablish a citizenry in resonance with the ecosystem.

Design Your Own Materials

It is expected that a new substance, known as *diamond* and constructed of all carbon nanotubes made of the highest molecular density and bonding power, will be fifty times the strength of steel and lighter in weight. Diamond's extraordinary clarity and strength will make it an ideal building material that will, as produced by nanobots, conform to any shape. Diamond substances, consisting of readily available carbon, will be as inexpensive as glass. Structural elements will vary from extremely dense to porous and lightweight—readily responding to the extreme stresses on heavy machinery, vehicles, or even buildings. Such large carbon structures of architectural scale will assume an appearance of transparency. Strangely new, these qualities made possible by nanotechnology create an intriguing paradox: lightweight, invisible structure that has tremendous strength.

Nanobots will produce clear sheets of diamond, a few millimeters thick, to form the exterior membrane of a building. These membranes could be opaque, or by electro-molecular realignment, they could become translucent or transparent. Such astonishing versatility within the molecular product is termed "morphability"—one of the quintessential aspects of MNT. Empowered by millions of controlled nanomotors, the artifact easily alters its characteristics.

Protective membranes regulate light and air and act as the building insulator. In warmer weather, the molecules respond by collapsing tightly, exhausting the air; for increased insulation the molecules expand into a thick foam with innumerable closed air spaces. Further advantages of morphable substances include such applications as interior room partitioning and adjustable, self-adaptive furniture that responds to position, attitude, and comfort requirements. J. Storrs Hall has developed "Utility Fog"—a linked mechanism that transforms an object into any shape. If one surfaces a floor with a layer of "Fog," furniture could extrude or dissolve into various forms or styles. Likewise, if interior walls are surfaced with "Fog," partition, layout, décor—the entire domestic environment—could be changed at will.

Investigations into kinetics suggest structural elements that may be jointed or pivoted. Studies of animal forms indicate how they evolve as moving parts. These characteristics may be evident in our buildings as transformations, extensions, retractions, self-folding, unfolding, even self-locomotion. Hall's "Air Car" is designed to have self-extending legs, while its wings adjust in shape and attitude for maximum performance at various speeds.With all the versatility of these substances, objects now familiar to us will appear new. Architects will indeed be presented with rather different design factors.

Architectural Expression

The word "growth" is extensively used in the field of MNT, and is accepted not just as an analogy to nature, but rather as an artificial reenactment of natural growth processes. It is altogether reasonable, therefore, to adopt "growth" as a basis for architectural expression.

Throughout the history of architecture, formal expression has derived from methods of construction. Molecular growth will bring us back to natural form. This is not stylization, biomorphism, or representation. Natural structuring or branch systems establish optimal strength-to-weight ratios. Molecular-engineered buildings are expected to be 10 percent as massive as buildings today, resulting in entirely new systems of structuring and radically different forms.

We will look back upon present day structural steel assemblies and connections of milled parts, bolted and welded, as not only grossly inefficient and costly, but ludicrous. Molecular growth process will replace the abrupt joints and edges of contemporary construction with imperceptible transitions from one specialized substance to another, as bone tissue to ligament to muscle to skin. Structure will be integral with the building shell, walls, and enclosure, and building materials will be seamlessly fused in a completely unified entity.

Looking back from the future, our present buildings will seem quaint. As we anticipate such buildings of strength, lightness, integral structure, seamless continuity of surface, transparency, and evolving, growing forms, molecular nanotechnology will reshape the man-made environment. These new characteristics explain how the molecular growth process, subject to architectural design orchestration, will insist, in its own right, to express itself.

EPILOGUE

With all of the dazzling opportunities offered by a revolutionary building process, which we are told will be inevitable, what course are we to take? Molecules, we must be reminded, can be programmed to produce utilitarian box shelters, or houses of any frivolous style. Designs of historic revival, popular as nostalgic escape from technology shock, may continue for, as Marshall McLuhan has said of most cultures, "we proceed into the future looking back through the rear-view mirror." It has also been observed that, in the United States at least, with few notable exceptions, engineers don't look ahead because they're not paid to do so. We will overcome technology shock as we always have. Understanding the implications of the new technology is ultimately a matter of how we direct our minds and emotions.

As an experimental architect, I choose to look forward; which is to come to know and understand this newly emerging building technology, as radical as it may be, to find its evolving characteristics, and express them in architectural terms. For these radically new characteristics will be the basis of our designs for a New Architectural Species. As other members of this species, I now propose three more projects: the "morphable house," the "self-erecting bridge," and the "self-erecting tower."

I am mindful that the molecular house and high-rise apartment building may not be realized for some years, and that my architectural concepts and designs must be viewed, at this time, as somewhat precocious. Yet it would be well for our society to be prepared with intelligent and serviceable architectural proposals when the "assembler breakthrough" occurs. I am mindful also of the many talented architects in the coming decades with more advanced knowledge of this technology at their disposal than is available now, who may express themselves differently. However, it is my earnest hope that I will be considered as one of the few architects at this time to have grappled with this challenge. May my projects be, in any event, an exhortation to those who follow me.

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