

ENGINEERING FOR ARCHITECTURE 1980

# ARCHITECTURAL RECORD

MID-AUGUST 1980



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# LOOKS



Architect: Loeffler/Johnson and Associates,  
Pittsburgh, PA  
Contractor: Crump, Inc., Pittsburgh, PA

## On using the right consultants at the right time

At a Round Table back in 1975, architect Lew Davis said: "It's become easy to be a good architect. All you need is good clients—and good consultants. We rely on our consulting engineers, and when new forms are required—as for energy conservation, for example—we will rely on our consultants to work with us and produce those new forms." He was oversimplifying, of course—but just as we've often heard the thought expressed that "good architecture is the reward of good clients," it seems equally true that "good architecture is produced by good architects who choose good consultants."

As we finish researching and writing this annual *Engineering for Architecture* issue (this is the seventh), I am struck once again by the thought that there are an awful lot of consultants around this country who know an awful lot about solving design problems—programming problems, structural problems, energy-conservation problems, lighting problems, daylighting problems, hvac problems. This issue is full of their work—full of examples of architects working with engineers and other consultants to create buildings that in every sense are more beautiful, and/or more functional, and/or more buildable because they are the result of a good working relationship between architect and consultant.

For example, as you go through this issue, you will find a number of case examples of building designs that integrate in the best and most sophisticated sense the thinking of the architect and the structural engineer. See, for instance, the lead article on the New York City convention center.

The intensely interesting article (page 84) on how the design studios and the "computer studio" at Skidmore, Owings & Merrill's Chicago office work together is another clear example of the benefits of architect and "consultants" working in an in-house symbiotic relationship.

This year's Round Table—on "The passive approach: using natural means to conserve energy"—opens up an area of consultant expertise that we surely will (surely should) see burgeoning in the near future. As moderators of the Round Table (page 92), both senior editor Bob Fischer and I were in awe of the breadth of knowledge and expertise that was apparent. We organized the Round Table to discuss passive uses of solar energy—but soon found ourselves on far broader ground, talking about very advanced techniques in the use of daylight, talking

about systems for passive cooling, talking about new strategies of building and neighborhood configuration.

In this relatively new area of design concern, the frustration of the expert consultants was clear—for they see all around them missed opportunities to save energy by passive means for the simple reason that the average practitioner is just too pressed to stay on "the cutting edge" in all of the disciplines that impinge on good design.

They speak in frustration because they want to help, they want to see more designs that take advantage of the fast-developing technology of passive design, they want to get their hands and minds on design problems where they can help. But they understand the problem: Walter Kroner of RPI's Center for Architectural Research, and one of the panelists, said "We are dealing with some very new ideas—and we must remember that most professionals were educated some time ago and are very busy trying to keep up their practice. The teachers suffer the same problem: architectural students are turned on about passive approaches to energy-efficient design, but we are not equipped to teach them."

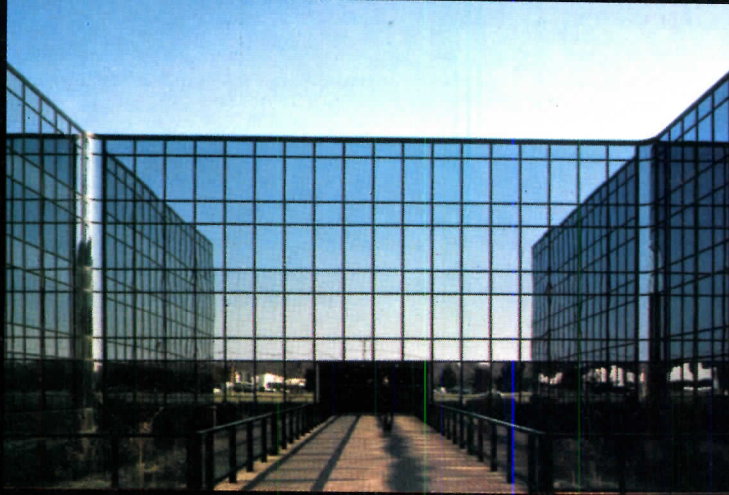
The consultants speak in frustration for another reason: it is clear that they take the same sheer enjoyment in tackling a tough problem within their discipline that an architect takes in tackling a difficult design or planning problem. That enjoyment is evident as you research an issue like this—engineers and other technical experts speak of their work with the same enthusiasm as an architect describing his newest design.

There are of course no simple answers: there is no pat solution to the problem of keeping up with technology in all of the areas that impact on design.

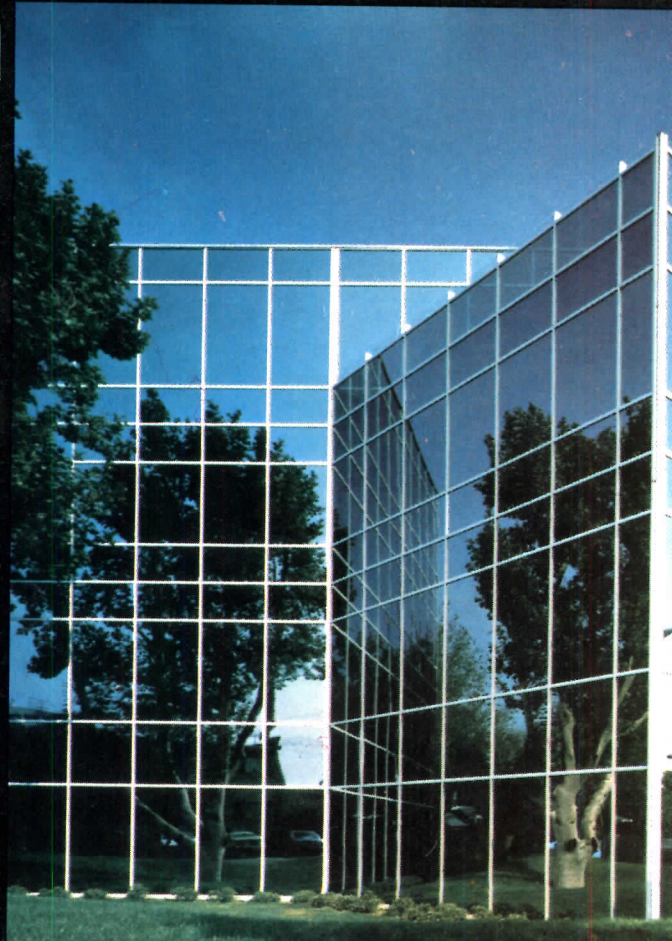
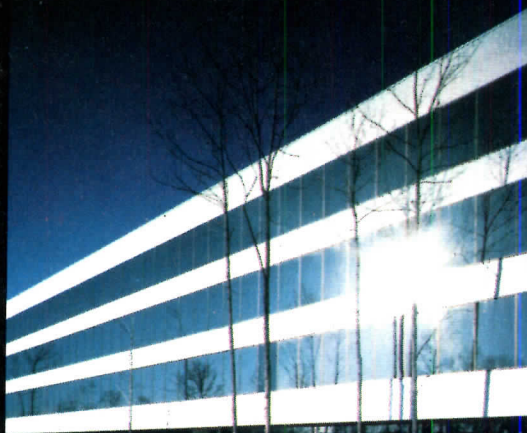
But this issue does seem a good occasion to remind all of us involved in architecture that the expertise to solve almost any design problem exists. As we wrote in the first *Engineering for Architecture* issue back in 1974: "We want to do this issue because we think the place to search for solutions to our problems in this industry is with people." And this issue—like its predecessors—is intended to honor the best work of the best engineers and consultants: to recognize their absolutely essential and all-too-often unrecognized inventiveness and resourcefulness in working with architects to achieve economical and rational and beautiful buildings. —W.W.

# Guardian reflective glass

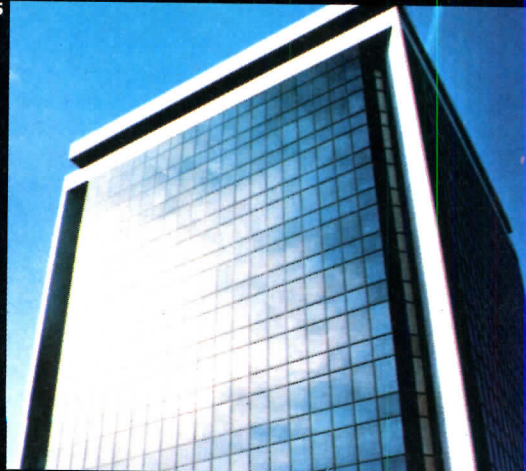
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3,4



5



1. Melville Office Plaza  
Melville, Long Island, New York  
Arch: J. Crammas & N. Green  
Glaz. Contr: Levitt Bros.  
SS-8 Silver Reflective

2. 3D/International Tower  
Houston, Texas  
Arch: 3D/International Inc.  
Glaz. Contr: Cupples Products  
SS-14 Silver Reflective Insulating

3. Bingham Farms Office Bldg.  
Bingham Farms, Michigan  
Arch: Seymour J. Levine  
Glaz. Contr: Benz Glass  
TE-10 Earthtone Reflective

4. Four Seasons Office Building  
Sherman Oaks, California  
Arch: Landau Partnership  
Glaz. Contr: Sitalines  
SS-8 Silver Reflective

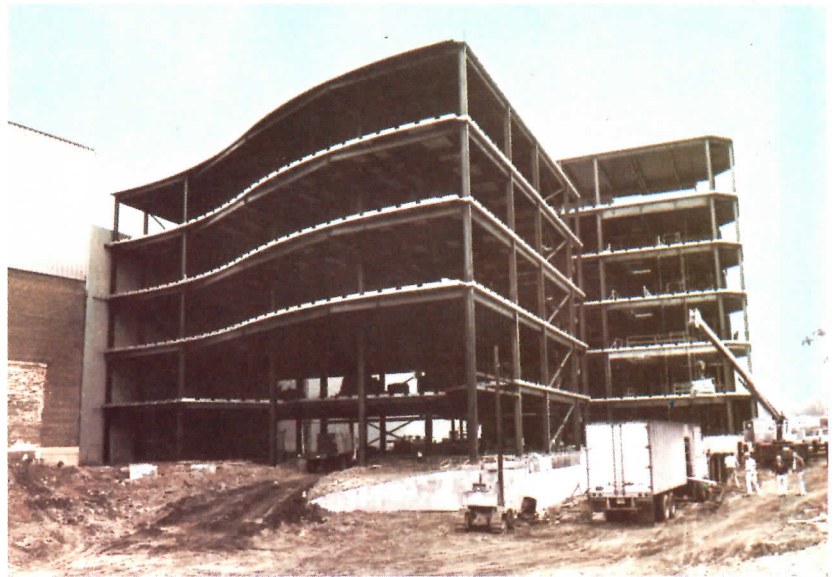
5. Fluor Arabia Office Building  
Al Khobar, Saudi Arabia  
Arch: Welton Beckett Associates  
Glaz. Contr: Cupples Products  
TE-10 Earthtone Reflective



**Credits:**

**Owner:** Memphis Publishing Company  
**Architect:** Walk Jones & Francis Mah, Inc.  
**Structural Engineer:** Gardner and Howe  
**Fabricator/Erector:** Pidgeon Thomas Iron Co.  
**Construction Manager:** Morse/Diesel, Inc.  
 All firms are located in Memphis, Tenn.

The project was built by the "fast-track" construction method. Steel was ordered in advance of completion of the finished working drawings, which helped speed construction. Bethlehem supplied 600 tons of structural shapes for the project. All primary framing members are ASTM A572 high-strength steel.



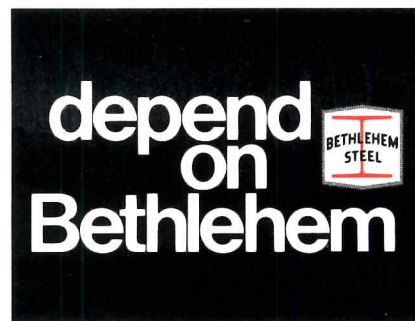
**Dead load and seismic considerations**

The dead load of the structure had to be minimized because of the unstable soil bearing conditions at the site. Selection of a high-strength steel frame permitted the use of a foundation consisting of drilled piers with belled bottoms. This eliminated the need for a deeper, more costly foundation.

The structural frame dead load was further reduced by designing the part of the exterior wall that is covered with precast concrete wall panels to be self-supporting. The precast concrete wall panels are attached to the steel frame for lateral support only. Typical bays measure 32 ft by 28 ft.

Lateral loads are resisted by a combination of rigid framing, shear bracing, and K-bracing. Shear walls or X-braced bays, used alone, would have been impractical because of the anticipated floor

uses and the exterior glass curtain walls. Unit weight of the steel frame is 10.5 psf.



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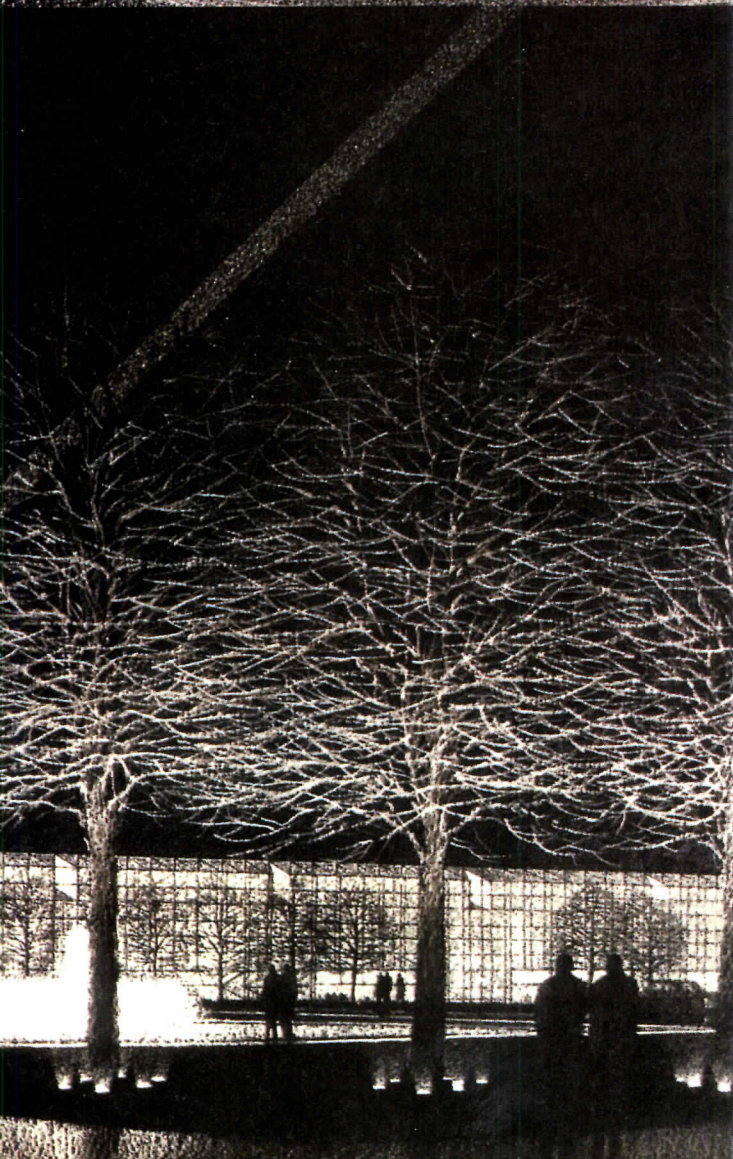
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Renderings by Steve Oles

A soap bubble is the contradictory metaphor drawn by designer James Freed for the massive New York Exposition & Convention Center. Freed also calls the building "an elephant dancing on its toes."

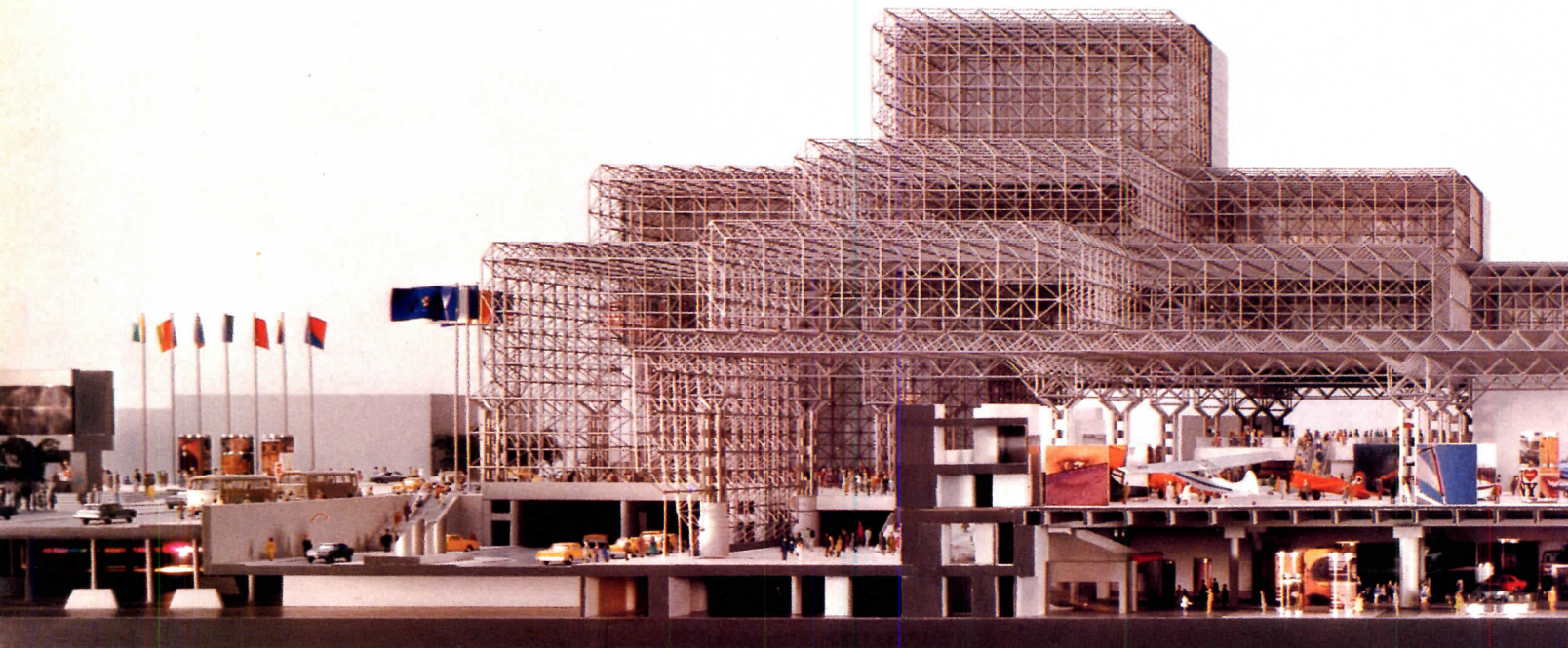
Admittedly huge, the building stretches 1,200 ft along Manhattan's 11th and 12th Avenues, a mere 600 ft along 34th and 39th Streets, and 700 ft through the center.

For financial reasons, the \$200-million building, funded by the state's Urban Development Corporation, had to incorporate a million square feet on two floors. Nonetheless, the architects and the client felt strongly that the public which had paid for the building should have permanent, easy and festive access to it, and that, apart from working exhibitions, the building should not be "open to the trade" only. The space given over to the public opens with a 270-ft-square Great Hall, marked by a monumental entrance on 11th Avenue and surmounted by a lantern 175 ft high. It continues with a 360-ft bridge overlooking the major exhibition hall, and culminates at 12th Avenue in a restaurant commanding a view of the Hudson River.

Because the exposition center is essentially what Freed calls "a warehouse," the functional requirements of its occupants unknown and variable, the designers could not rely on internal uses to modulate the long facade. The key to taming the five-block face lay in the space frame that supports walls and roofs. Faceted chamfers mark the placement of columns on the upper exhibition floor at 90-ft intervals. (The geometrical manipulations that allow such precision are described on following pages).

Sheathed in semi-reflective glass, the building will appear opaque by day, when it will gain apparent lightness by mirroring the sky, as well as midtown hotels and office buildings. At night, interior lighting will turn glass transparent, revealing the traceried space-frame walls and roofs. The building will have clear glass at the entrances and for the skylights above the high public spaces. Because exhibitors will generally prefer no daylighting, walls will be spandrel glass.

NEW YORK EXPOSITION & CONVENTION CENTER, New York City. Owner: *Convention Center Development Corp.* Architect: *I. M. Pei & Partners—I. M. Pei; James Ingo Freed, partner-in-charge of design; Werner Wandelmaier, partner-in-charge of management; Michael Flynn, associate partner-in-charge of technology; Charles Young, senior associate, project architect—design; Robert Milburn, associate project architect—production.* Associate architects: *Lewis, Turner Partnership—Roger Lewis, partner-in-charge.* Programming for project: *James Stewart Polshek & Associates—Joseph Fleischer, partner-in-charge.* Engineers: *Weidlinger Associates (structural); Salmon Associates (associated structural); Woodward-Clyde Consultants (soils); Syska & Hennessy (mechanical/electrical); Pierre A. Dillard (associated mechanical/electrical).* Consultants: *Cerami & Associates, Inc. (acoustic); Jules Fischer & Paul Marantz (lighting); Hanscombe Associates Inc. (cost).* Construction manager: *HRH Construction Corp.; Westking Construction Company, Inc. (associate).*



Nathaniel Lieberman

The architects counted ease of visual orientation one of their primary planning goals within the convention center's vast interior—half a million square feet on each of two exhibit levels. The glass Great Hall towers 160 ft above the pedestrian entrance level to create "a celestial honorific space." The area also serves a circulation function, however, by becoming the nexus of public and trade circulation patterns. Two pedestrian axes within the building, plus a vertical open space that perforates the two to join them at the Great Hall, organize the whole and supply visible structural clues to visitors' whereabouts.

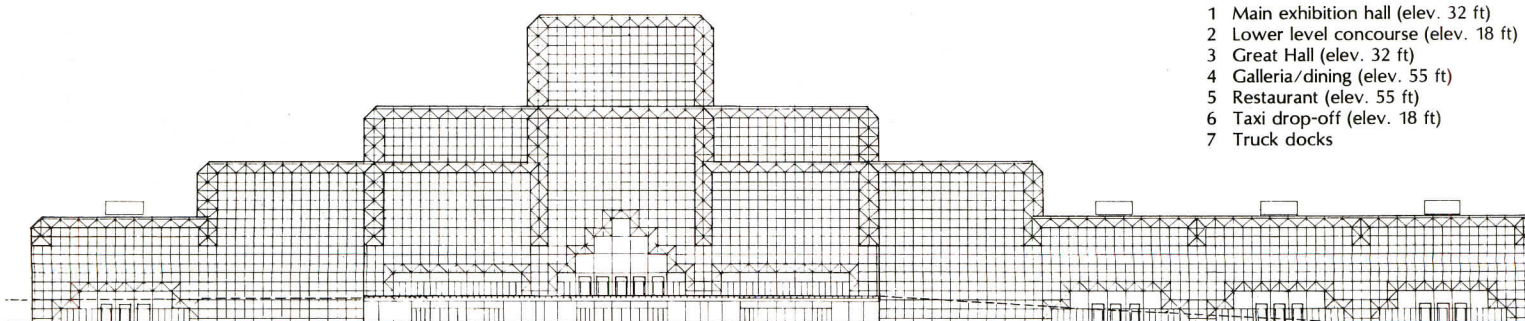
The Concourse, intended as the organizing route for trade shows on the lower level, runs north-south at elevation 18 and intersects the east-west axis of the Great Hall and the Galleria at elevations 32 and 55. (The

difficulty of numbering levels on the site, essentially flat but immense, prompted the designers to identify them by elevation above sea level, starting with elevation 5 at the level of mean high tide along the Hudson River.)

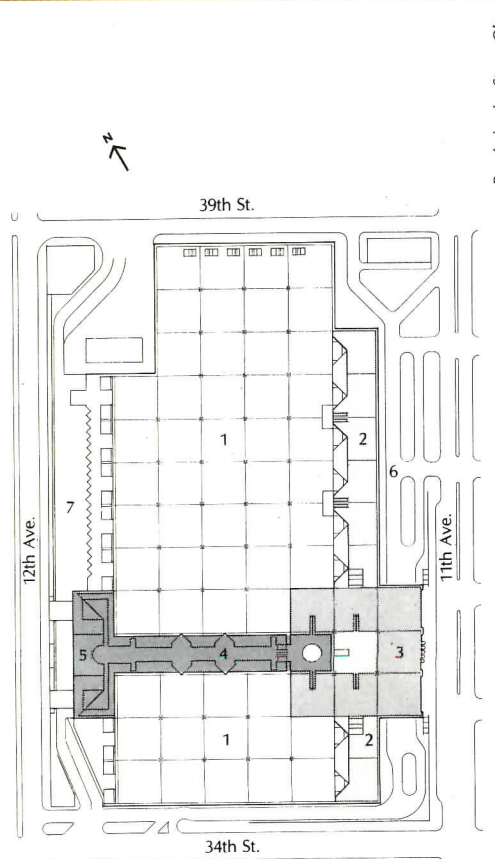
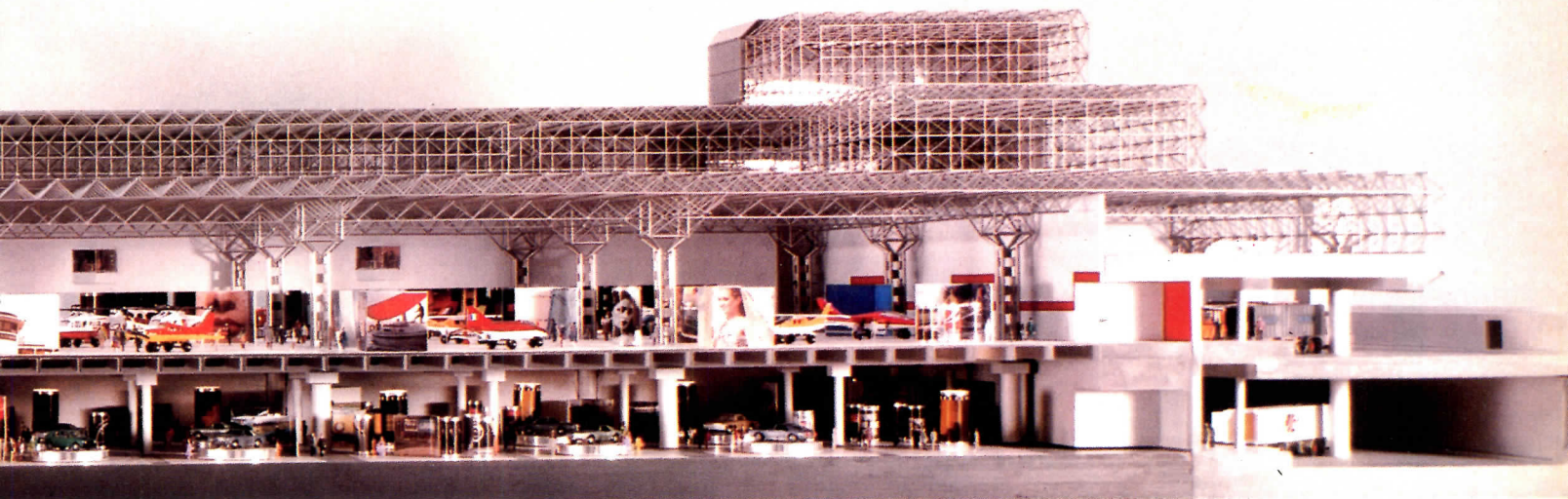
A viaduct that rises about 14 ft from 37th to 34th Street was one of the site's main impediments, and yet allowed entrances at different levels. A taxi drop-off running the length of the building at level 18 allows entrance at ground level through subsidiary doors and directly beneath the Great Hall as it projects beyond the building's face and crosses the concourse at a right angle. But at the top of the viaduct, pedestrian entry is allowed at elevation 32, giving direct access to the Great Hall and, via stairs, to the Galleria at elevation 55. Visitors in the main exhibit hall can orient themselves by the Galleria and

by the light entering through the lantern. On the lower exhibition floor, daylight will penetrate an oculus beneath the lantern.

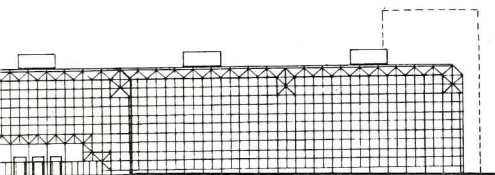
The center's 90-ft bay system derives from the givens of trade-show practice: 30-ft modules determined by two rows of booths 10 ft deep separated by a 10-ft aisle. The designers ordained that the metal columns supporting the space frame in the Great Hall and the upper exhibition space be "transparent," consonant with the texture of the space frame. On the lower level, however, columns are concrete to satisfy a code requirement for fireproofing to 20 ft. Freed is rather pleased by the contrast in form and scale—"Egyptian below, lacy above." The spacing of the lower columns, which support the slab for the main exhibition hall, may vary between 30, 45 or 90 ft.



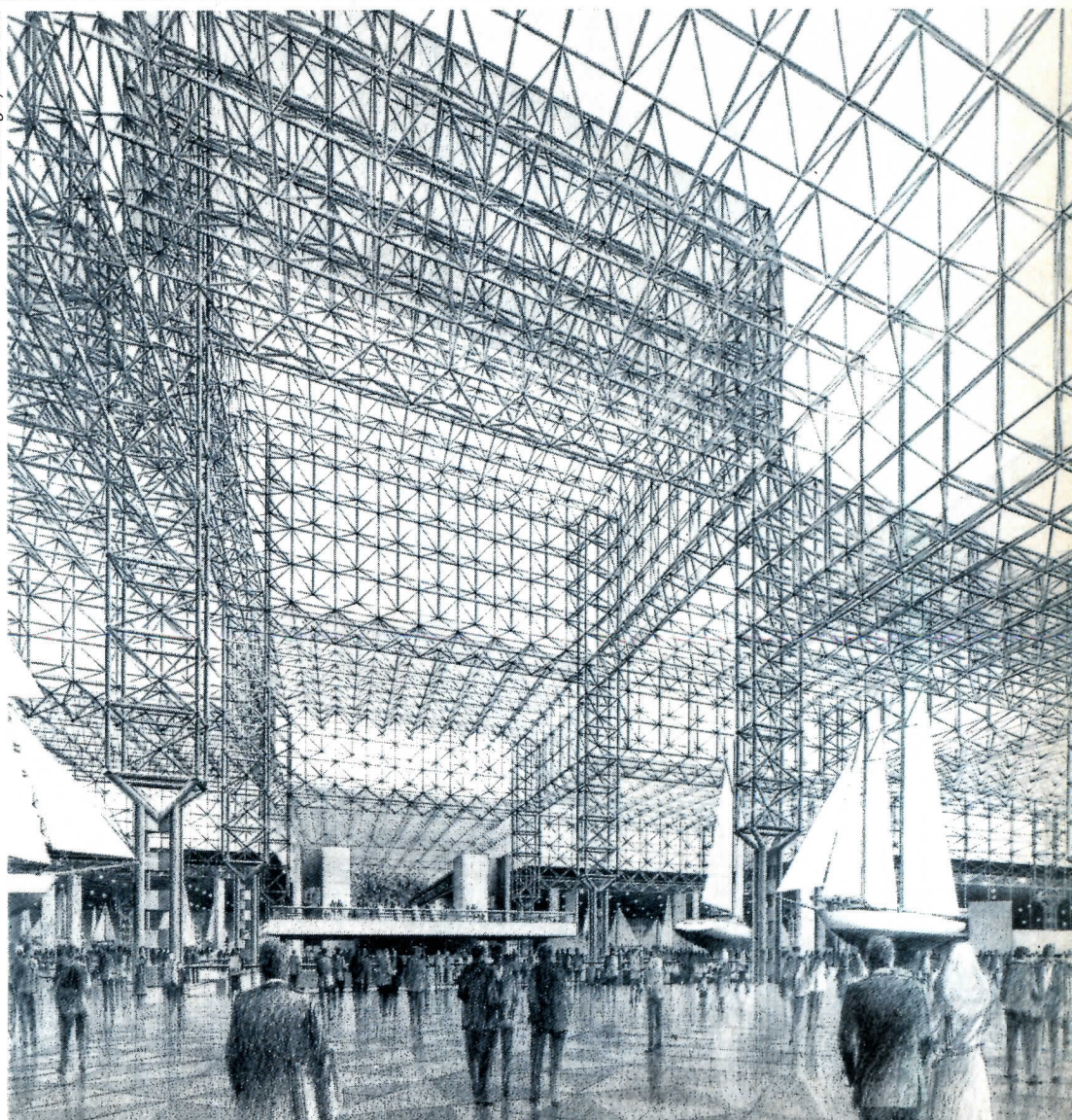


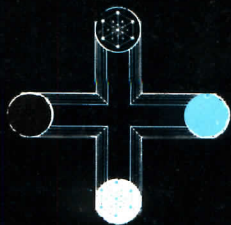
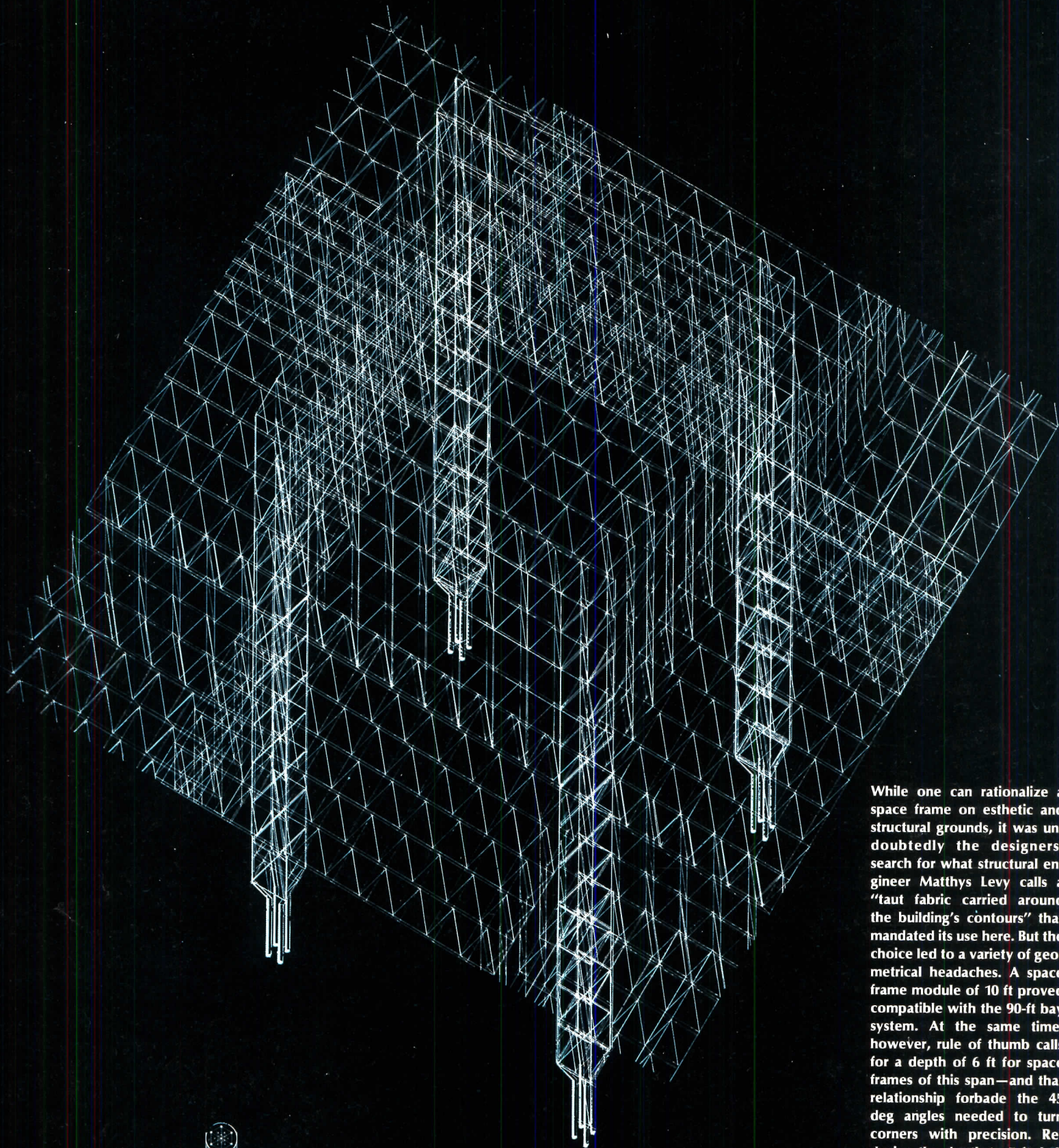


Drawing by Marianne Szanto

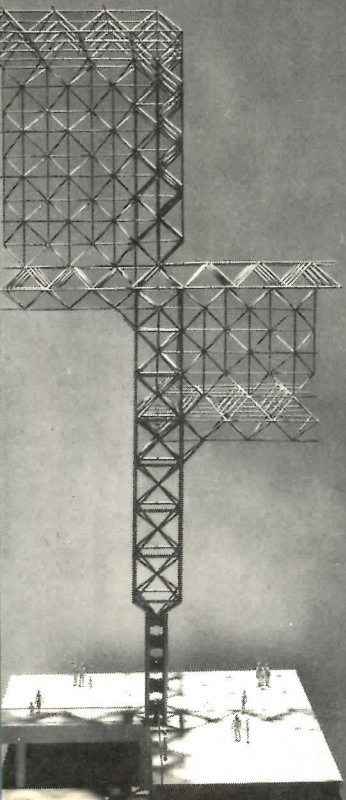
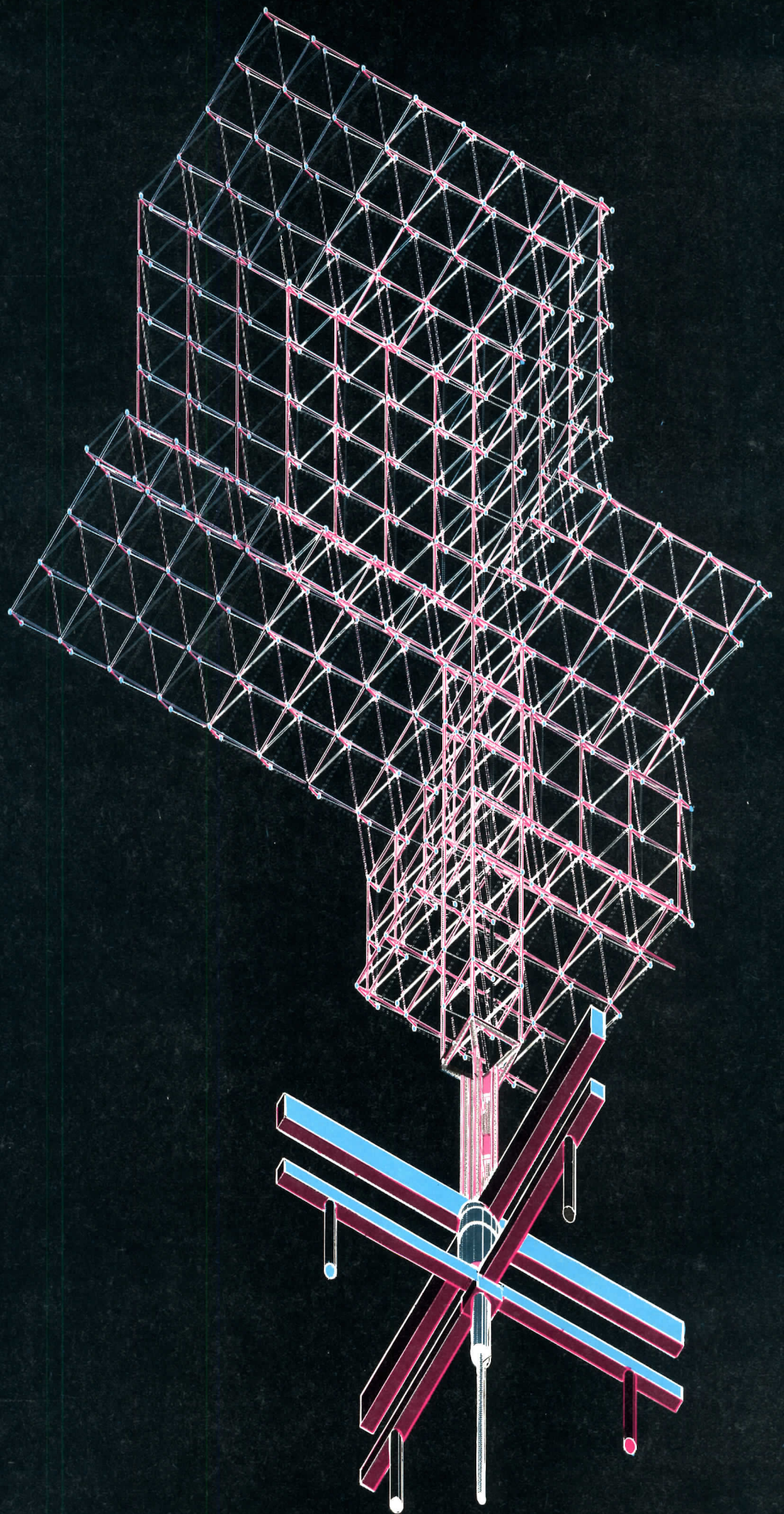


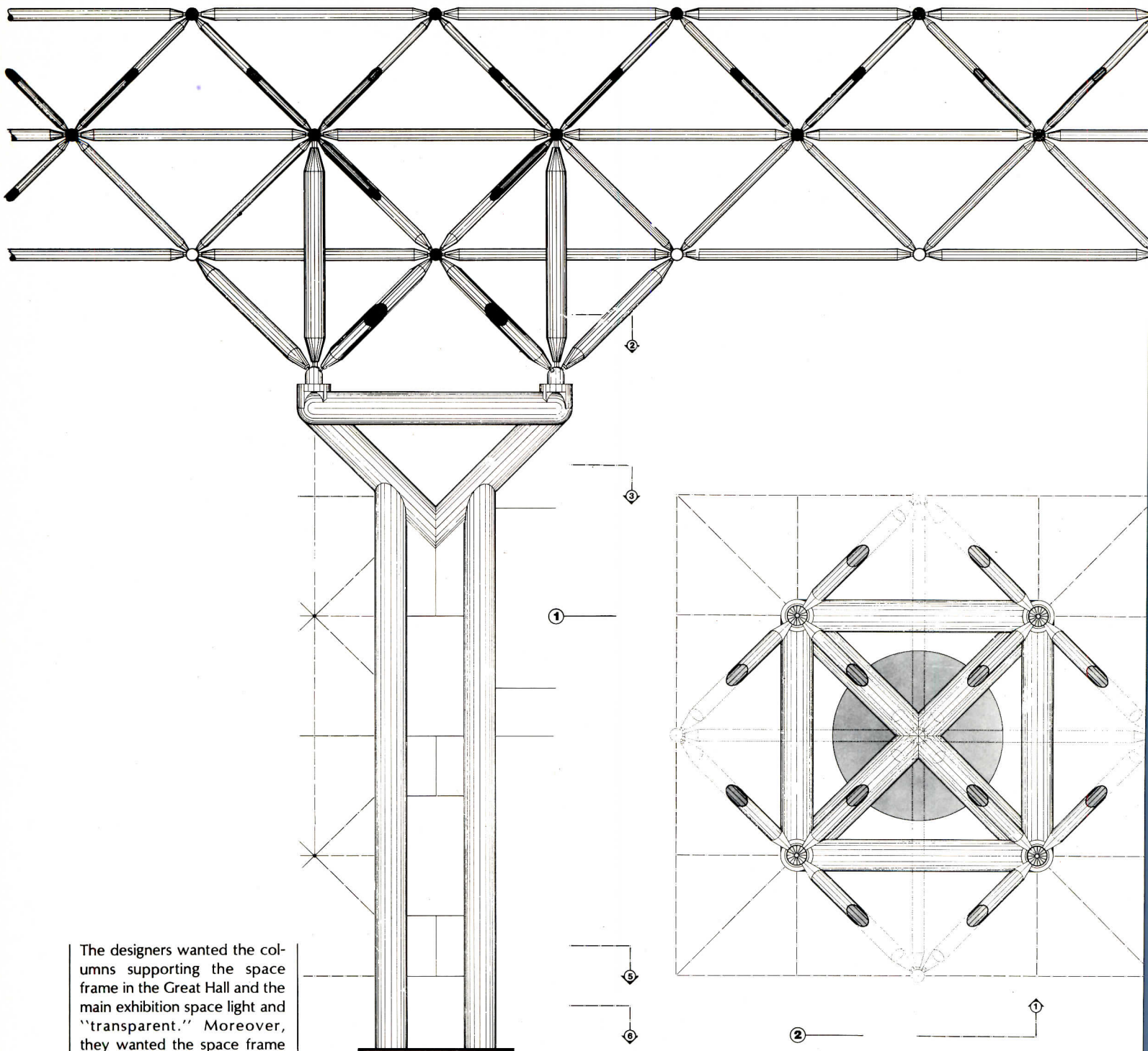
Rendering by Steve Oles



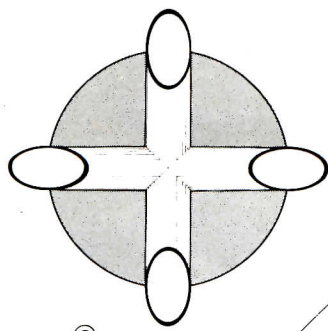


While one can rationalize a space frame on esthetic and structural grounds, it was undoubtedly the designers' search for what structural engineer Matthys Levy calls a "taut fabric carried around the building's contours" that mandated its use here. But the choice led to a variety of geometrical headaches. A space frame module of 10 ft proved compatible with the 90-ft bay system. At the same time, however, rule of thumb calls for a depth of 6 ft for space frames of this span—and that relationship forbade the 45 deg angles needed to turn corners with precision. Reducing the depth to 5 ft, half the 10-ft module, established the necessary 45 deg diagonals and allowed the structure to wrap horizontally at the ends and vertically to the skylights. It also allowed some subtleties in faceting the form around the entries and, notably, at the lantern, where the vertical wall is undercut as it meets the roof. The small model in inset at right incorporates all conditions to be met by the space frame.

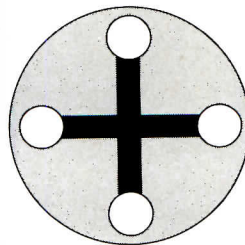




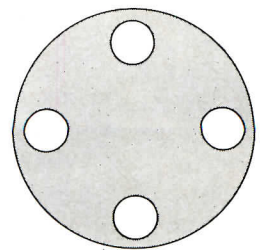
The designers wanted the columns supporting the space frame in the Great Hall and the main exhibition space light and "transparent." Moreover, they wanted the space frame to seem a natural outgrowth of the columns. To minimize the size of the columns at their bases, four metal tubes are set in a 5-ft cruciform and stiffened by metal webs separated for visual penetration. Seeking to marry all structural elements, the designers shaped the column to modify the familiar pyramidal support, which James Freed considers "inherent to the carried element but not to the carrying element." The 10-ft-square capital supports diagonals that diminish in size as they move toward and merge with the space frame structure. At the edges of the 90-ft bays, a third chord is added below the space frame to create a 10-ft-deep diamond truss (top).



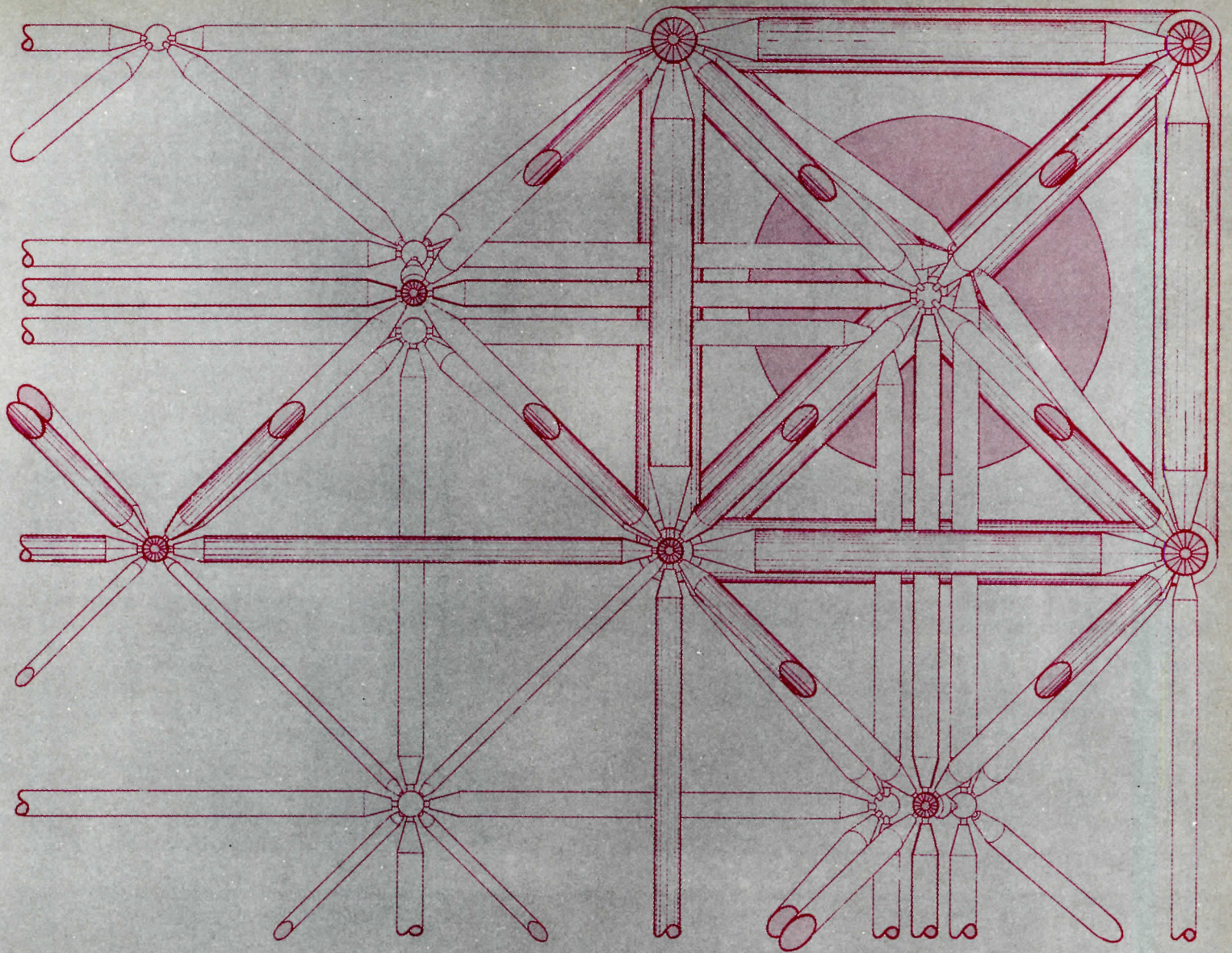
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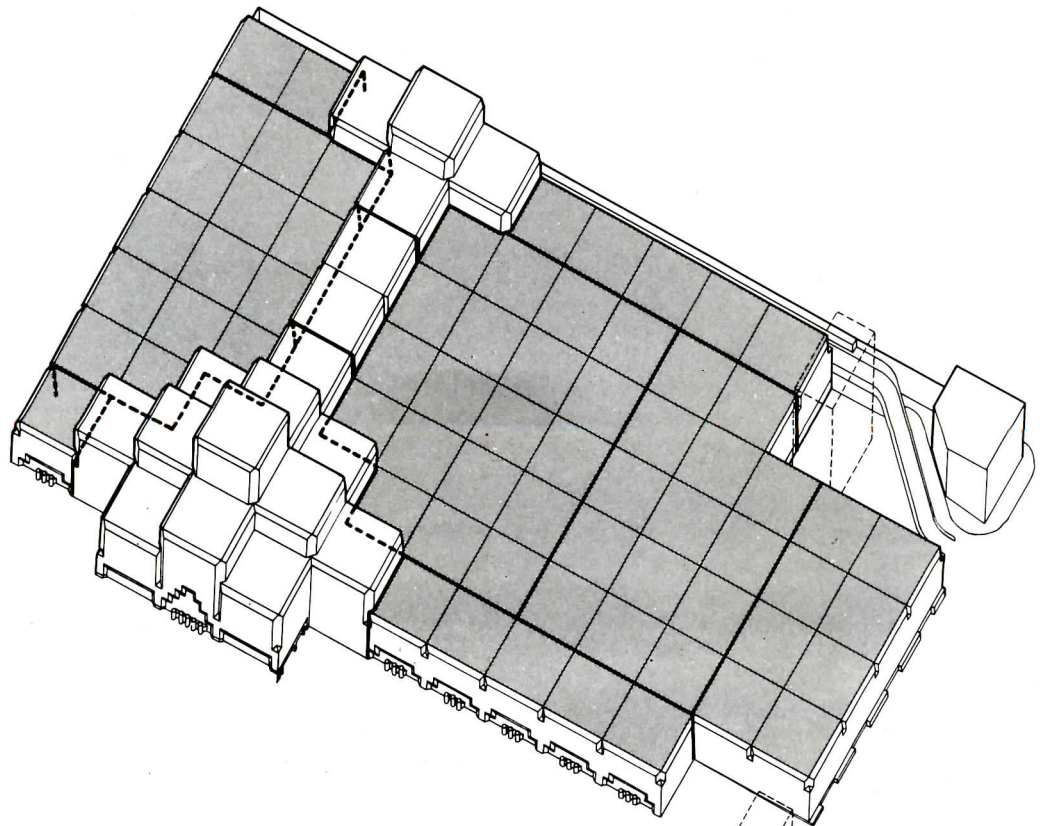
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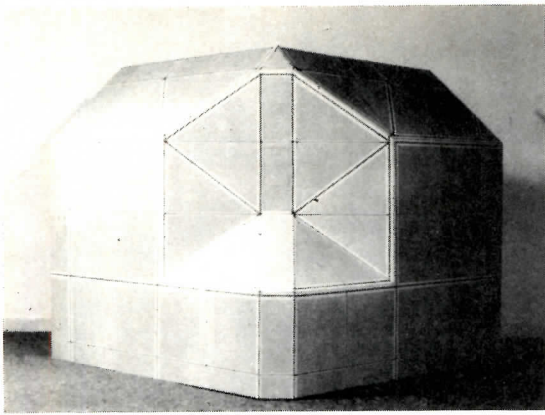


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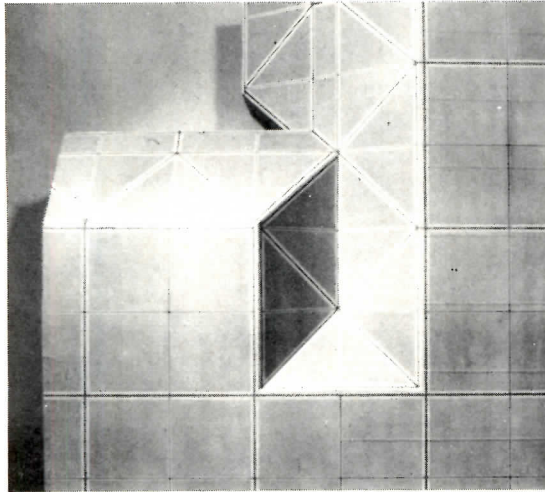


The diamond trusses bounding the 90-ft bays are split vertically for expansion along the lines described in the aerial axonometric at right (see also drawing on page 47, which shows the paired lower chords of the divided truss as they meet column diagonals). The structural geometry of the expansion joints gets really interesting, however, when roof meets wall at the corners of the Galleria (above). The detail that translates the space frame from horizontal to vertical is a 10-ft diagonal—severely foreshortened in this drawing—that reaches from a node on the outermost split chord to a node on the “upper” (i.e., outer) chord of a vertical space frame module, and thus returns the space frame to its normal geometry. (The plan on page 47 was taken at elev. 67.5 ft, that on this page at elev. 82.5 ft.) At points near the perimeters defined by the expansion joints, Matthys Levy reports, sliding joints will accept lateral forces.



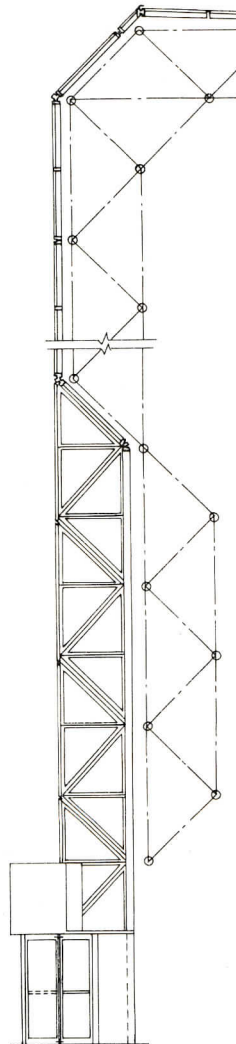


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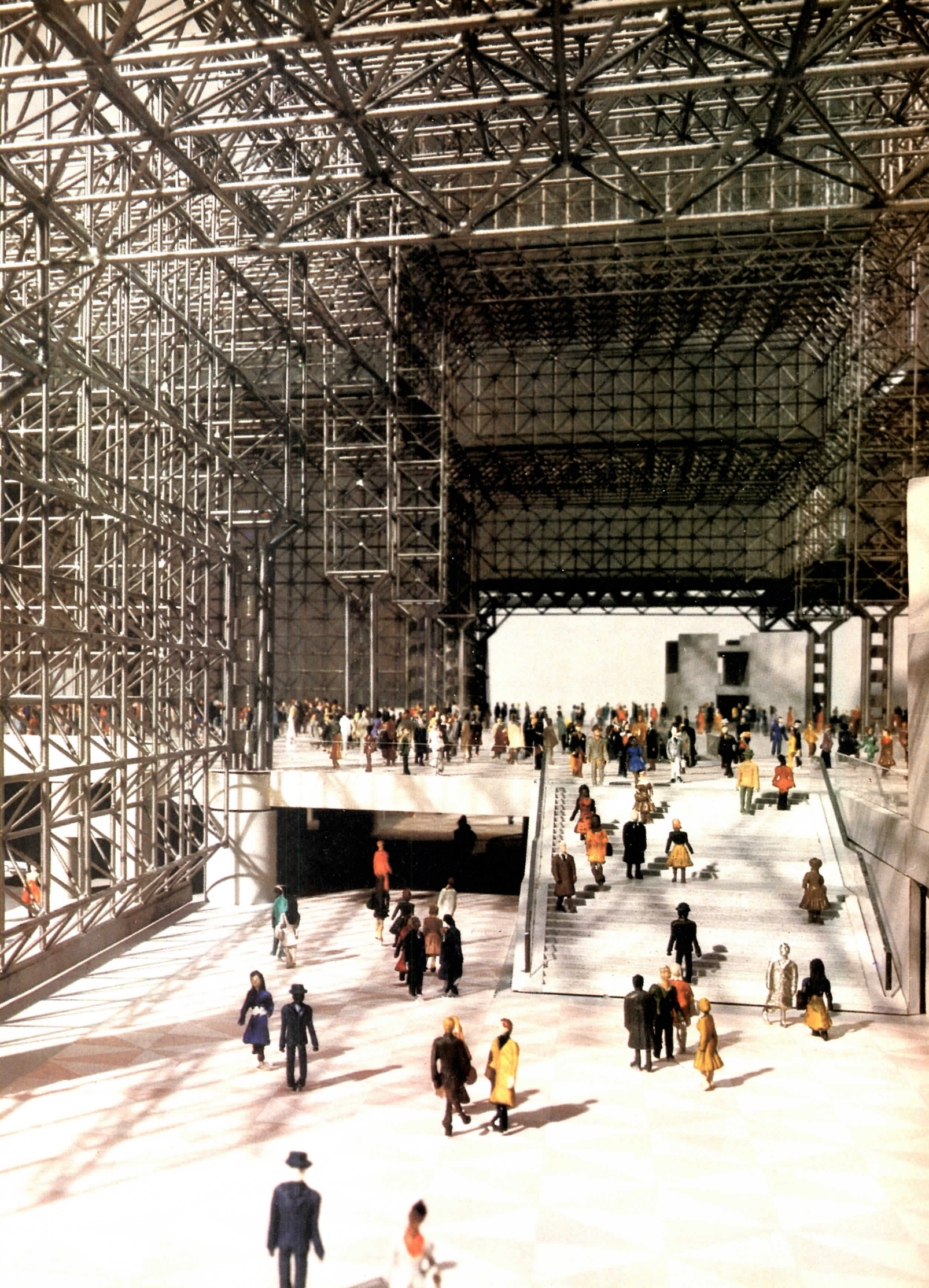
Dennis Gibbons photos



The glass skin of the convention center produced what architect Michael Flynn, Pei associate partner for technology, calls a "graphic description" of the skeleton that lies behind it—not only by mimicking the space frame's 10-ft module but by following exactly its bends and folds. Because the curtain wall hangs 1 ft 3 in. outside the space frame, the fabric had to be pieced to envelop the larger volume. This "zipper" is seen at the re-entrant corner at the end of the building (1) and along the top of the sloping lights (2). Aluminum framing subdivides the 10-ft glazing modules into four squares, both because 5-ft lights are economically reasonable and because the asymmetric arrangement of thick and thin edge frames prevents the look of wallpaper on the large expanse. Because of the discrepancies in size, the lengths of glazing frames cannot always duplicate those of the structure—a fact that generated a whole new set of geometrical headaches if corners were to meet cleanly. At the main entrance, where the curtain wall turns in to form a beveled surround at the monumental gate to the Great Hall (section at left), the space frame follows its own geometry to double back and leave space for a plane of clear glass above the revolving doors.

Nathaniel Lieberman





# Architects' (and engineers') GUIDE TO SPACE FRAME DESIGN

by Dr. Paul Gugliotta  
Paul Gugliotta Architects Engineers

A space frame is the most stable and efficient frame structure that can be built because it is self-bracing in three dimensions, and because all members participate in proportion to their strength in carrying three-dimensionally-applied loads (both vertical and horizontal) to the supports. The supports may themselves be braced by the space frame, making them more stable and efficient because column lengths have been effectively reduced. The members (chords and diagonals) are efficient because they carry primarily axial forces—either tension or compression—transmitted through three-dimensional connections. A space frame can be very economical to fabricate using properly designed connections.

A space frame or space truss structure is a plane, multiplane, or curved array of at least two

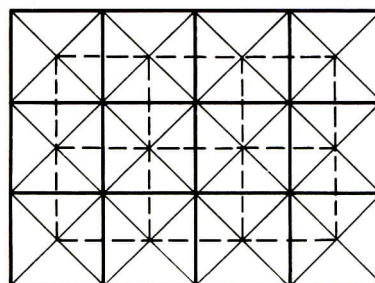
layers of intersecting chords, with diagonals connecting the outer and inner chord intersections, or nodes (Figure 1).

A space frame has rigid connections at the intersections of chords and diagonals that cause internal torsions and moments to be developed in the members. A space truss has hinged joints with no moment or rotational resistance and, therefore, no internal member moments. Both are popularly referred to as space frames.

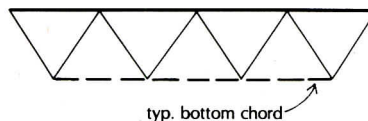
A space frame of the same size and members will be stiffer than a similar space truss—that is, it will deflect less under the same load. Its members will be more highly stressed, however, since they must resist bending moments and torsion as well as axial loads. Paradoxically, the space truss generally is allowed to carry more load than the space frame,

## Types of arrays

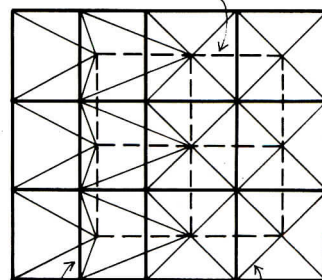
Figure 1



### Planar

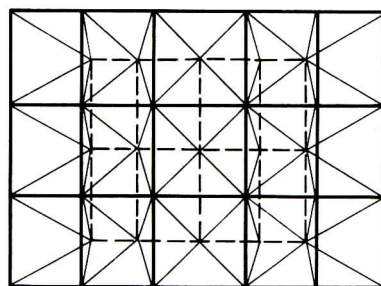
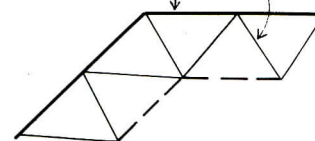


typ. bottom chord

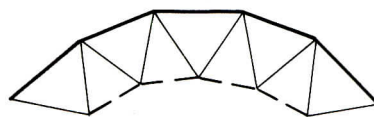


### Multiplanar

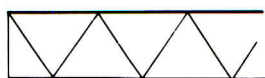
typ. top chord      typ. diagonal



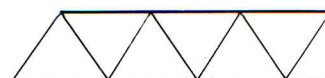
### Curved



### Edge variations



square



sloped-out



sloped-in



because its members resist only axial forces. The reason is that although the space frame with its rigid connections is stiffer than the space truss, AISC specifications require members having combined axial and bending loads to be designed more conservatively than those having axial loads alone.

The choice between space-frame or space-truss action is determined by the joint-connection detailing selected, which depends upon such factors as appearance and relative costs, and analysis is made accordingly. A space frame is more time consuming and expensive to design and analyze than a space truss, and the computer time required is much longer and more costly. The member geometry is no different for a space frame or a space truss, and the term "space frame" will be used to refer to both space frames and space trusses.

Space-frame chord arrays, or modules, may be square, rectangular, triangular, or geodesic—the shape coming from the geometry of the building to be spanned (Figure 2). Also, there may be more than two layers. A third layer is very inefficient structurally—because a middle layer is near the effective neutral axis, only very small loads are imposed on this layer.

Nonetheless, a middle layer can be useful if it is necessary to use small space-frame members to span a long distance. In this case the middle layer braces the diagonals and reduces their lengths, although their number is doubled.

The module size is usually the same for both chord layers, but one module may be twice as large as the other to reduce the number of members and number of connections (Figure 3). Also one layer may be skewed relative to the other to increase structural efficiency and reduce the number of chords and connections in the skewed plane. The outer and inner chord layers are usually parallel so that all diagonal lengths are equal, which makes the system easier to design, fabricate and erect. However, the distance between chord layers may vary, resulting in varying diagonal lengths (Figure 4).

Space frames are very efficient and safe structures in which loads are supported in part by each chord and diagonal member in proportion to the strength of

each. The applied load will travel by the "stiffest" routes to the various supports, with most of the load detouring around the more flexible members. Space frame stability is not significantly affected by the removal of a few members, which results in a rerouting of forces around the resulting "gaps," with the remaining members sharing the additional forces equitably in proportion to their stiffness or strength. This is the reason that a space frame is stable and safe, even when overloaded.

Space frames are considerably more efficient than two-way truss systems, which are superficially similar. Space frames usually have close to half the weight for the same loads and spans. Further, common design practice seems to result in two-way truss systems having many more pieces and joints than similar size space frames.

The two-way truss system is not as efficient as the space frame because it lacks effective torsional strength that would allow it to distribute loads between trusses—the only place this can occur is at panel points. The space frame, in contrast, has torsional strength because of diagonals connecting the staggered chord intersections.

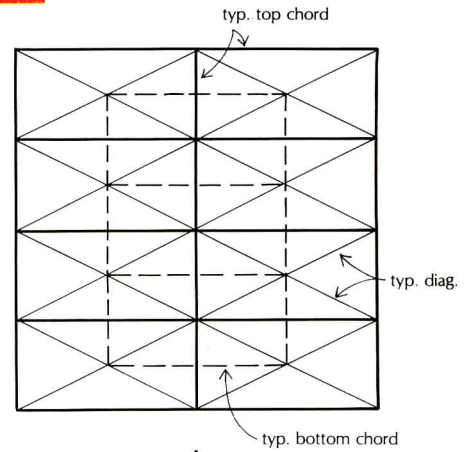
The structural action of a space frame is much like that of a flat plate or shell in the method by which loads are distributed to supports. The flat plate develops three-dimensional resistance in addition to its two-way bending action, and is much more efficient and versatile than other types of concrete slabs, or beams and slab configurations. In fact, some flat plates and shells are analyzed by having the computer approximate their structural characteristics as space trusses or space frames. And simple space trusses are analyzed by hand calculations by assuming they act as flat plates. (See box on page 61).

Space frames need a minimum of three supports to be stable, although most have at least four supports. Generally, the more supports a space frame has, the more efficient the structure will be. For example, the maximum member force in a square space frame with perimeter supports is only 11 per cent of the maximum member force in a square space frame with four corner supports, and the range between maximum and minimum member forces will be corre-

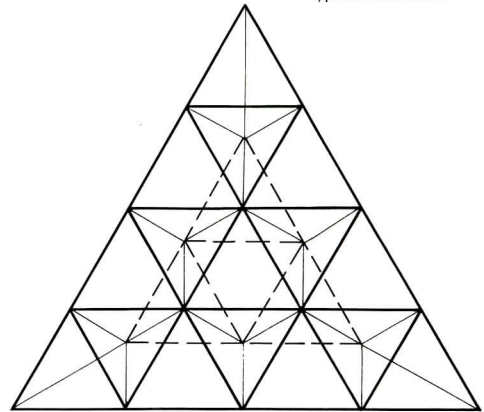
## Module shapes

Figure 2

### Rectangular



### Triangular



### Geodesic

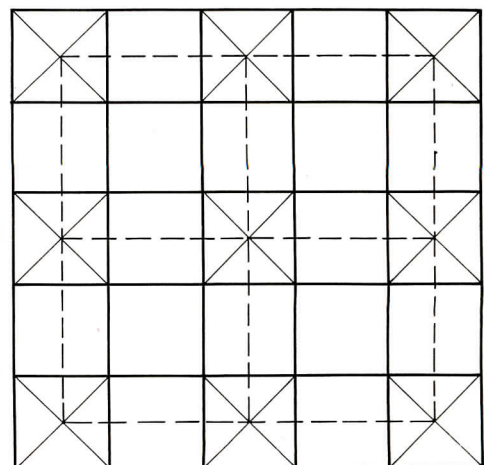


United States Pavilion, Montreal

## Module size variations

Figures 3 and 4

### Chord length

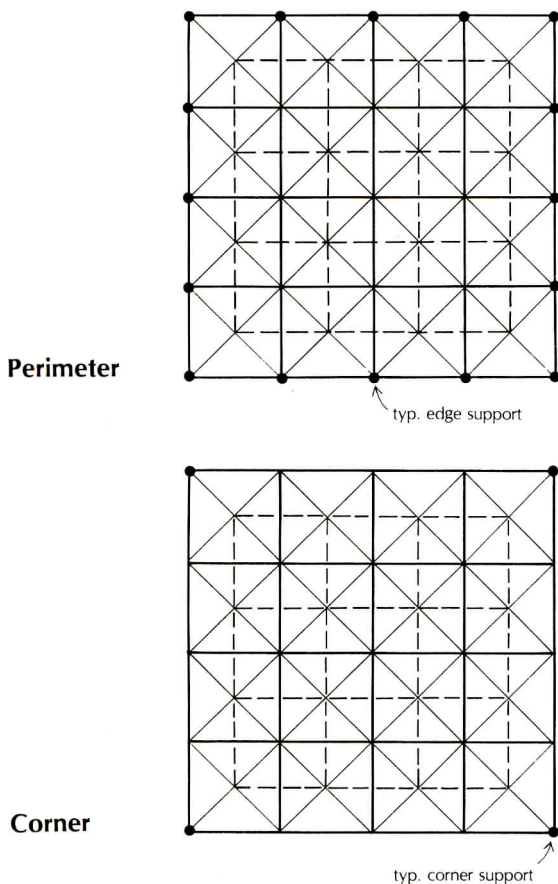


### Diagonal length



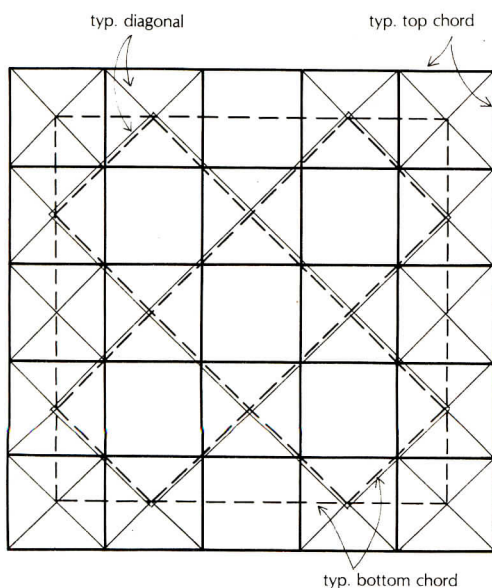
## Extent of support

Figure 5



## Skewed bottom chords

Figure 6



spondingly less (Figure 5). The narrower the range is between the maximum and minimum member forces, the more standardized and uniform the members can be, and therefore the more economical the member sizes and connections.

In the design of the space-frame structure for a building, the geometry of the space frame must follow that of the building, with the chord module size being developed from the building dimensions. The larger the module, the fewer members and nodes required, and the more economical the space frame, since most of the labor costs are directly proportional to the number of pieces handled. The weight of a space frame with large modules is usually less than that of a similar space frame with smaller modules. The size of the modules may be dictated, however, by the maximum size of members available for the particular project. The number of members and nodes is inversely proportional to the square of the module size (i.e., with a 5-ft module there will be four times as many members and nodes as with a 10-ft module, and both sizes are usually man-handleable.) An optimum module size is between 1.5 to 2.5 times the space frame depth. An economical space frame depth is usually between  $\frac{1}{18}$  to  $\frac{1}{20}$  of the clear span, or about  $\frac{1}{9}$  of the cantilever span, should that control. Many economical space frames have module sizes ranging from about  $\frac{1}{2}$  to  $\frac{1}{14}$  the space-frame span.

It is uneconomical to have an extra structural grid above the top chords to carry the roof or floor deck, since this extra layer weighs and costs more, is difficult to erect, and is redundant. A roof deck placed directly on the top chords can act compositely with the top chords, bracing them and making them more efficient in resisting compressive forces, and making the space frame exceptionally strong as a diaphragm resistant to winds and seismic loadings. When the top chords are in compression, as in a single-span building, and/or carry local bending moments from a floor or roof deck, they are sometimes made shorter than the lower chords, which are generally in tension, so their structural performance is not affected by their length. The shorter top chords will then be lighter and will have smaller local spans and moments,

and, from the standpoint of buckling, shorter "column" lengths.

The module sizes are changed either by: 1) doubling the lower chord module size, 2) removing every other bottom chord (and reducing the number of lower chords and lower chord nodes by 75 per cent), or 3) skewing the lower chords relative to the top chords, which increases the size of lower chord module by 141 per cent and reduces the number of chords by 50 per cent (Figure 6). Either of these module enlargements increases the theoretical structural efficiency, and actual costs will be reduced if members and connections are properly designed and constructed because of fewer pieces and connections, and less weight.

The efficiency and economy of an edge-supported space frame, and sometimes of a point supported space frame, may be increased by placing the chord grids at a skew to the space frame edges (Figure 7). This causes the areas across the corners to become very "stiff," and to act as supports, causing stress reversals, so that top chord compression members go into tension, and bottom chord tension members into compression in the corner areas. These stress reversals make the structural span effectively less, in a manner similar to continuous beam or continuous plate structures. Skewed grids will not be beneficial if the edge spans are too great, since the edge member forces increase greatly for large edge spans. The skewed connections at the edges must be properly designed to receive the extra chords and diagonals meeting there, so as not to become cumbersome and expensive—negating the savings in structural efficiency, weight, and material cost gained by the skewed grid.

The efficiency of a space frame supported on widely spaced columns may be increased by carrying the space frame down to the column top as an inverted pyramid (Figure 8). The spreading out of the concentrated column reaction on the space frame reduces the maximum chord and diagonal member forces adjacent to the column supports, and also reduces the effective spans, making the members smaller, more uniform, and more efficient and economical. The use of crosshead beams

on column tops (Figure 9) produces the same effect on the space frame as the inverted pyramid, but usually costs more in material and special fabricating costs.

Space frames are ideal for carrying skylights, since these must be supported at many points in a grid pattern similar to that of space frames. The skylights are usually attached to gutter systems that are supported in turn at the space frame nodes by adjustable bolts that allow slope adjustments for gutter drainage (Figure 10). On sloped space frames, skylights may be applied

directly to the top chords because the slopes eliminate the need for gutters (Figure 11).

Space frames are flexible structures, most of which are erected by bolting the members together. Thus they can be added to, or changed in size, and are completely demountable. Whatever welding is required for their fabrication is usually done in the shop, and it is unusual for field welding to be required on a space frame. Since the member sizes are small compared to the spans, space frames can be packed compactly and shipped efficiently.

### Typical Space Frame Calculations

#### Loading:

live load = 30 psf  
 dead load = 10 psf  
 space frame = 5 psf  
 total load = 45 psf  
 Load/module =  $5 \times 45 = 225 \text{ plf}$   
 = .225 klf

mid-strip = span/2  
 column strip = span/4 + cantilever

#### Moments:

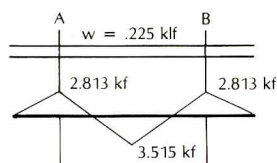
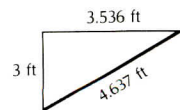
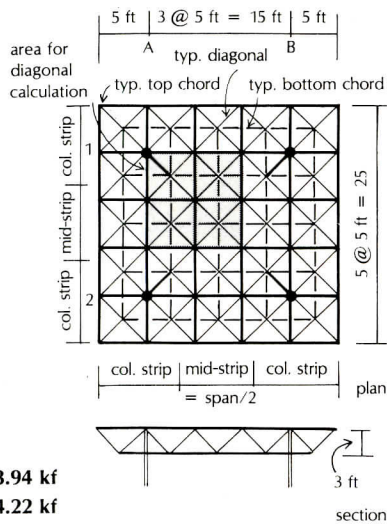
M for cant A = M for cant B  
 =  $.225 (5)^2/2$   
 = 2.813 kf  
 M for AB =  $.225 (15)^2/8 - 2.813$   
 = 6.328 - 2.813  
 = 3.515 kf

-M for col strip =  $1.4 \times 2.813 = 3.94 \text{ kf}$   
 +M for col strip =  $1.2 \times 3.515 = 4.22 \text{ kf}$   
 -M for mid-strip =  $0.6 \times 2.813 = 1.69 \text{ kf}$   
 +M for mid-strip =  $0.8 \times 3.515 = 2.81 \text{ kf}$

Max comp. chord = max tens. chord  
 = approx. M/3 ft

#### Max. diagonal force at A-1

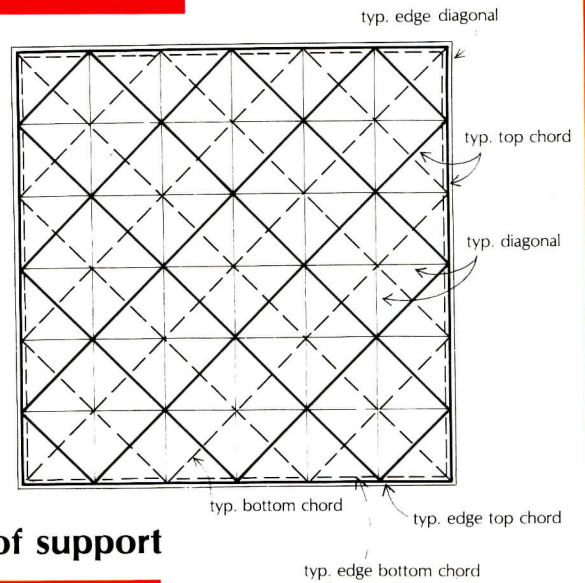
$V = 45 (7.5)^2 = 2,531 = 2.531 \text{ k}$   
 Diag. =  $4.637/3 \times 2.531$   
 = 3.91 k



M col strip (kf)	3.94	4.22	3.94
C = T for col strip (k)	1.31	1.41	1.31
M mid-strip (kf)	1.69	2.81	1.69
C = T mid-strip (k)	.56	.94	.56

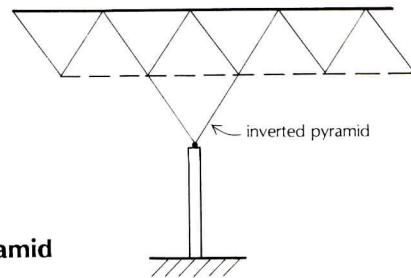
## Skewed chord grid

Figure 7

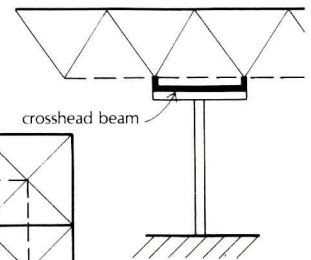


## Types of support

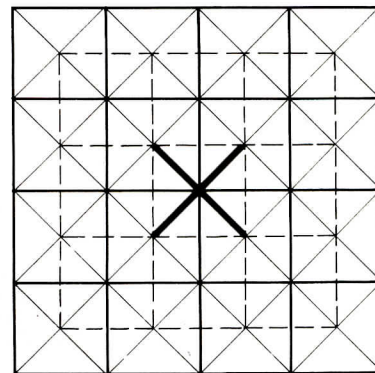
Figures 8 and 9



### Inverted pyramid

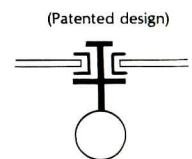
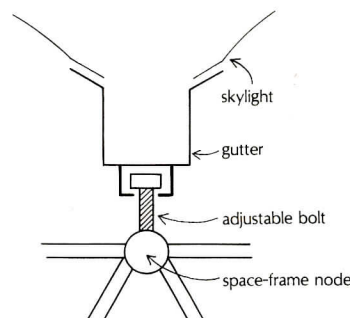


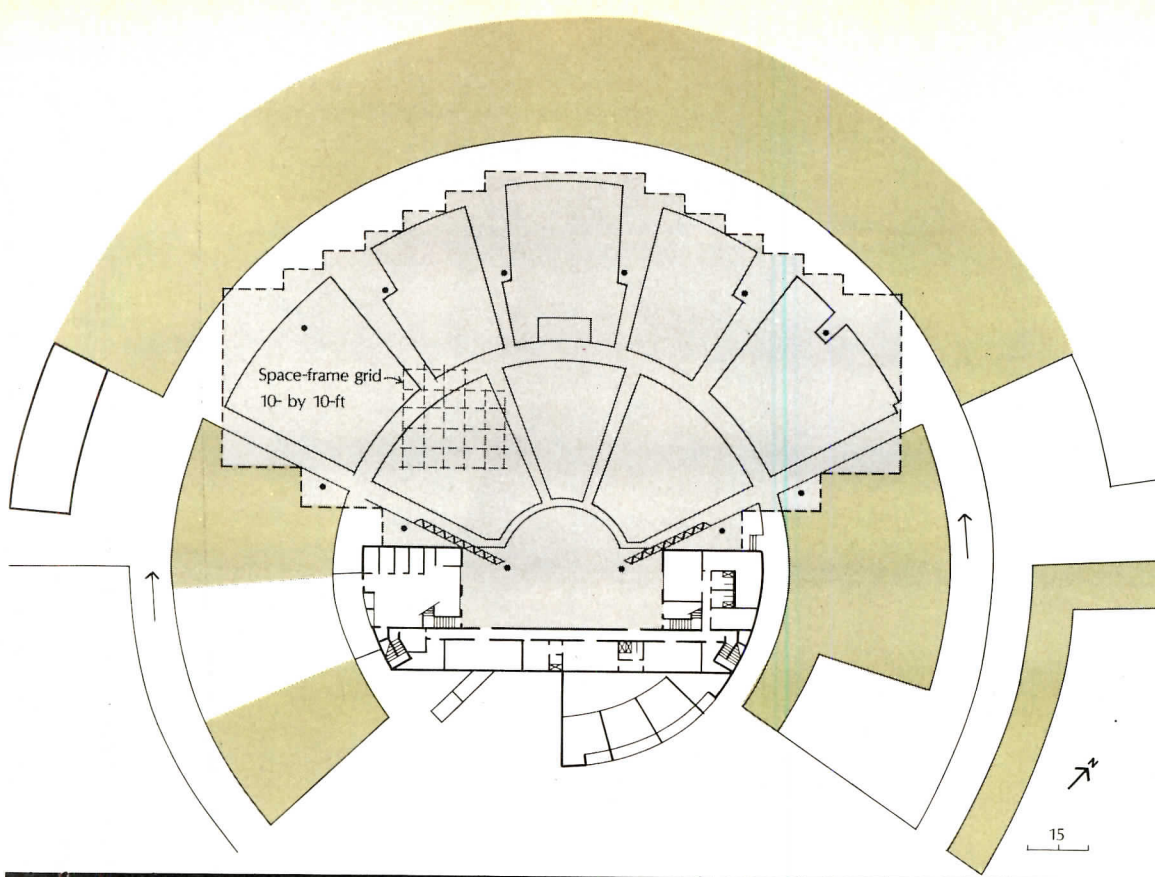
### Crosshead beams



## Gutter details

Figures 10 and 11





# A FESTIVE SPACE FRAME SHELTERS OUTDOOR CONCERT

The continuing fondness among the young for rock concerts derives as much from the audience's sense of shared communion as it does from the music itself. And the larger the audience, the more intense the pleasure of shared participation. This social fact mandates exceptionally large auditoriums for these events. Moreover, producers of all concerts recognize the need for substantial ticket sales to offset the size of production costs and performers' fees.

As far as its owners and architects can determine, the Poplar Creek Music Theater near Chicago is the largest outdoor theater in the world designed for musical performances, both classical and popular. Intended as a prototype for a national chain of similar theaters, Poplar Creek can accommodate an audience of 20,000—7,000 of them under roof, 13,000 more on the sloping lawn that curves around the back of the house and in front of the folded acoustic fence.

As for any smaller auditorium, unobstructed sightlines were considered essential, a requirement met at Poplar Creek by a 60,000-sq-ft steel space frame. The roof, an irregular rectangle symmetrical only on either

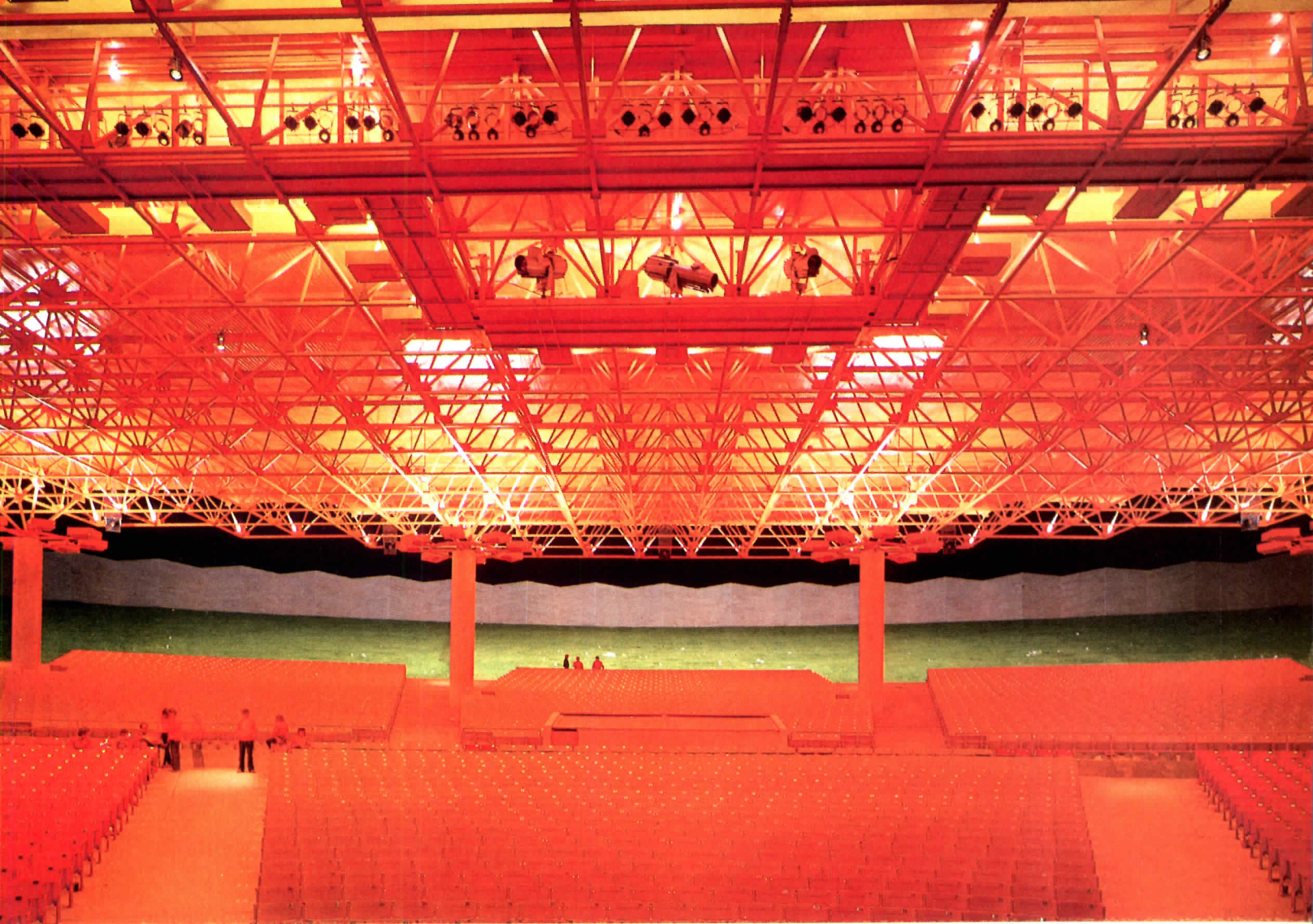
side of the front-to-back axis, spans a maximum of 150 feet at the center and gives a 240-ft length of unobstructed space within the oval rows of columns. The space frame supports cantilevers overhanging as much as 50 ft along the roof's serrated edges.

Steel-tube space frame chords were shipped in 50-ft lengths to the site, where diagonals were field bolted to form 50- by 50-ft and 50- by 80-ft sections that were hoisted by crane. The structure, with a depth of 8 ft, bears on inverted 8-ft pyramidal space frame sections, which in turn bear on concrete columns 42 in. in diameter. The patented space frame uses square tubes of varying sizes—4 in. for chords, 3 in. for diagonals, and 5 or 6 in. for the pyramids.

Since only six of these columns circle the back of the house, they offer minimal visual obstruction to spectators on the lawn. They also offer minimal visual obstruction to performers on stage, who, the architects report, have observed an unexpected sense of intimacy with their large audiences, who are easily visible on the bermed lawn against the house's back wall—that is, the acoustic fence at the top of the slope.

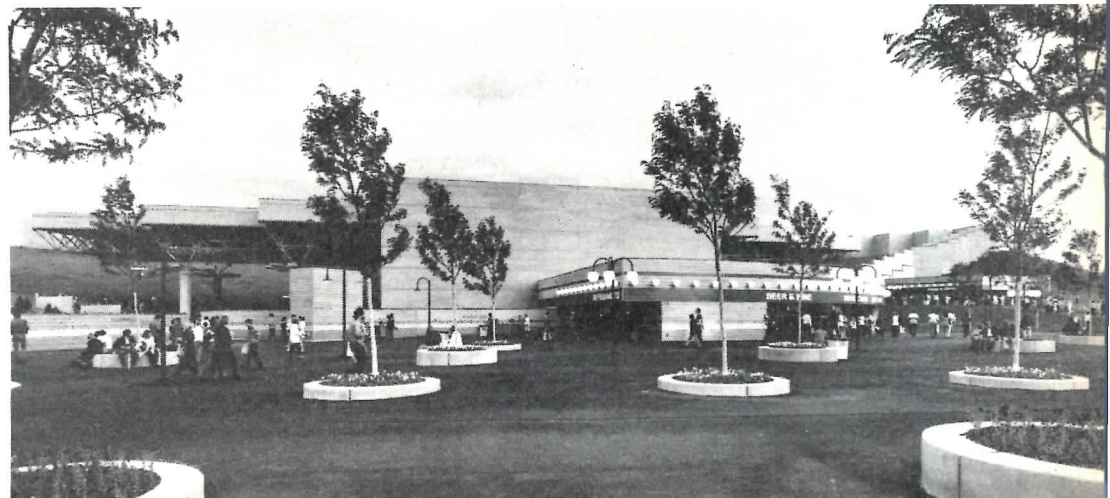
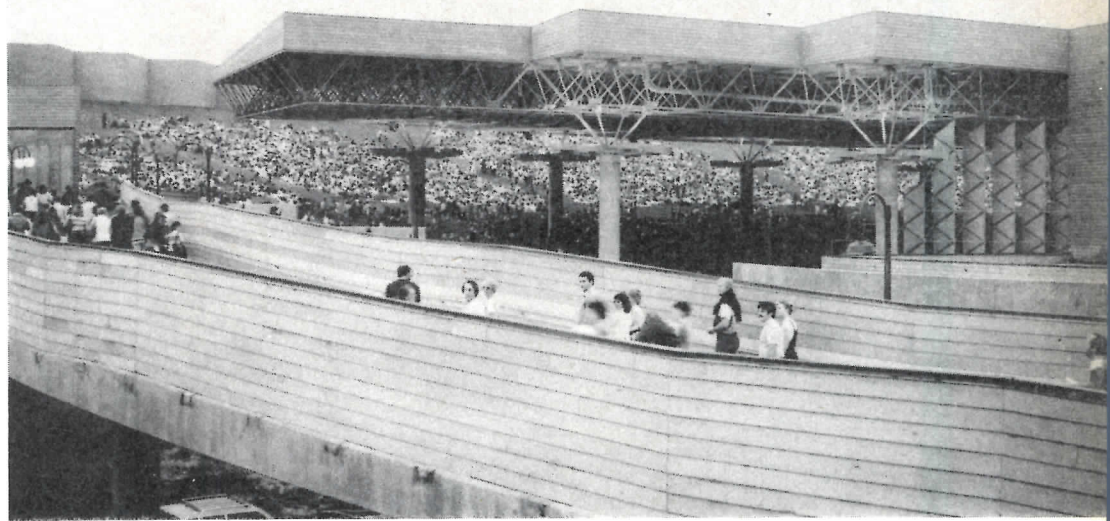
The roof supported by the space frame has a 3-in. tongue-and-groove wood-plank underside for acoustical reflection, and an array of acoustically reflective panels mounted above the lower chords directs sound to the seated audience, as do speakers mounted between the chords. Listeners on the lawn outdoors hear music via a digital delay horn system hung on the back edge of the roof; horns are equipped with a constant directional characteristic to limit the spread of sound.

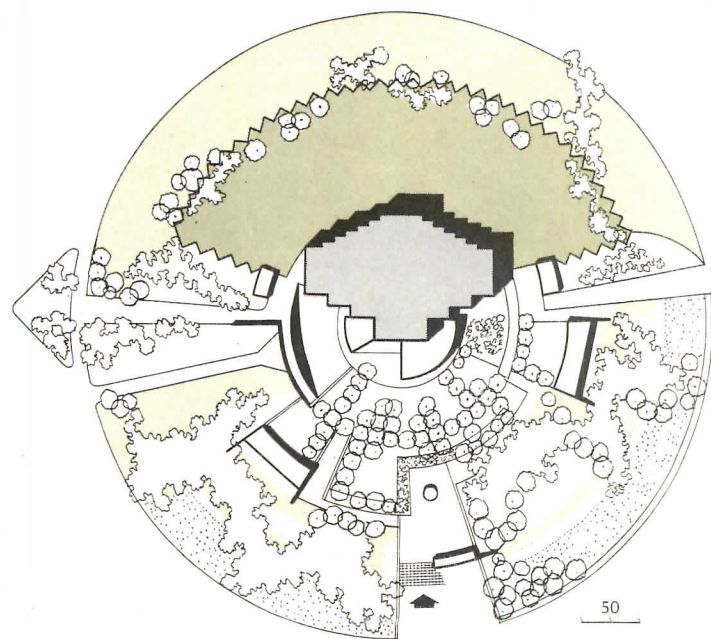
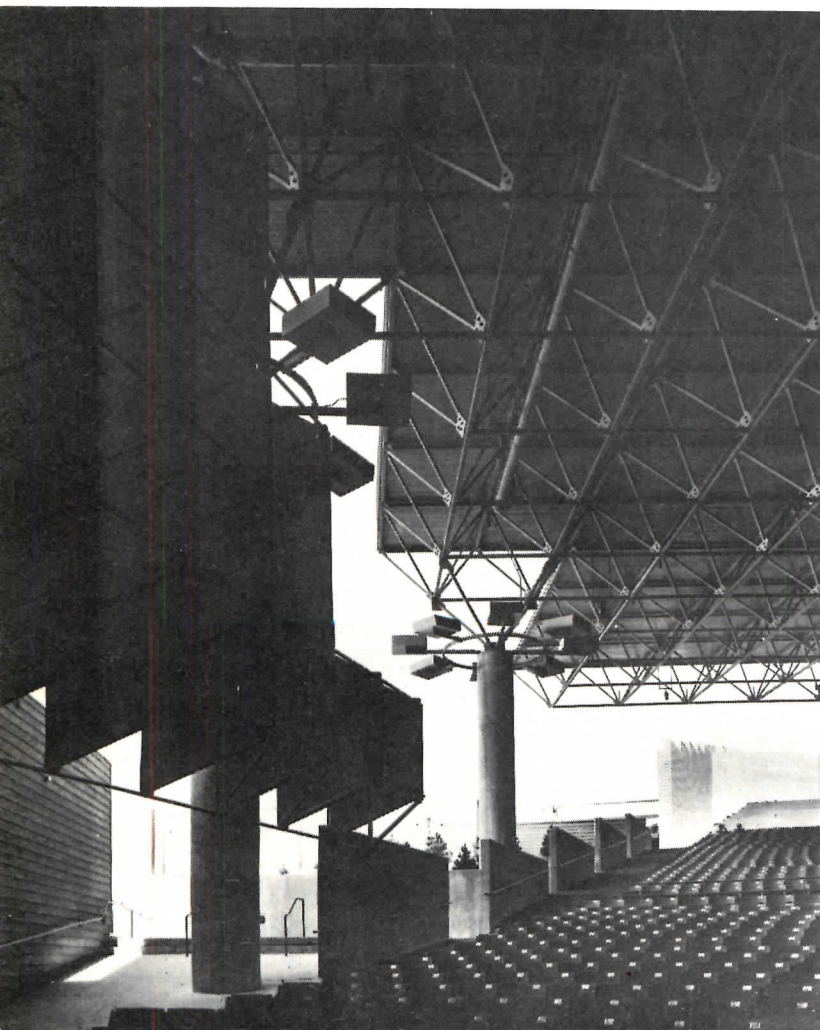
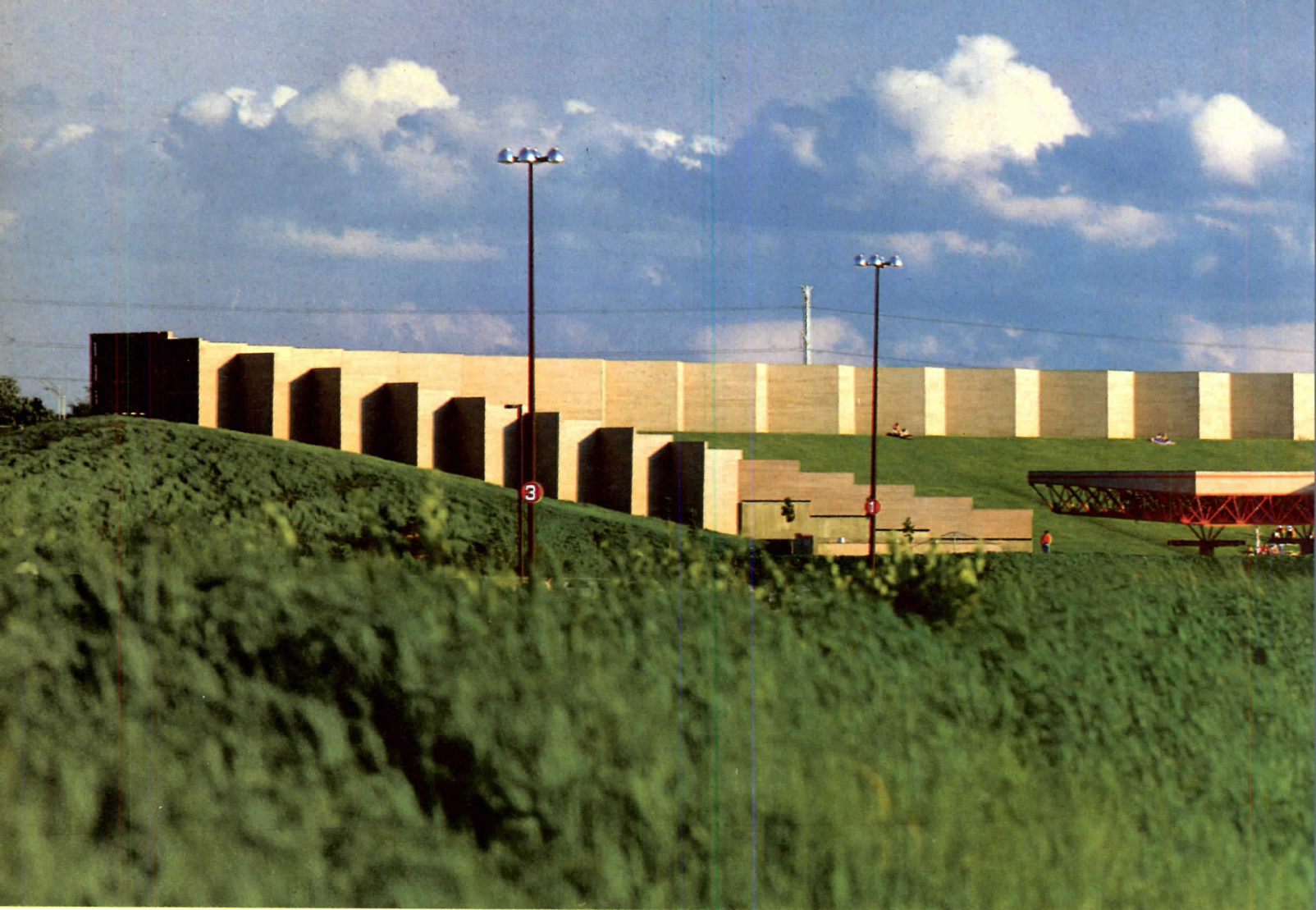
POPLAR CREEK MUSIC THEATER, Chicago. Owner: NED-PROP, an Illinois joint venture by Nederlander Realty Company of Illinois, a co-venture with RKO General. Architects: Rossen/Neumann Associates, Inc. Engineers: Paul Gugliotta Consulting Engineers Inc. (structural); Wolfson, Leavitt & Associates, Inc. (mechanical/electrical); Schumacher & Svoboda (civil); John Black Associates (site sanitary and water). Landscape architects: James C. Scott Associates. Consultants: Ralph Alswang (theater planning); Imero Fiorentino Associates (theater); Klepper, Marshall & King (acoustics); Kamperman Associates, Inc. (acoustics). Sound systems: Stanal Sound. Construction managers: Elzinga & Volkers.



*Timothy Hursley/Balthazar Korab Ltd. photos*

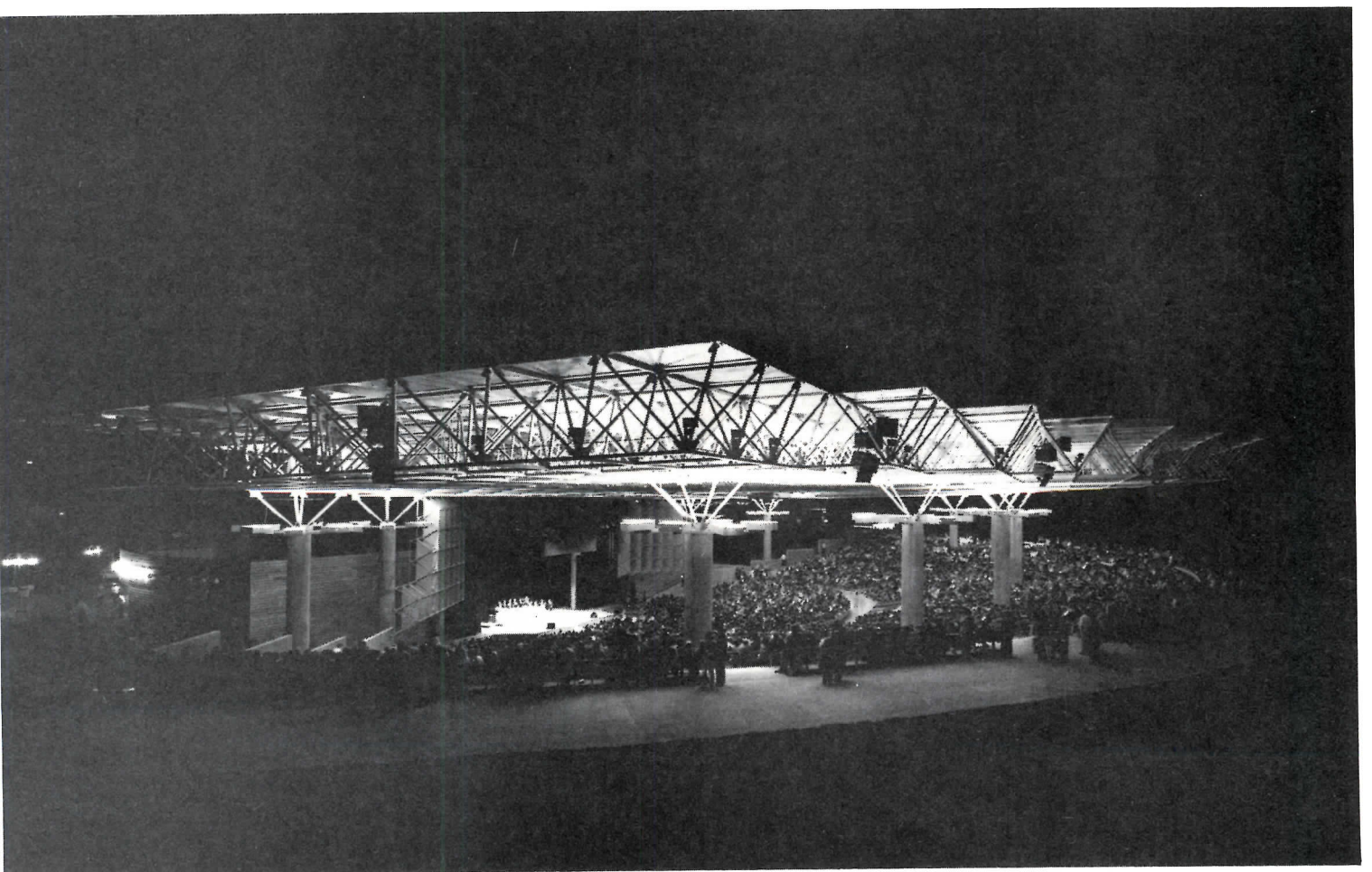
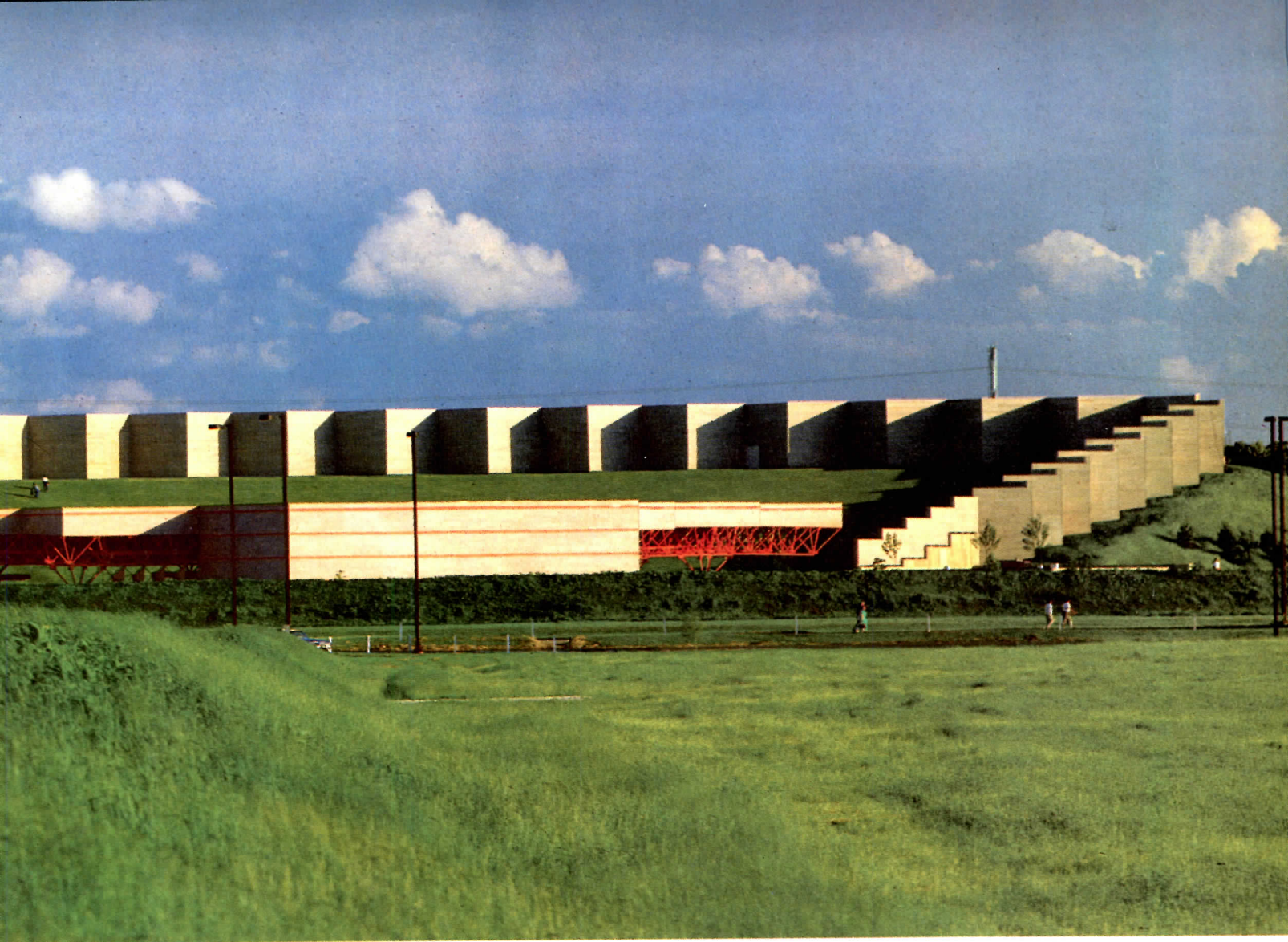
Circulation at Poplar Creek reverses customary audience movement: spectators enter the complex back of the stage, pass through the concession area (bottom right), then progress on a curving bridge to enter seating at the ends of rows or to reach the lawn behind the seating. A free-standing multiplanar space frame identifying the entrance (bottom left) is built on a 5-ft grid, against the 10-ft grid of the roof. Shaping the site, originally a flat cornfield, required moving 370,000 cu yd of earth to lower the stage and raise the berm. Cedar siding has an orange-red stripe to match the painted wood ceiling.





Siting conditions and stringent state and local noise regulations, particularly with regard to residences, complicated the acoustical considerations at Poplar Creek, especially since the theater may generate sound as loud as 110 dB, and even though only one house lies within the stage's cone of sound. At the same time, the audience requires acoustical

protection from traffic noises on the adjacent tollway. At the back of the lawn, a 20-ft wood wall, stretching 1,000 ft plus 140-ft extensions at each end, provides the necessary two-way sound barrier. Next to the stage, acoustic side walls (below left) comprise wood panels mounted on a space frame whose 5-ft grid halves the scale of the roof.





Near Chicago, a 60,000-sq-ft space frame covers the seated audience at the Poplar Creek outdoor music theater, which accommodates 7,000 people indoors, another 13,000 on the bermed lawn in back. The steel-tube space frame, an irregular rectangle, bears on 12 concrete columns 42 in. in diameter. Radiating uprights at the tops of columns provide house lights, which were lit, though dimmed, for Bob Hope's performance at the theater's opening this year (below).









Robert E. Fischer

# Identification for a grand hotel

Every hotel needs a featured space that attracts guests and beckons the public for its patronage. For the Grand Hyatt, a new hotel in the shell of the old Commodore adjacent to Grand Central Terminal, this feature is a sidewalk cafe 18 ft in the air called the Sungarden. The cafe looks both outward on the activity of 42nd Street, and inward to the 40-ft-high lobby, serving as a skylight. The cantilevered structure is indented for 42 ft in the center to signal the entrance, though the space frame bridges between the longer 56-ft sections for visual continuity.

The architects for the hotel, Gruzen & Partners, and consult-

ing architect Der Scutt deem this feature a public amenity because of the life it will bring to this part of the city, where considerable renovation and new construction is now occurring.

The space frame, a major design element of the Sungarden, which will seat over 200 people, is a patented system that uses prestressing rods within the tubes to assemble the space frame and to resist loads. Developed by Dr. Paul Gugliotta, the system comprises hollow tubes, hollow-ball nodes, and threaded rods that are fastened to the nodes by bolting. Compressive forces are resisted by the tubular members, and tension forces by the rods

sheathed by the tubes. The tubes generally are steel with a brass-colored finish, except for those tubes within the public's reach. These are steel with brass-metal tubular sheaths that can be more easily cleaned of fingerprints.

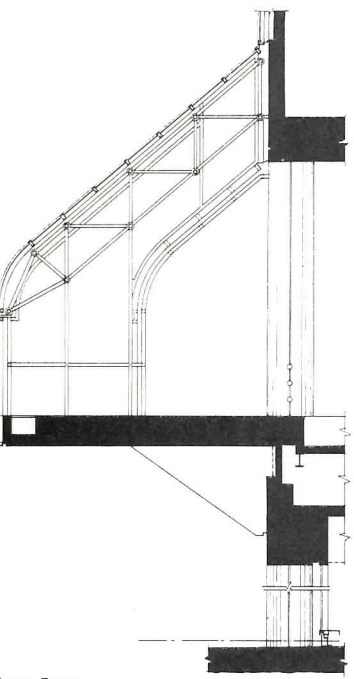
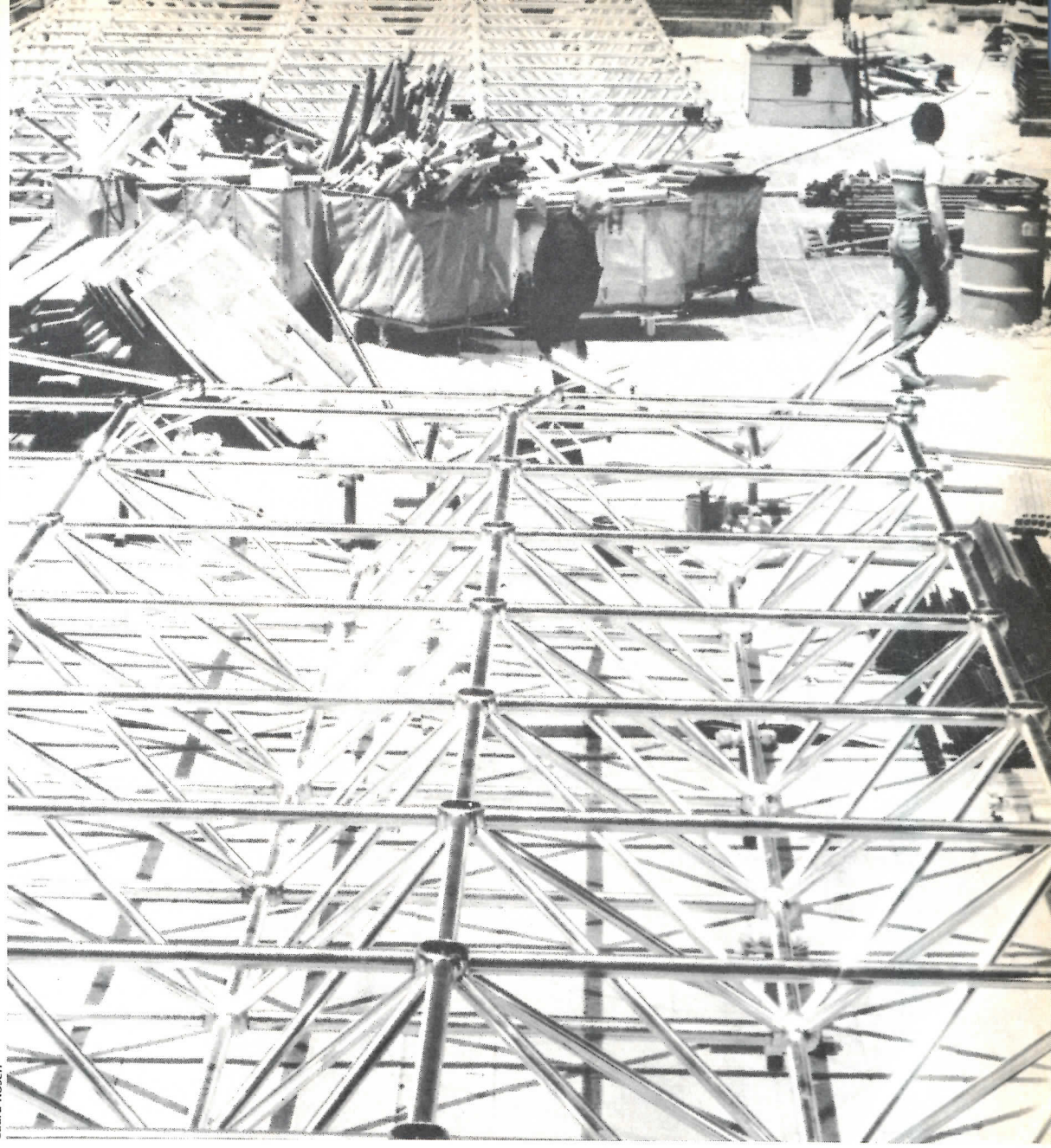
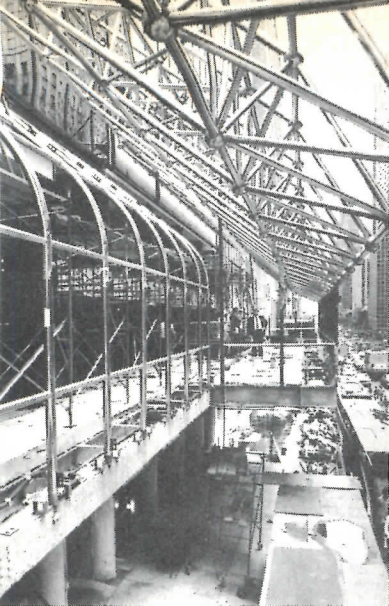
The laminated glass will be supported by black-anodized, square-tube mullions fastened to tabs on the node caps that are bolted in place after the rods have been prestressed.

Structural design of the space frame was complicated by the uneven modulation of the curtain wall spandrels across the front of the hotel, the result of odd shaped window openings in the old hotel structure.

The space frame was assembled on the roof of the hotel ballroom and was lowered in three sections—the two 56-ft-long end sections and the 42-ft-long section that covers the indented section of structure (see photo top left across page, and detail).

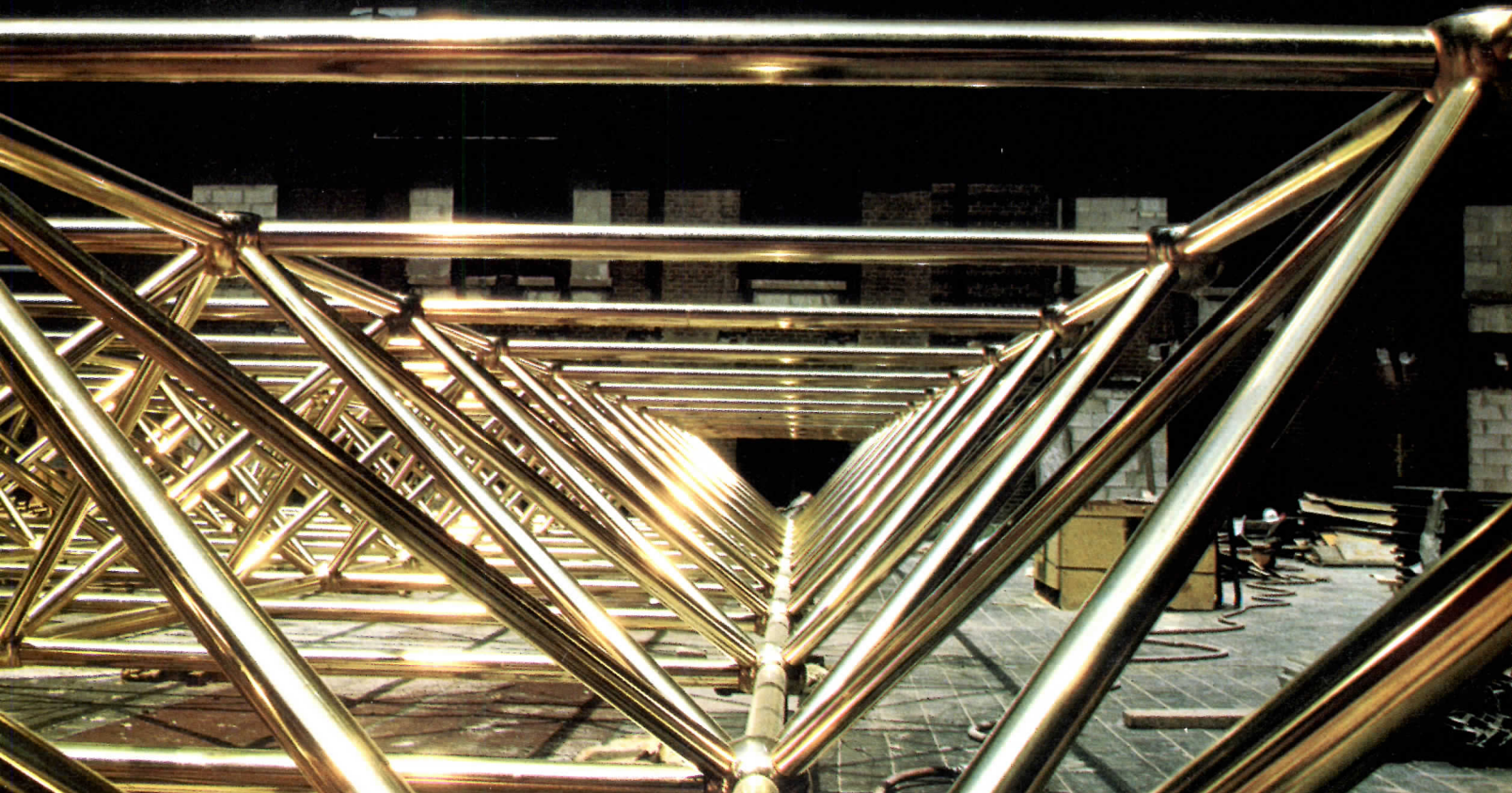
To shield the cafe from unwanted sun, motor-driven fabric shades will be pulled down directly under the sloping glass, while manually operated roller shades will be drawn to block sun at vertical glazing.

The cantilevered concrete and steel platform was designed by the project's structural engineer, Irwin G. Cantor.



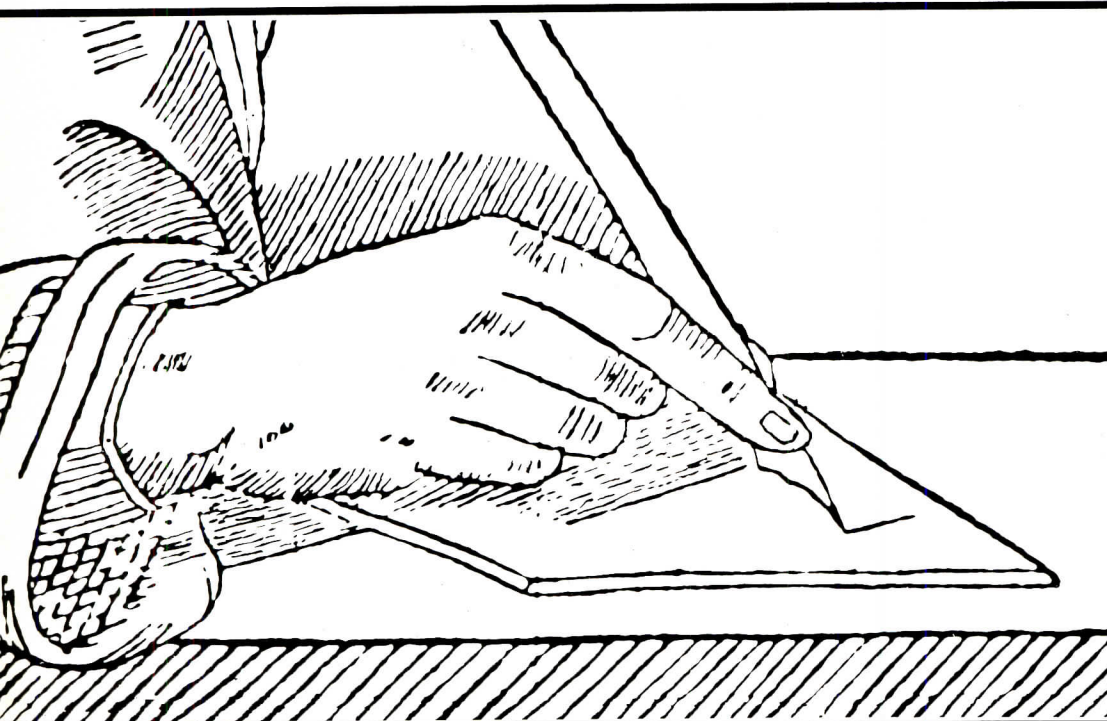
Laura Rosen

Laura Rosen



# Toward workability of the workplace

By Margaret F. Gaskie



Because forty-two per cent of the American workforce now goes to the office, its productivity is a source of increasing concern. For this reason interest should grow in a landmark survey of 10,000 workers by the architectural research firm BOSTI, which seeks an "airtight case" on why workers like or dislike their offices. The survey seeks answers to questions about real vs. perceived needs for privacy, flexibility, lighting, and the subjective area of status. The project is now in its middle stages but already offers some food for thought. For "the ill properly diagnosed holds the seeds of its own solution."

Ten thousand workers in 100 offices across the country, pencils poised to register their yeas and nays, are the subject of a survey that heralds the most ambitious foray yet made into the sometimes murky landscape of behavioral research aimed at probing the impact of design on its consumers.

The expedition is organized and led by the Buffalo (N.Y.) Organization for Social and Technological Innovation (BOSTI), a nonprofit research group whose president, Michael J. Brill, expects the survey to capture for the first time "objective and quantifiable" data on the linkages between specific components of the workplace and the occupants' sense of satisfaction with the place and their work.

If the comprehensive and sophisticated research program put together to that end in fact accomplishes its goals, it will, Brill says, "once and for all put the design of office environments on a rational footing." More important, it may serve the larger end of reasserting the validity and value as design tools of the methods and outcomes of psychosocial investigation.

## Behavioral research has been around for many years, but . . .

For a heady time in the late 1950s and 1960s the proposition, neither novel nor particularly profound, that buildings should but often do not serve the needs and facilitate the activities of those who occupy them struck the design professions with the force of revelation. Its corollary, the consequent benefits of collaboration between the disciplines whose role was to shape the built environment and those whose skill was to describe and predict the impact of the environment on the user, was embraced as received wisdom. A rubric of consultation was very quickly established in a fine flurry of jargon: user-needs analysis, man-environment research, user-oriented design . . .

But the partnership proved precarious as the would-be collaborators, designer and researcher, lustily chorused solidarity, linked arms, and strode briskly in the diverging directions dictated by the constraints of their separate disciplines.

For the architect, the decisive constraint proved the economics of his trade: relatively fixed fees nibbled by the growing horde of consultants needed to cope with the growing complexities of building design, and project schedules that often skimmed on design time and allowed none for shoe-horning in behavioral studies that to be useful should be made before design and after occupancy.

The consultant, for his part, was constrained by his trade's lack of a validated, standardized, and readily applicable body of information about the behavioral effects of buildings generally, or of aspects specific to particular building types, that could serve as a point of departure for bringing his expertise to bear on the definition of user needs peculiar to a given project.

That the partnership did not jell, however, makes no less true the truism that buildings should support their intended functions and no less urgent the implied need for

sound data on the requirements of their intended users. The objective remains, though couched now in terms less philosophic than pragmatic—productivity, efficiency, cost effectiveness.

### The new study builds on the limitations of earlier research

In mounting its massive study of workers and the workplace, the BOSTI group benefits from a clear awareness of the limitations that have hindered application of behavioral science techniques to building design. "Almost all of the previous work regarding the impact of environment on behavior," Brill argues, "is suspect. If you don't agree with it, you can always point to some exception or some flaw in the research design and say 'well, that doesn't apply.' What we want is an airtight case."

The odds on its constructing one are improved by the fact that the organization's principals have worked both sides of the street. The disciplines represented on BOSTI's staff of more than twenty run the gamut of the soft sciences—systems analysis, human factors engineering, social psychology, education, economics, and business management, as well as planning and design. But both Michael Brill and vice president Pamela Clayton are architects with solid backgrounds in planning and design, who moved to architectural research via programming. Both maintain close ties with the design community, as consultants and as teachers of design. And both have a keen awareness that if the outcomes of research are to contribute substantively to design they must include specific and incontrovertible data, free of provocative but fuzzy generalizations.

"Crisp" knowledge is needed, says Brill. "There will always be areas where the architect will have to make seat-of-the-pants decisions—and then toss and turn at night wondering if he made the right one—because some things just can't be quantified. It's our interest as an organization to shrink those areas where objective bases for design are not to be found."

That "the impact of the office environment on productivity and job satisfaction," as



the project is formally dubbed, was targeted as the area for developing information on so grand a scale is in part simply a matter of its lying athwart a continuum of BOSTI concerns. From its inception, the organization has pursued on behalf of corporations and public agencies increasingly searching investigations into the workings of the workplace, including several projects in collaboration with Clayton's architectural research and programming firm, Spaces for Systems, since merged with BOSTI.

This sequence of studies engendered considerable understanding of office mechanics and dynamics, homing over time on the links between physical planning and worker productivity, but there remained gaps. "Clients wanted to know," observes Brill, "how to get the biggest bang for the buck. That we couldn't answer."

BOSTI was, however, well placed to phrase the right questions (for examples, see box, page 72) and was, furthermore, equipped with a finely honed and tested arsenal of methodological tools with which to tease out definitive answers.

In addition, the time was right for generating the level of public and private support needed to explore in adequate depth and breadth the complex range of interplay between the characteristics of the office environment and the behavior of the office worker. A budget of a third of a million dollars, princely for research of this kind, was put together by organizing multiple sponsorship, much of the support coming from former clients who if presumably satisfied were not yet sated, and including the National Science Foundation, the National Endowment for the Arts, GSA, Bell-Northern Research of Canada, Westinghouse, American Seating, Owens-Corning Fiberglas, AT&T, 3M, Southern Company Services, Corning Glass Works and New York State.

### The goal: increasing office productivity in an increasingly service-oriented economy

The effect of the workplace on human performance is of course a major issue of concern not just for the worker and his employer. The United States is experiencing a distinct and accelerating shift from a product-oriented to a service-oriented economy, the latter sector now accounting for 45 per cent of the country's Gross National Product. Sixty-five per cent of the work force is now employed in so-called service industries—such fields as communication, information handling, education, health care, financial services, government—and 42 per cent of it works in offices.

This shift in itself need not occasion pointing in alarm, save that it has been accompanied by, if it has not precipitated, a marked drop in national productivity. It can be argued that traditional measures designed to document output of wheat or widgets are misleading when applied to work whose outputs are knowledge or service. Yet the discrepancies are pronounced enough to give pause: an 83 per cent rise in the productivity of production workers between 1960 and

1970, for example, against an increase of only 4 per cent in the productivity of office workers over the same period.

At the same time, the costs of the office component of business have far outstripped the costs of business as a whole, jumping from 25 per cent of the total in 1960 to 40 per cent in 1975. In light of its lagging productivity in comparison with production labor, the office sector has therefore suffered a disproportionate increase in its real costs for accomplishing a given amount of work.

This disheartening economic scenario, moreover, plays against a backdrop of continuing growth and change, not unaccompanied by stress. Economists predict that the office sector will continue to expand relative to the economy as a whole, and that despite the current slowdown it will pace the construction market for the next decade and a half, pouring major investments into plant—buildings, components, fittings, furnishings, and equipment.



### The problem worsens with rapid changes in the configuration of offices

Offices are of course changing in configuration, molded by forces working from within and without. Some of the changes are adaptations dictated by a real or perceived economy of scarcity in which energy, materials, and space are resources to be expended cautiously, with a sharp eye to long-term efficiency and performance—in short, payback. "You see managers giving the same kind of scrutiny to buying books for the corporate library," says Brill, "that they used to save for a top of the line computer." (Which, if not hyperbole, might have something to do with the low estate of office sector productivity.)

Other changes in the office environment, though, are formal responses to functional flux—in communication methods, business technologies, management style and structure, organizational patterns. Above all, they reflect the expectation of change as a permanent condition, a cliché so widely per-

ceived as wisdom that its companion cliché in the physical realm, flexibility, has become the guiding principle of office planning.

Change in the workplace then is a commonplace. Worker performance is a concern. And the conviction that the two are causally connected is widely held, not alone among the design professions. "Our new offices" are widely credited by the business community with such feats as increased productivity, reduced turnover and absenteeism, and soaring employee morale.

**Fair question: are our present assumptions about office design and flexibility valid?**

All would be well were the anecdotal evidence that environment matters backed by hard, verifiable data showing that to be the case, and indicating precisely how and how much. Such data are conspicuously missing.

In their absence, the very real possibility arises that the issues to which office planners are most assiduously addressing themselves

Does it merely annoy workers or does it also affect their work?

These issues, Brill emphasizes, are worthy of study "in a systematic, rigorous way," without discounting insight. "Decisions based on lousy data are very likely to be lousy decisions."

Because both the kind and degree of environmental impacts on job satisfaction are in question, the BOSTI study is carefully designed to distinguish between the purely physical environment and the psychosocial environment with which it interlocks. Thus particular stress is placed on weighing the "moderating effects" of employee characteristics, job content, communication patterns, work group norms, management structure, and organizational attributes.

Brill describes the research scheme for the study as quasi-experimental—"as close as you can get to the kind of formal scientific design that runs rats under controlled conditions as you can get and still be working in the

environment here comprises agencies as disparate as their corporate counterparts, not only in size and geographical location but in mission and so in type of work done and type of personnel principally employed.

All told, the survey can be assumed to cover, in sufficient numbers to maintain sample reliability when sorts for specific characteristics are made, a representative spectrum of individuals, job types and levels (including 3,000 managers), and organizations.

An equally critical control is the extension of the survey through time. If the respondents are in most respects representative of office workers generally, they are atypical in that all are moving from one work location to another over the two-year span of the study. Each will complete the survey questionnaire some four to six weeks before moving from the original workplace, and each will respond to the same set of questions in a repeat survey six months after settling into new quarters. In addition, half of

**Here are sample questions from the BOSTI survey**

**On lighting:**

- a) My work is difficult to see when I am working at my primary work surface.
- b) The effects of the lighting in this office are pleasant.
- c) I feel bothered by reflections or glare on *written materials* at my work space.
- d) I feel bothered by reflections or glare on *office equipment* at my work space.
- e) Shadows make it difficult to read written or printed materials at my primary work space.
- f) My work space often feels dark.

**On privacy:**

- a) I am often distracted by seeing other people when I am trying to work.
- b) I am often interrupted at my work space by people stopping to chat with me as they go by.
- c) It is very difficult to have a confidential conversation at my work space.
- (The next three questions are concerned with frequency of occurrence):
- d) How often do you close the door to avoid being observed?
- e) When you close the door to signal others your need for privacy, how often does it work?
- f) How often do you have difficulty in concentrating because of noise when the door is open?

**On status:**

- a) This whole office area and its furniture make me feel as if I could be working in any one of a hundred similar organizations.
- b) My work space accurately reflects my rank of status in this organization.
- c) There is enough room at my work space to display all the personal items I care to.

are not or are no longer the real issues at all. Thus their best efforts may lead only to the replacement of one cliché with another, newer one.

A case in point is the open-plan office, which in one permutation or other now accounts for 40 per cent of all office space. In its pure, office landscape guise, the open office was developed as a physical analog of the need for social and intellectual interaction *within the work environment*.

But is it true—and was it ever—that proximity governs interaction? The proposition comes into question as offices increasingly see the introduction (some would say invasion) of sophisticated communications technology.

Further, is it true that interaction is or should be the controlling factor in office layout? The growing backlash attributable to such side effects of open planning as loss of privacy suggests not. Or turning the question around, how serious is the lack of privacy?

real world with real people doing real jobs."

The real world of the study, however, is in fact mediated by inbuilt controls, and it is through these that the project promises to deliver the objective, normative data that it advertises.

The key control is simply the size and scope of the study population. For behavioral research, and indeed for respectable research in most fields, a sample of 250 to 300 is considered ample to assure statistical reliability. By that standard, the study sample of 10,000 is, as Brill confesses, "obscene."

In addition, the groups being surveyed are markedly diverse. They are employed in 100 government and corporate offices (read environments) across the country, in numbers ranging from fewer than a dozen to more than 1,500. Eighty of the offices and a like proportion of respondents are in the public sector, which at first glance would seem to threaten a skew in the sample. A second glance, however, reveals that monolithic gov-

the sample is being resurveyed at an interim point six weeks after the move.

In this way short-term "Hawthorne" effects (any change is for the better) can be isolated from the more lasting impacts attributable to the differing environments. For the credibility of the study lies in the fact that while workers' reports of their feelings, attitudes, and preferences concerning their jobs and physical surroundings at any given time are necessarily subjective and thus meaningful primarily in relative terms, changes in reported levels of job satisfaction and productivity over time can be quantified. When the change can in turn be linked explicitly to specific differences in specific aspects of the before and after environments, it becomes possible, as Brill notes, "to state some things with certainty."

The significance of the longitudinal study's capability of tracing the element of change over time is heightened by the nature of the environmental changes being experi-

enced by the workers surveyed. The study examines the office workplace in minute detail, from adjustability of chair height to number of file drawers. But it does so in a context that will also illuminate more fundamental issues in office planning, notably the relative merits and demerits of basic spatial configurations and the validity of the design premises from which they derive.

#### Under comparative study are all four of the typical office schemes

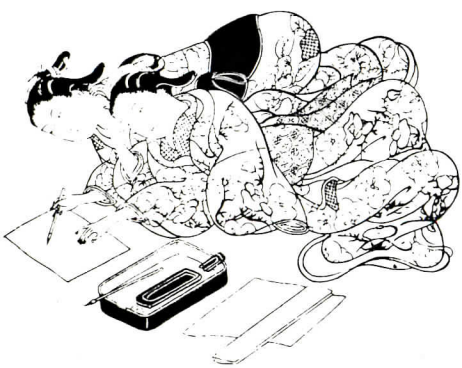
The office types being studied are open pool offices with no partitions between work stations (bullpen), open offices with freestanding partitions and conventional furniture (open), open offices with integrated enclosure and furnishings (systems), and traditional fully enclosed offices (private).

Predictably, by far the largest number of workers—8,000, or 80 per cent—are making the transition from conventional office quarters to one or another variant of the open plan, or to or from a mix of open and conventional offices. However, the remainder of the sample, in numbers large enough according to Brill to serve as valid entities for control and comparison, are moving instead from one form of open plan to another, from conventional office to conventional office, and even from open office to a more traditional plan.

Although such subtleties of contour add substance, it is the sheer scale of the BOSTI study that gives it weight—and that necessitates conducting the greater part of the investigation at one remove. In addition to "the large number of people surveyed," a BOSTI handout cites among the guarantors that the study will yield hard information "the in-depth and wide-ranging questionnaire, the objective measures used for cross-validation, and the tightness of the study design."

First among these equals, however, is the pre- and post-move questionnaire that provides the basic raw materials of the study, eliciting from the respondents not only their attitudes toward the work environment but the principal body of factual description of themselves, their jobs, their organizations, and their physical surroundings.

Accordingly, the 56-page document was the object of meticulous attention from the BOSTI team, including extensive and costly pretesting and ongoing tuning, to assure clean, unambiguous input for computer coding and analysis. Terms that might be value-tinged or subject to misinterpretation are



purged, office and desk yielding to workspace and work surface. Terms for the four types of workspace whose comparison is a central element of the study never appear in the questionnaire. The spaces themselves, though, emerge clearly through individual reports of such observable aspects of the workspace as the degree of enclosure in plan and elevation. "They won't make a mistake telling us what's there," Brill notes. "We can decide what it is."

For a few items, corroboration is requested through a separate supervisor's questionnaire, the most important instance being productivity. Workers' evaluations of their own job performance are determined by self-ranking on a ten-point scale from "absolutely unacceptable" to "absolutely ideal," covering nine qualities ranging from meeting deadlines to getting along with others. These are checked against their supervisors' ratings of the same characteristics and, where applicable, through objective mea-

confidentiality, visual privacy and lines of sight, distances between people, walking distances, and other factors, with emphasis on the conditions that appear most critical in sustaining the delicate tension between the need for privacy and the countervailing desire for interaction.

Because the survey yields both objective and subjective indicators in a number of areas, concrete data on objective phenomena that are subjectively responded to can help sort out apparent contradictions and can define the physical ranges and the cutoff points separating good from acceptable from dismal.

"If someone says his work is difficult to see but the effects of the office lighting are pleasant and he's almost never bothered by reflections or glare on his work surface [all questionnaire items], you want some hard physical evidence of what the lighting conditions really are for that individual. What's he got—candlelight?" Brill wants to know.



asures of output such as keystrokes per day or letters sent.

For the most part, though, checks on the questionnaire data are internal, with inconsistencies of response ferreted out obliquely by key issues posed in varying forms and in several contexts. The questionnaire's relaxed but orderly progression from topic to topic masks, albeit in a manner instantly transparent to the computer, a tightly structured hierarchy of issues moving in sequence from those directly affecting the individual (both space-related and job-related) to the interpersonal to the group to the organization. The data keyed in the more than 50 categories subsumed by this hierarchy form the basis of computer sorting and matching to pinpoint correlations among them.

Cross-validation by on-site physical measurements is being undertaken in only twenty offices but "that's enough," Brill asserts.

Readings are being taken of lighting quality and quantity, ambient noise and speech

According to Brill, less formal physical observations are also being made as appropriate, including photos of personal spaces, and "a fair number" of interviews are being conducted to elucidate findings that appear to be anomalous—partly to check for glitches in the research instruments, and partly because "we're after the why as well as the what."

In a talk presented to an industry group as the survey got underway, Brill outlined the BOSTI office environment study under the title "The Office Environment Really Does Matter" and summed up: "By using a before-and-after survey, we are able to see changes in productivity and job satisfaction and to know what characteristics of the environment, the equipment or the job caused them and to what degree. We will be able to sort out these effects for many different qualities, including job types; use of communications devices; age, sex, tenure and other demographic data; level in the organization;

levels of privacy and interaction; specific qualities or components, space, configurations of the physical environment; size of work group; open versus closed versus mixed offices; and types of systems furniture."

In brief, a yes to the title's implied question whether office environment matters, and a sweeping promise. Is it being fulfilled?

**The survey is now in process—  
but some preliminary results are in**

The survey proper stands roughly at midpoint of the projected timetable, with "only a few thousand" returns in hand, and the process of analyzing and evaluating the masses of raw information has progressed little beyond simple tallying. "We're looking at a good ten years of work here," Brill predicts without noticeable dismay.

Tentative first sorts have, however, been made which match data sets falling under the category "individual" in the pro-

will be brought to bear on the task of pinning down the whats and whys of data from the full sample. Thus the early returns are suggestive only. But suggestive they are.

They contain, for example, strong hints that a number of cherished assumptions about office planning—from so apparently innocuous a concern as color selection to a core concept as fundamental as flexibility—may prove open to challenge.

On the other hand, the gauntlet should not be flung just yet. For there are also strong hints that even seemingly definitive findings regarding the physical environment may prove inconclusive, if not deceptive, unless tempered by mediating insights into the individual and his psychosocial surround. Few of the findings so far emergent from the office study fail to evoke an answering why—and that query, in turn, leads to who and where.

To the broad question what impacts of the physical environment are brawny enough to be reflected in job satisfaction, the answers

however, uncertainties of interpretation become more pronounced.

Matched against the full laundry list of environmental desiderata, the four office types under scrutiny—bullpen, open, systems, and private—fare much as expected. That is, by every measure bullpen and open offices are held in low esteem, the progression moving upward through systems to private.

It does not progress very far, however, as more than half the workers so far surveyed register general unhappiness with their work spaces—a disgruntlement quotient that is much higher than has emerged in previous studies and may simply suggest that this early sample represents a disproportionate number of people who are quartered in the least favored types of space.

Another mild surprise is that, contrary to the conventional wisdom, systems and private offices run almost neck-and-neck in terms of over-all satisfaction, and systems offices pull ahead when the measure is esthetics, or visual quality. Why? Brill speculates that it may be because in this sample systems offices are generally the newest.

Even in measures relating to privacy, there are ambiguities inviting speculation. Two things are clear: Everyone wants more privacy, and private offices offer the most. Yet when asked directly "If you could decide, how many people would work in the same room as you do?" two-thirds would choose not to work alone. Perhaps this reflects the importance of easy interaction. And perhaps it suggests the respondents know something office planners don't.

For while all standards by which the degree of privacy is assessed are best met by private offices, the best is not very good. More than one-third of the people now occupying private offices, for example, say they cannot conduct a confidential conversation there. Again, one-third report inability to control access to their work space. "That's astounding," says Brill. "Don't they have doors? Can't they close them?" And even by the criterion of freedom from visual distraction, private offices reportedly have only the slimmest of edges over systems offices. Such responses beg a closer look not only at the individual office but at the over-all office layout and at prevailing group norms governing interaction within it.

**Some questions about flexibility  
are raised in the early returns**

Brill considers highly significant the findings that relate to "the whole issue of flexibility, the need and capacity for relocating people and tasks." The light shed—or shadow cast, depending on point of view—is the discovery, hinted at in earlier studies for BOSTI clients and now being confirmed, that three-quarters of office workers never move from one space to another unless the whole organization moves. But the remaining quarter moves—"this means a physical space is knocked down and put up again"—as often as four times a year. Who these highly peripatetic people are, doing what jobs at what

gram hierarchy with one another. Taking as a baseline the data on work space size, shape, and configuration that define the four basic types of work space under study, the four have been weighed in relation to the degree of satisfaction they afford with respect to other "workplace-related" elements (ambient conditions, safety and security, furniture, communications equipment and use patterns, workspace design and use patterns) and to a lesser extent with "job and worker-related issues."

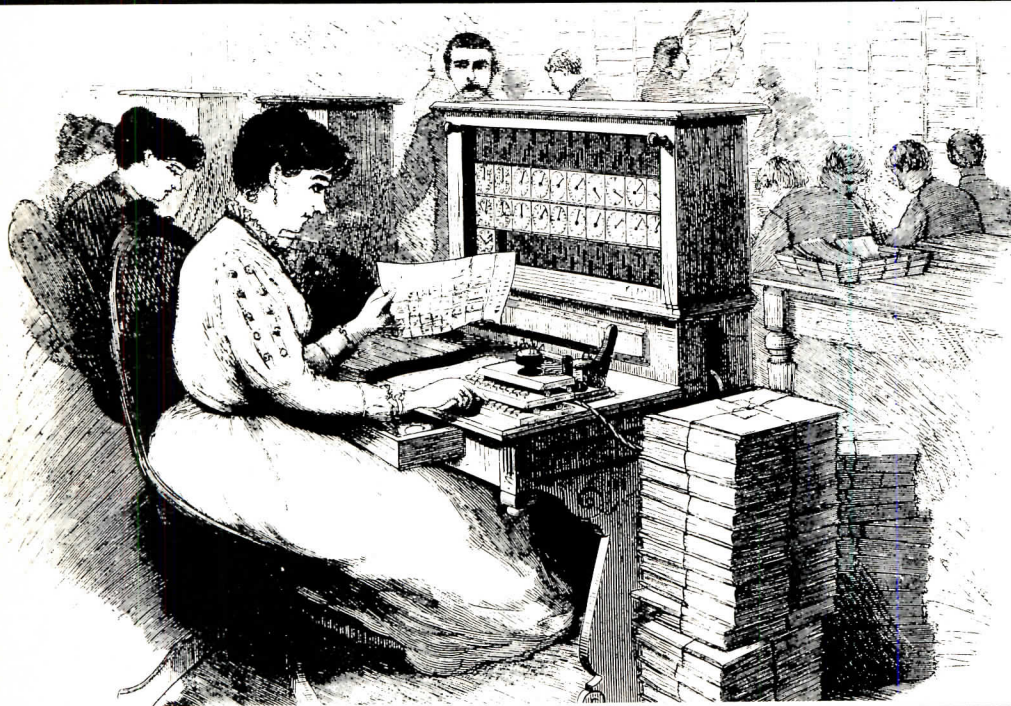
The importance of particular environmental elements to over-all environmental satisfaction has been probed, as has the relationship of environmental satisfaction to job satisfaction. And because the privacy-interaction issue is widely seen as a central one, it too has been given a quick look from several perspectives.

These are rough cuts of preliminary and incomplete information, innocent of both the precision and the comprehensiveness that

are predictable. The strong impacts are those affecting interaction and access to others and, conversely, those affecting the individual's degree of control over his own privacy. A second constellation centers on the issue of personal mastery over the environment in ways ranging from participation in design decision-making to the autonomy needed to stamp one's environment "personal," if only by adjusting chair height or venturing a philodendron.

Similarly, among the data relating specific environmental elements to a general level of environmental satisfaction, there is little to blink at unless it is how important how many things turn out to be. Although far from equal in ranking, an unexpectedly large number of physical descriptors, from over-all office layout to opportunity for personal display, yielded a contentment correlation of 0.4 or better—a connection Brill rightly describes as "extremely muscular."

As the focus of the survey narrows,





level in the organization, is obviously a question of some moment, and one that will be pursued.

For the survey is also turning up marked differences in organizational need for flexibility. Some organizations, it seems, move fewer than 20 per cent of their people in a year, some move between 20 and 40 per cent, and some shift more than 40 per cent of their workers each year. Moreover, the organizations that relocate large numbers of people also tend to move them more often, while those that move few people do so seldom.

What then of the office in which the design of everything from the structure to the power grid is predicated on an assumed need for mutability as instant and universal as can be afforded, and on the further assumption that the probability of relocation is equal for all workers?

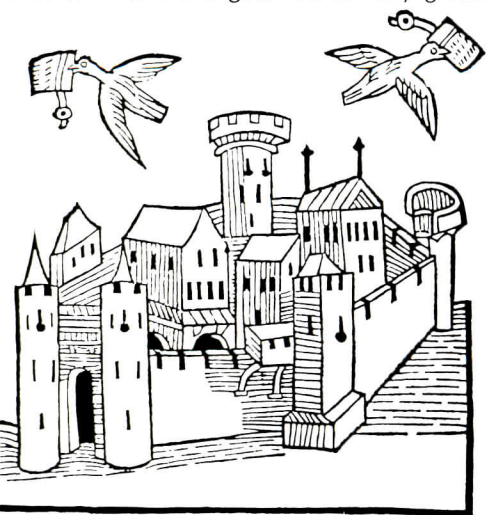
Brill believes that the ability to prediagnose organizations as "high movers" or not, and further to identify within organizations those jobs demanding a high degree of mobility, carries obvious and far-reaching design implications. "We'll find that for some organizations and some tasks the level of flexibility generally provided is far more than is really needed, and that for others it's not nearly enough."

#### Unexpected preferences symptomize the "executive suite syndrome"

Then there is what Brill calls "the executive suite syndrome," which also points to a gap, if a less serious one, between the assumptions of designers and the real needs, or in this case wants, of users. For example:

One brief section of the survey asks respondents to indicate by ranking on a five-point scale from "dislike strongly" to "like strongly" their preferences as to color and material for surfaces within their workspaces. Not, one would imagine, an inflammatory issue, but the responses were overwhelmingly one-sided. For walls or dividers, wood and fabric are acceptable: nothing else. For work surfaces, wood is favored and, down the line, wood-grained plastic laminate. Such alternatives as enameled metal and plain plastic finishes were actively disliked.

As for color, the heresy was complete, the most strongly disliked colors being intense ones such as fire engine red or kelly green



and neutrals—white, gray, beige. "When you think about it," Brill muses, "those, the neutrals and the primaries, are the colors of the Modern Movement. But what do people want? Pastels, muted colors, cool colors. And where in the office do you find those? In the executive suite, along with the woods and the fabrics."

Lest such data spark a move back to waiting-room beige and government green, Brill points out that these strong feelings when taken in combination with other preferences can suggest a more positive approach to interior design.

Most people, for example, indicated that if promoted they would like their work space to reflect their new status, preferably through more space or a privileged location. These, of course, are in short supply, particularly in open plan offices, but if other strong preferences are known perhaps trade-offs can be made by substituting one desired physical component for another. "Eventually, you might be able to change the whole definition of what constitutes a status symbol or a reward."

The theme of trade-offs based on clearly understood values and priorities pervades Brill's discussion of the office study's potential contributions and the eventual uses to which they may be put.

#### The fundamental conflict: differing values of designers, clients, and users

The result, Brill says, is an attitude of "we versus them" that often makes it difficult for both architect and client to see things from the other's perspective and so sort out those areas in which their values in fact overlap and those where agreement will be to disagree.

Accordingly, Brill believes that an underlying mission of studies like that of the office environment is to enlarge the body of objective, neutral data available, thus providing a common framework for discussion among all concerned parties that will allow a more rational delineation of values and priorities. Given reliable evidence of its impacts on productivity and the quality of working life, the environment can be properly seen as a tool that can be manipulated by planned strategies in support of known objectives. The focus of decision making can then turn to defining these objectives, making trade-offs as necessary but with a realistic understanding of human as well as dollar costs.

"Clarity about what you're doing," Brill says, "doesn't preclude making capricious decisions, but it lets you—and everyone else—know when you're making one."

At another level, the study will produce voluminous but specific design criteria that can be applied directly in the shaping of the office workplace. But it will also contribute, in the form of the survey instrument itself, a tool for the user who wants to go beyond the basic criteria to a richer understanding of a specific project.

As Brill points out, the usual programming tools available to architects—counts of how much storage space or work surface is needed, charts of who needs to talk to

whom—are silent on most aspects of the worker's psychosocial world—privacy, status, interaction. Using the survey questionnaire as a prediagnostic tool, these areas can be plumbed for a particular group and the results compared with those of the full original survey. Brill emphasizes that because of the size of the sample these will serve as standardized national norms which can be further broken down for finer comparisons by, for example, type of work or level of job or certain kinds of demographic data.

Thus, "What the designer will have is not just the capacity to take the temperature of a project and to use his readings in the design of the project but also a basis for discussing intelligently with the client what those findings mean compared with like installations."

Finally, the survey instrument should prove useful as well in post-occupancy evaluations and fine-tuning and still later in monitoring the effects of changes made in the office environment over time.

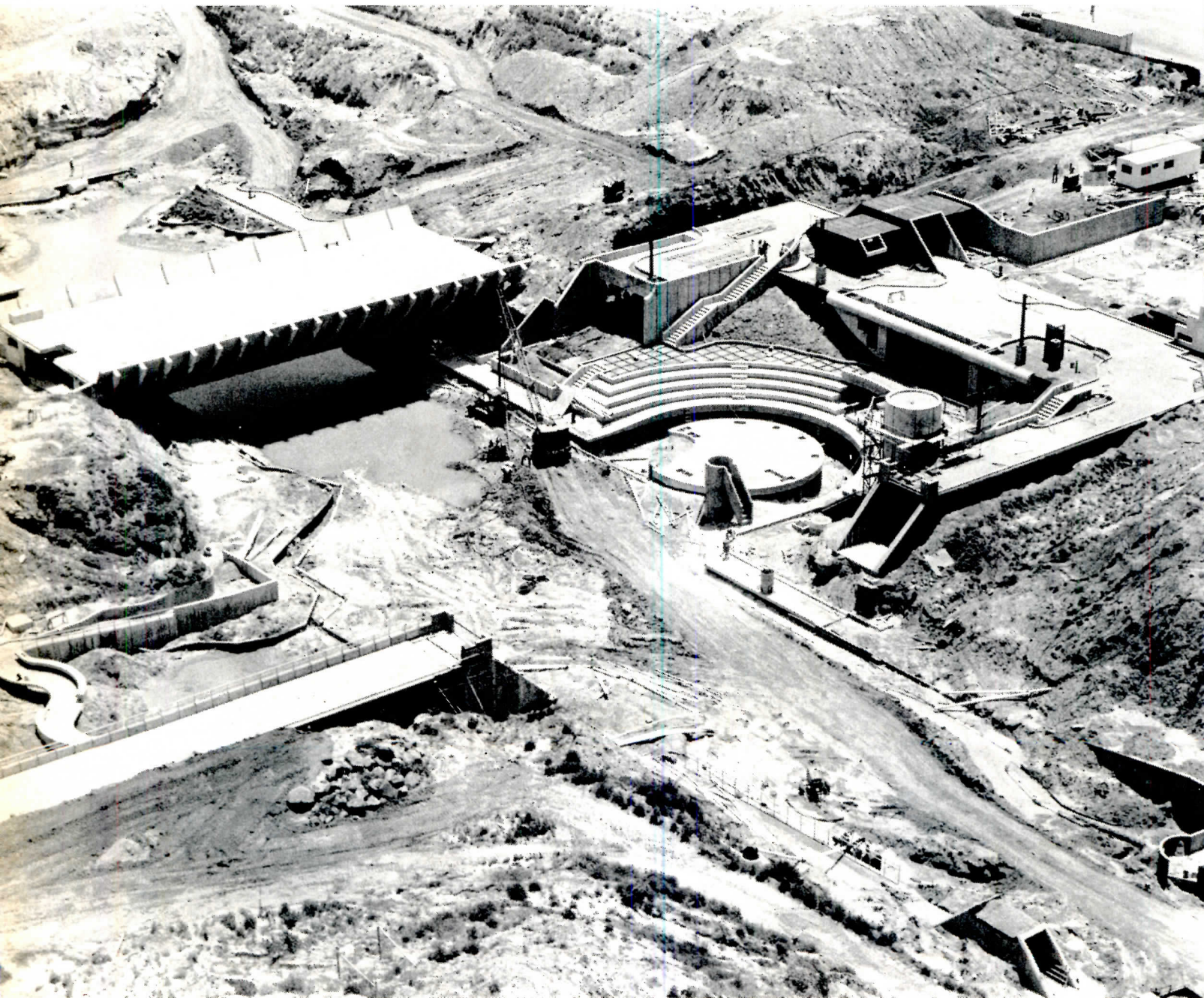
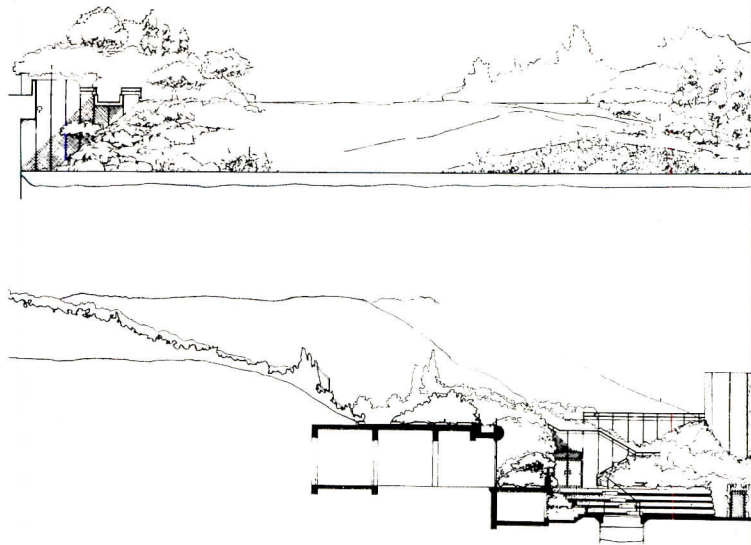


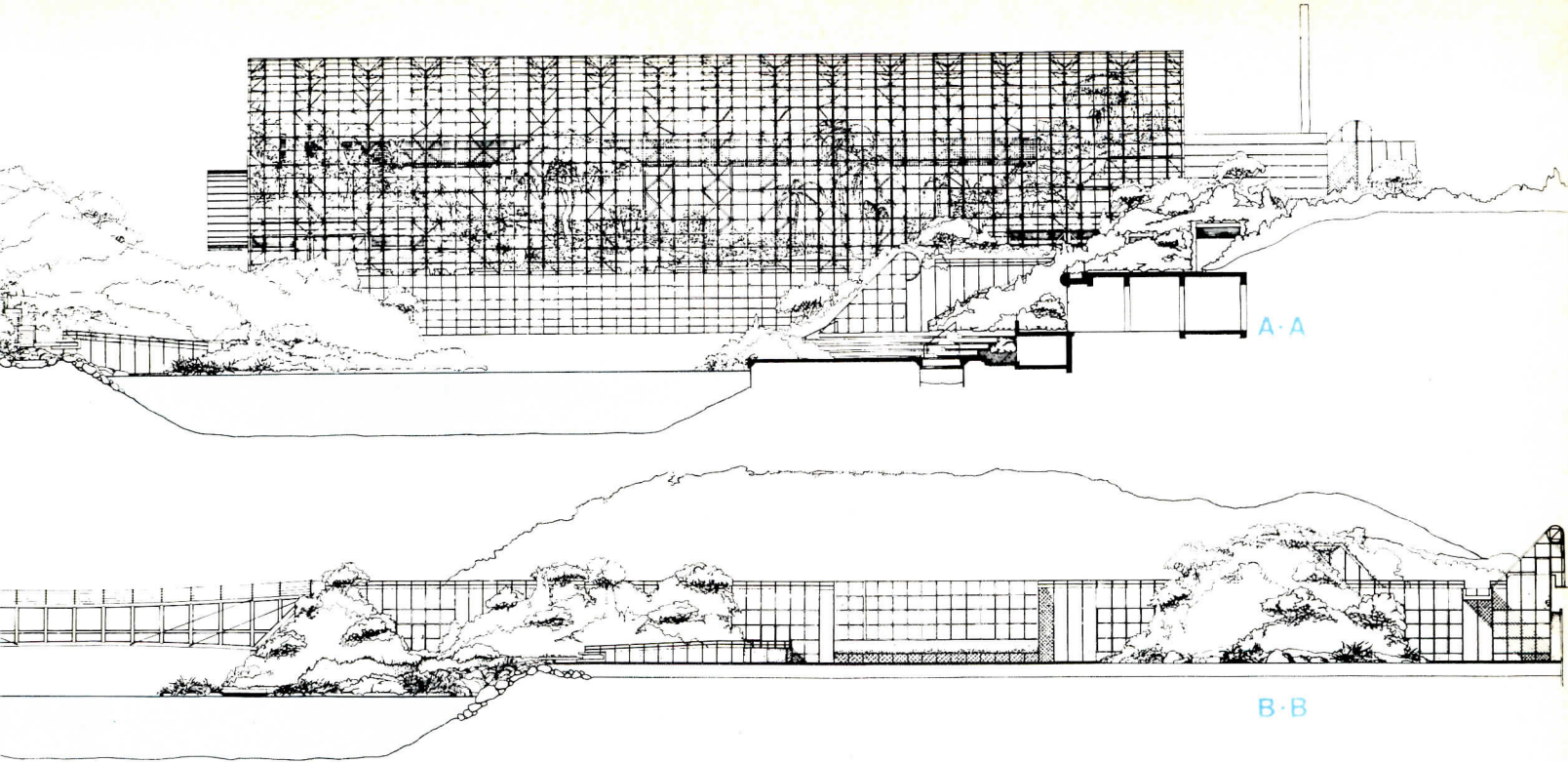
"I have a wild idea," Brill muses, "that somewhere down the road we could stop putting office interiors together piecemeal and instead take responsibility for providing a total office environment, complete with guarantees of performance—say, at least 85 per cent of the people here will experience productivity gains of at least 8 per cent over their previous levels.

"Constructors in other areas do it all the time, going to the buyer with a package that says 'Here's your new cracking plant. It will take this long to build and cost this much, and it will turn out so many barrels a day.' And they deliver.

"Architects, of course, don't have that kind of control over all facets of a project. But if we can gain crisp knowledge about some things in the environment—what they are, what they can do, how people use them—perhaps we in the business of placemaking can begin to see ourselves as more accountable for certain kinds of outcomes."

Two bridges  
at Myriad Gardens:  
a box girder  
for a conservatory,  
and a steel truss  
for pedestrians





On the edge of Oklahoma City's booming downtown renewal district, Myriad Gardens will offer greenery, water and the diverse charms of nature. According to architect William Conklin, the gardens aim to be "not a park, nor a shopping center, nor a civic center, nor a commercial entertainment center, [but will instead define] a new relationship between downtown man and the natural world."

The waterways at Myriad Gardens are more or less man-made. The long "canyon" that runs east-west taps and exposes a stream of clear water that had lain 25 ft underground. The land around has been shaped to retain the stream and allow the water to rise. The "north fork" opposite the circular water plaza and amphitheater, on the other hand, is an artificial lake that lies 6 ft higher than the canyon, into which it will feed a waterfall.

Two bridges will cross the canyon—the monumental Botanical Bridge, whose translucent housing will contain hills and trees (elevation A-A), and a smaller pedestrian bridge connected with Oklahoma City's underground pedestrian concourse (elevation B-B). The bridges will provide a pedestrian link between parking areas and the downtown core.

The concrete box girder that forms the base of the Botanical Bridge did not in fact become a bridge until after it had been cast. Preparation for construction included pumping to lower the water table and building con-

crete forms of earth. When the pour was complete and the concrete cured, burrowing beneath the span revealed the bridge in place. To run water under the bridge, someone simply had to turn off the pumps.

Above and around the box girder, hoop trusses will support a cylindrical acrylic superstructure, translucent overhead, opaque as it curves under the cantilevered edges. The conservatory housing takes visual rhythm from the regularity of 7-ft

three-chord trusses set on 14-ft centers, and the wall is further divided by framing into 3½-ft squares. The plastic sheathing comprises two acrylic skins separated by acrylic webs, all extruded as a single sheet; air trapped between the webs insulates the sheet.

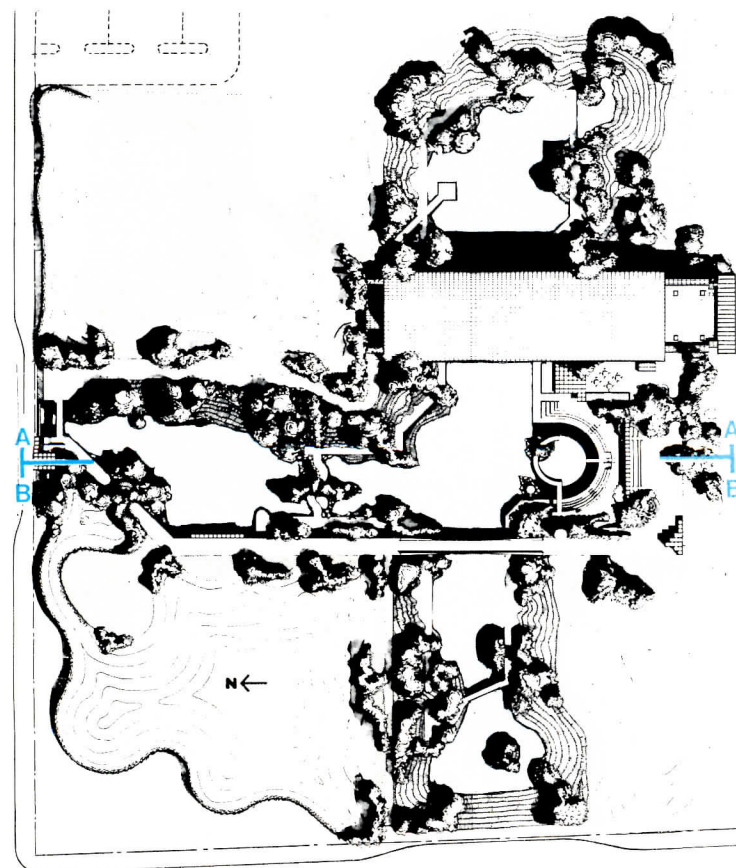
The concrete span seen in the construction photograph opposite will support only half the length of the completed Botanical Bridge, and the ends of the conservatory, as well as offices

and public spaces, will bear on caissons.

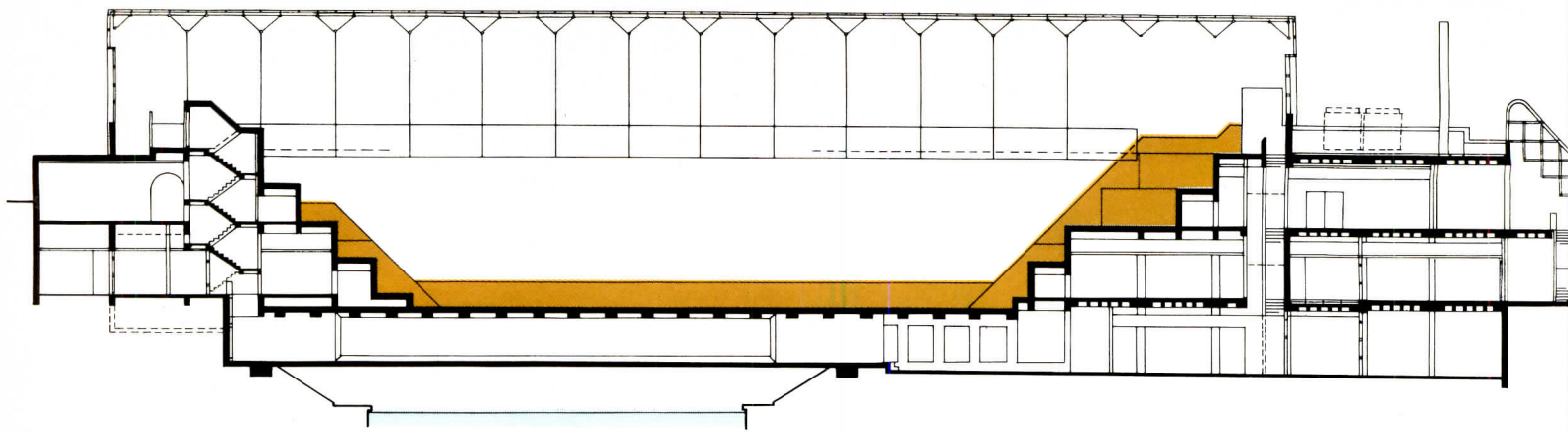
The smaller second bridge at Myriad Gardens, which architect Conklin happily describes as "curved in plan and curved in section," has two pedestrian levels supported by a steel-tube span. The lower level, enclosed on the sides and covered by the upper level, provides a weather-protected extension of the pedestrian tunnel that connects the city's major office buildings. The upper level, which is open, will provide an observation deck.

The first phase of construction at Myriad Gardens, now nearing completion, covers the concrete base of the Botanical Bridge, the pedestrian bridge, and the water plaza and amphitheater; the cylinder around the conservatory will be part of the second phase. Subsequent development of the site, as set forth in Conklin & Rossant's master plan, calls for such buildings as a convention hall and an arts center to fill in areas surrounding the water.

Concrete tunnels that run between the two bridges will house the downtown pedestrian concourse, a restaurant overlooking the water plaza, and a mechanical room for the amphitheater stage.



MYRIAD GARDENS, Oklahoma City. Owner: Myriad Gardens Authority—Dean Magee, Chairman of the Board. Architects: Conklin & Rossant. Engineers: Geiger Berger Associates (structural); Dubin-Bloome Associates (mechanical); RGDC (civil).



**The Botanical Bridge** will have a heavy concrete base—heavy enough to support soil to a depth of 4 ft, the minimum horticulturists find adequate for the growth of large trees. Structure and soil impose a greater load, at 61,000 lb per linear ft of span, than is expected for most highway bridges, the engineers point out. The post-tensioned girder extends cantilevers on both sides, and the cantilever ends turn up to form a trough. Hills

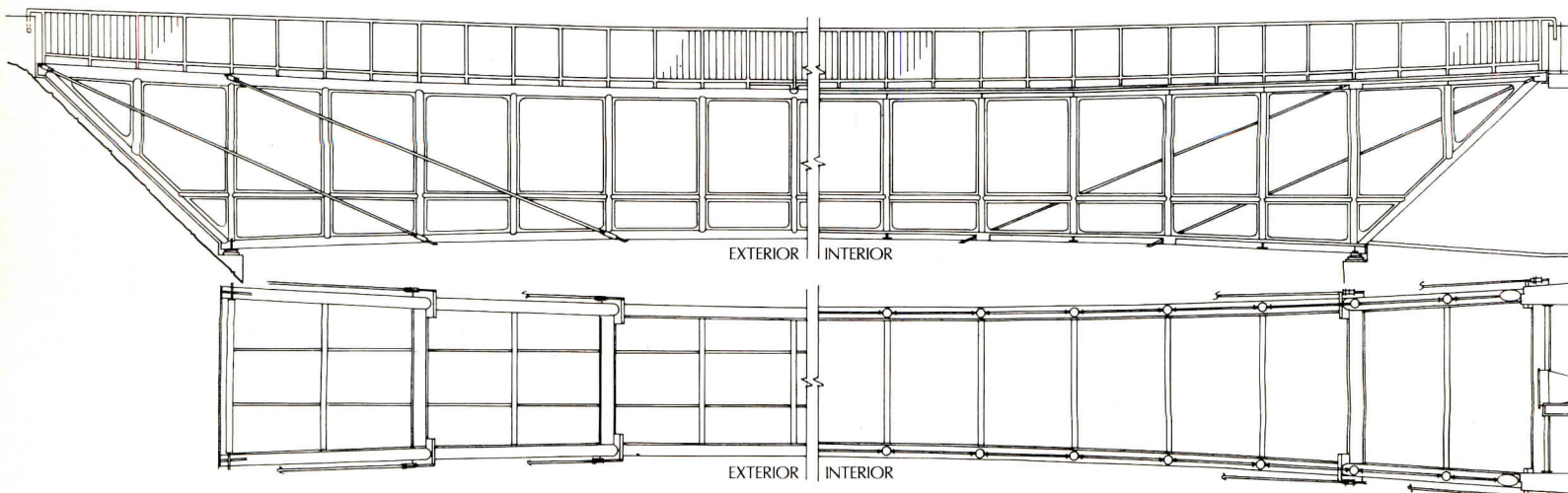
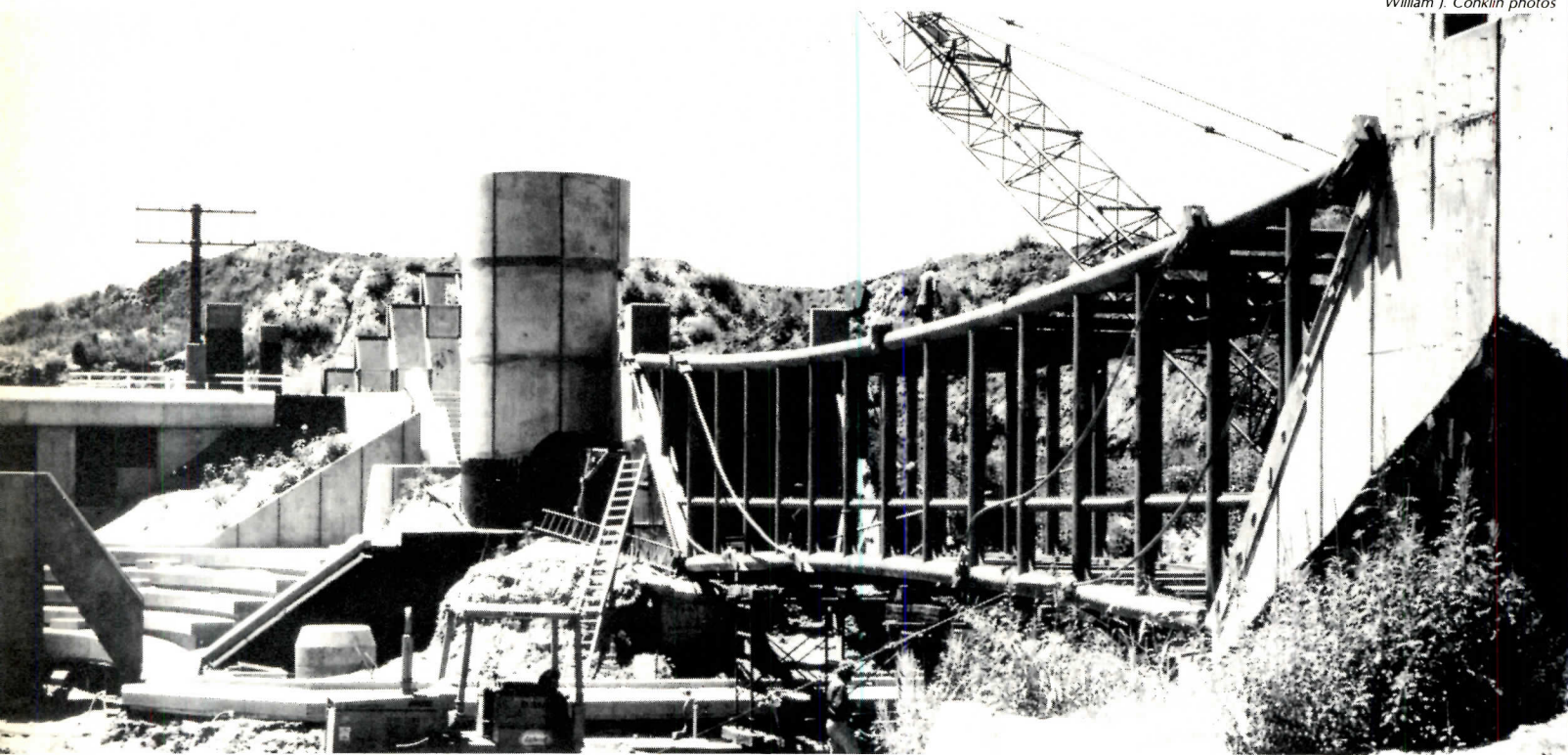
at the ends are supported by stepped concrete and foamed polystyrene block.

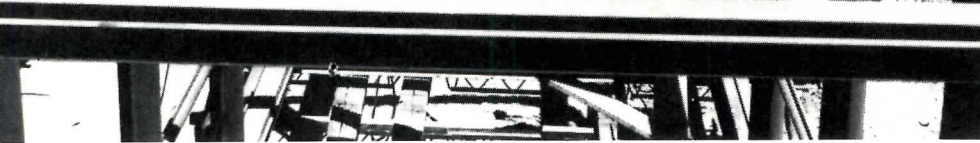
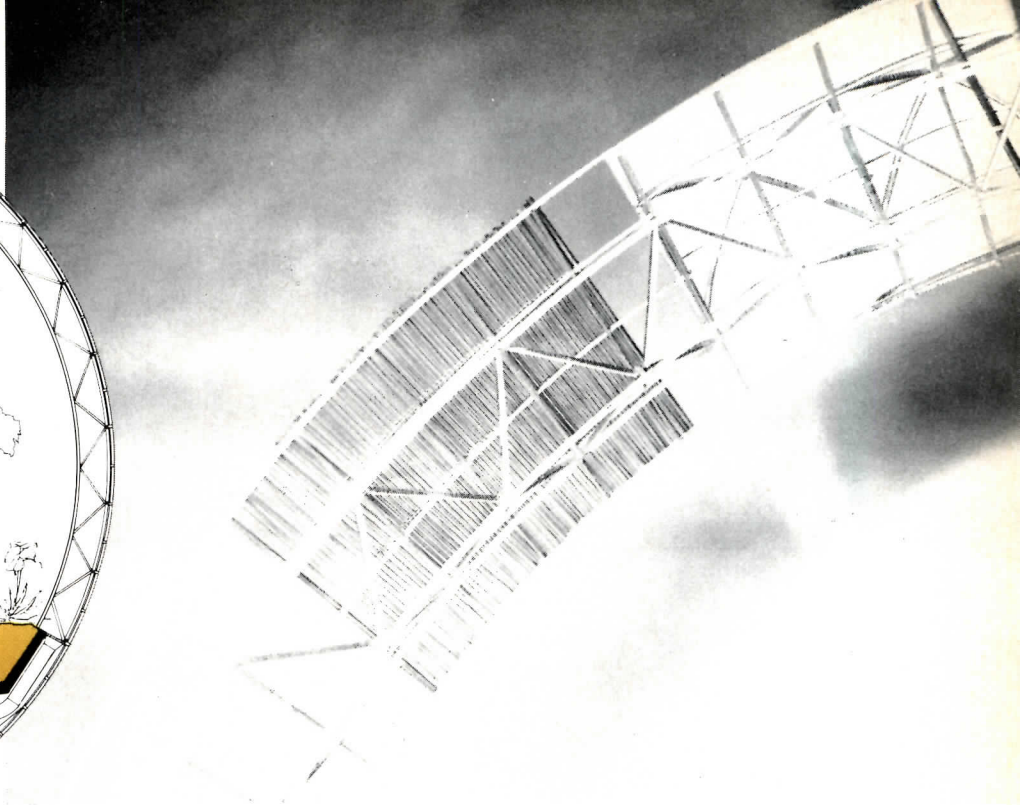
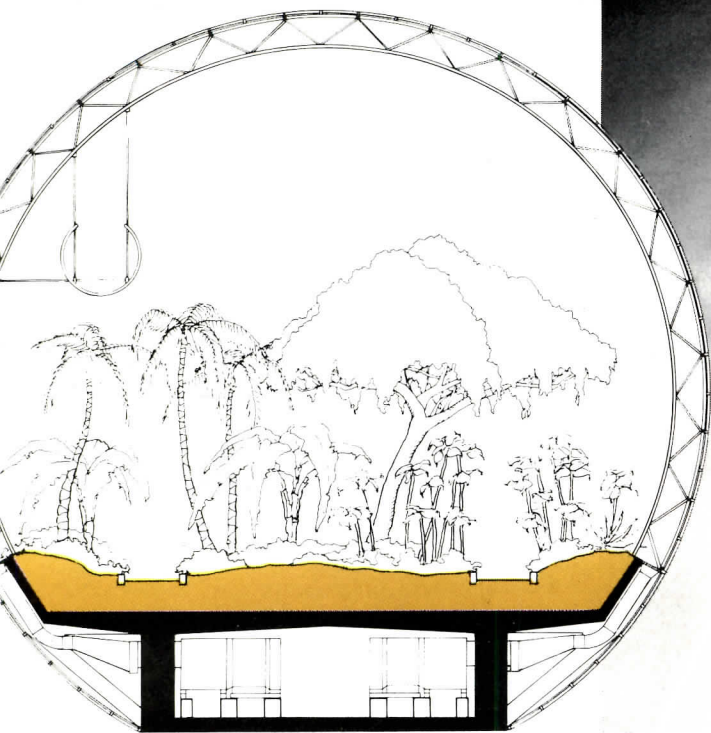
The three-chord radial trusses (far right) are set on 14-ft centers, the two upper chords spreading 7 ft. In addition to supporting the double-skinned acrylic sheathing, the trusses carry still another bridge: curved metal grating, hung from the truss by cables and tied every 14 ft, will hover at tree tops.

The choice of an evaporative cooling

system, made essentially for energy conservation, was acceptable partly because plants welcome the resultant relative humidity, partly because visitors expect conservatories to be warm (very few have any air conditioning). In any case, the interior temperature will rarely go above 85 F. Air will circulate around the circumference, issued and exhausted through alternate grilles at the bracketed ends of the cantilevers.

*William J. Conklin photos*





**The pedestrian bridge** curves identically in plan and in section. Users of the open upper level (immediate left) will descend a slope toward the center, those using the lower deck (bottom left) will ascend an opposed slope. Steel-tube webs of the Vierendeel trusses on the outside walls are set on the same 14-ft module that prevails on the Botanical Bridge. With similar members at the ceiling, they form a wasp-waisted corridor of concentric squares on the lower level.

The sides of the bridge, shipped to the site in 16 sections, were assembled partially on the ground, partially from the concrete abutments outward to the center. (Photograph below shows a welder completing the final connection between an end section and one of two center sections.) Stay cables will be tensioned only after the bridge receives all weight except glazing—i.e., decking for both levels and railings for the observation deck. Flanges on the vertical tubes will be fitted with rubber gaskets to support glazing.

To foster a visual impression of lightness, steel will be painted white and clear glass will extend the height of the corridor.



# SLEEK MODULE FOR AUTOMATED BANKING IS ENGINEERED FOR LIGHT WEIGHT AND MOBILITY



Rigid-frame modules create a "now" esthetic for inexpensive, "drop-in" shopping-center minibanks

In pursuit of the consumer as customer, New York's Citibank is installing movable, automated kiosks at shopping centers, commuter railroad stations, and perhaps one airport. Frequency of use—as many as 20,000 transactions a month at a Westchester kiosk—demonstrates the customers' appreciation of electronic banking services at such locations 24 hours a day, seven days a week.

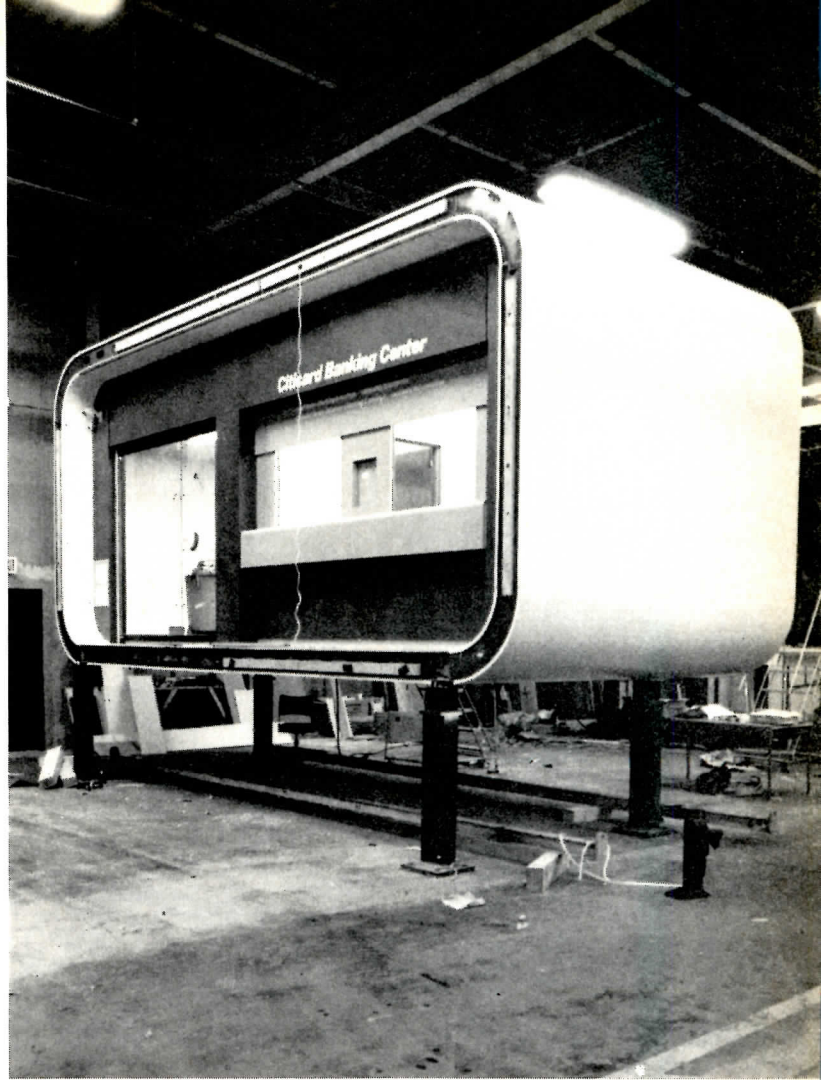
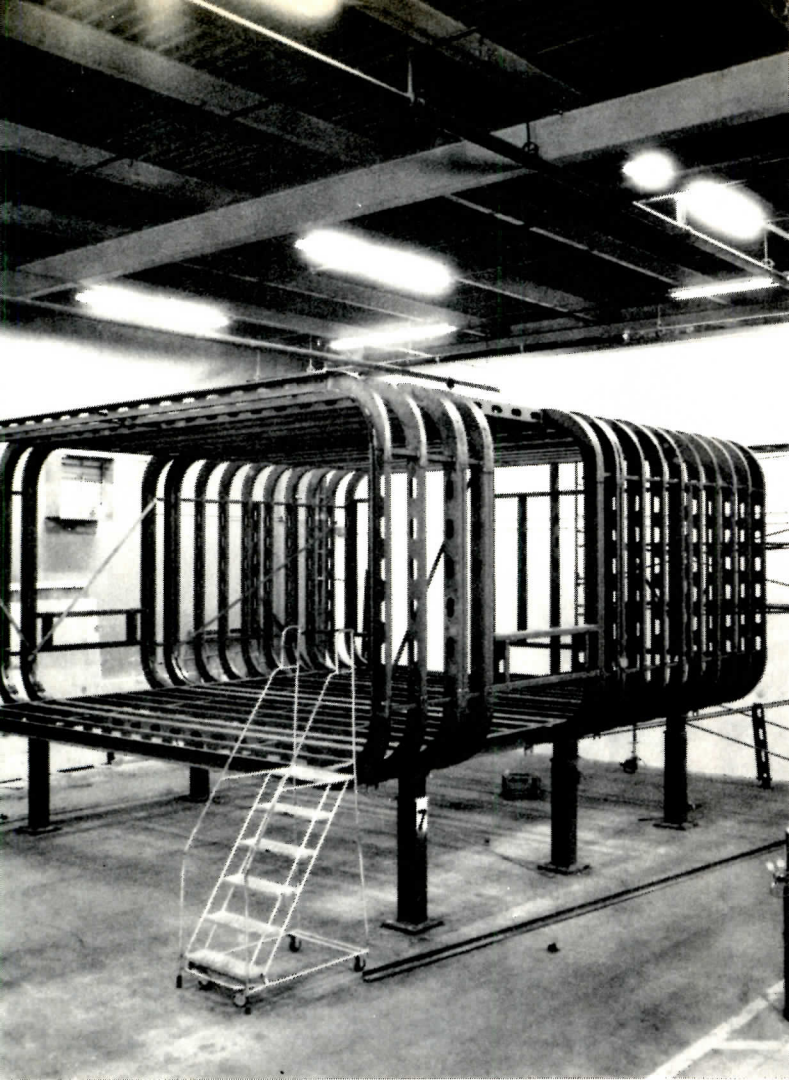
So far, Citibank has installed six of the modules—three on Long Island and three in the region that initiated the project (Bronx, Westchester, mid-Hudson); two more will be built for Queens. The region also has under study the feasibility of combining two modules for a minibranch, and three or four modules for a full-size branch. In short, the bank is replacing brick and mortar with a technology responsive to the criteria set for the project.

Joseph R. DiPaolo, assistant vice president for facilities management, who conceived the banking kiosk project, specified these criteria: 1) the module must be both transportable and relocatable, 2) its cost must be reasonable, 3) it must have a modern appearance, depicting a "now" system to create a positive image for the bank, and 4) it must be easy and inexpensive to maintain.

From the start, DiPaolo says, he wanted a "fuselage-type look" for the module, and it is clear this spirit was carried out by designer Lloyd J. Landow of Landow and Landow Architects. Commenting on the design, the

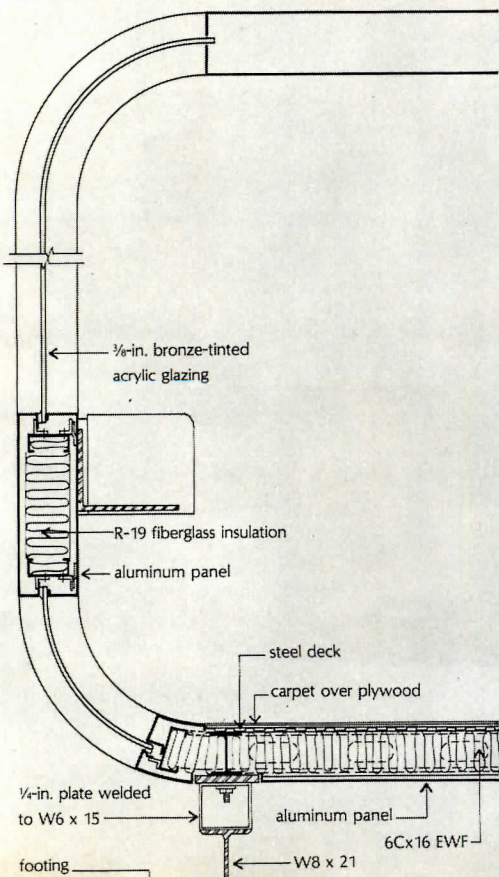
jury for the 1979 American Institute of Steel Construction Awards of Excellence said, "Very handsome and carefully detailed. The design is inherent to the system . . . looks like prefabrication has finally come of age . . . good thinking for the '80s." DiPaolo is quick to credit input from his team for such accolades. The team, in addition to the architect, includes: structural engineers DeSimone & Chaplin Associates, the contractor, Nathan Saffan of Comstruct Associates, and, for expeditious rigging and trucking, Mariano Brothers.

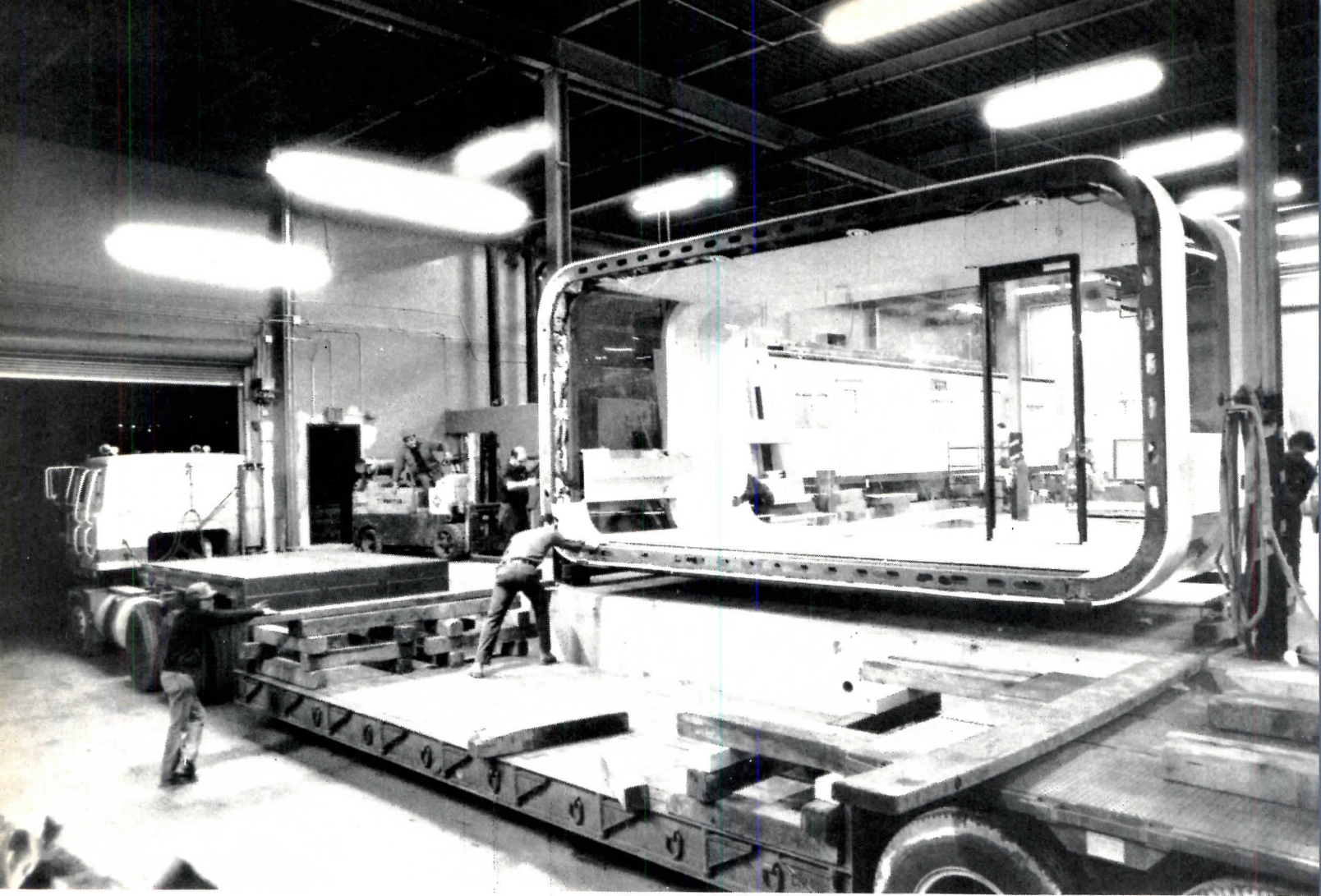
Engineers Vincent DeSimone and James Chaplin developed the cage system of cold-formed punched steel sections that work as rigid frames, decreasing the effective span from 22 to about 16 ft, permitting the use of only 6-in. 16-gauge members for the floor. Corners of the hoops are welded to provide fully-developed connections. They also developed the bridging and diagonal-bracing detailing to give rigidity in the longitudinal direction. Nathan Saffan worked with DiPaolo to improve panel design and fastening details. Originally porcelain enamel on steel, the panels were changed to 1/8-in. aluminum coated with a white fluorocarbon finish.



The structural cage is a series of 17 lightweight steel hoops fabricated from punched C-sections (6-in. 16-ga.). Corners are channel sections of welded steel plates. Construction sequence: 1) I-beams are set atop pedestals, 2) floor members are welded to I-beams, 3) bottom corners are welded to the I-beams, 4) the top of the hoop is attached by welding to bottom corners, 5) bridging is installed, 6) panels are attached to hoops with clips.

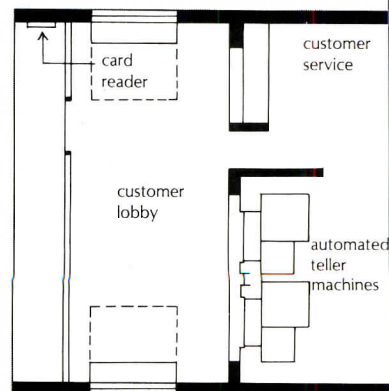
The module was designed as two 11-ft-deep sections for transportation. It was assembled as one unit in the factory, unbolted, taken apart, and loaded onto the truck's flatbed. Front and rear sections are below and above.





▼ In the factory the sections are demounted by forklift and moved on a platform to the flatbed. This module was transported 60 miles from the factory to a shopping center at Bellmore, Long Island.

▲ The modules are fully finished in the factory, inside and out, including glazing. The curved side glazing panels are 3/8-in. bronze-tinted acrylic plastic. The front glazing is 1/2-in. butt-glazed tempered glass. The door is full-height tempered glass. The unit is shipped with built-in counters and a 4-ton air-conditioner which is located above the customer service area.

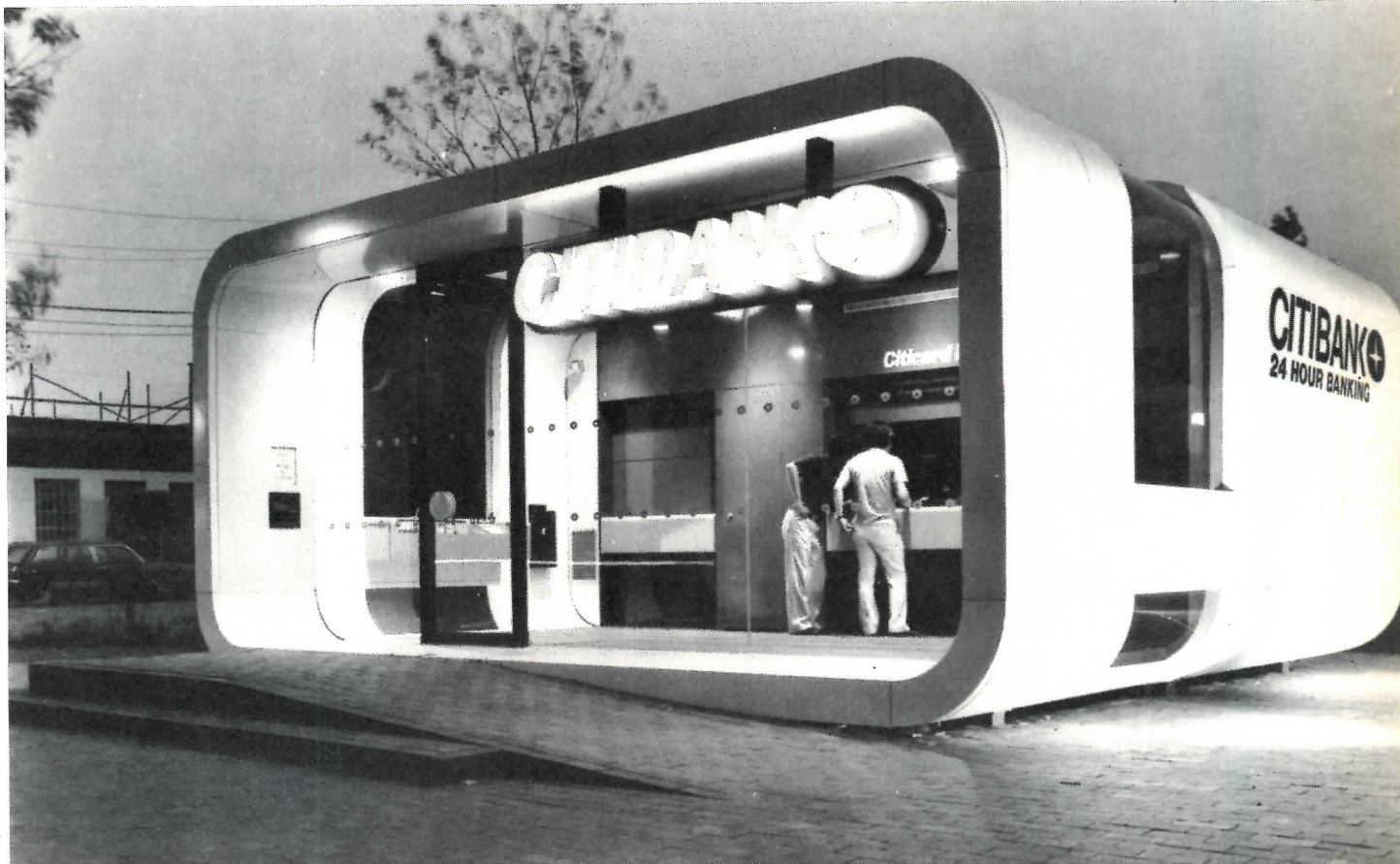


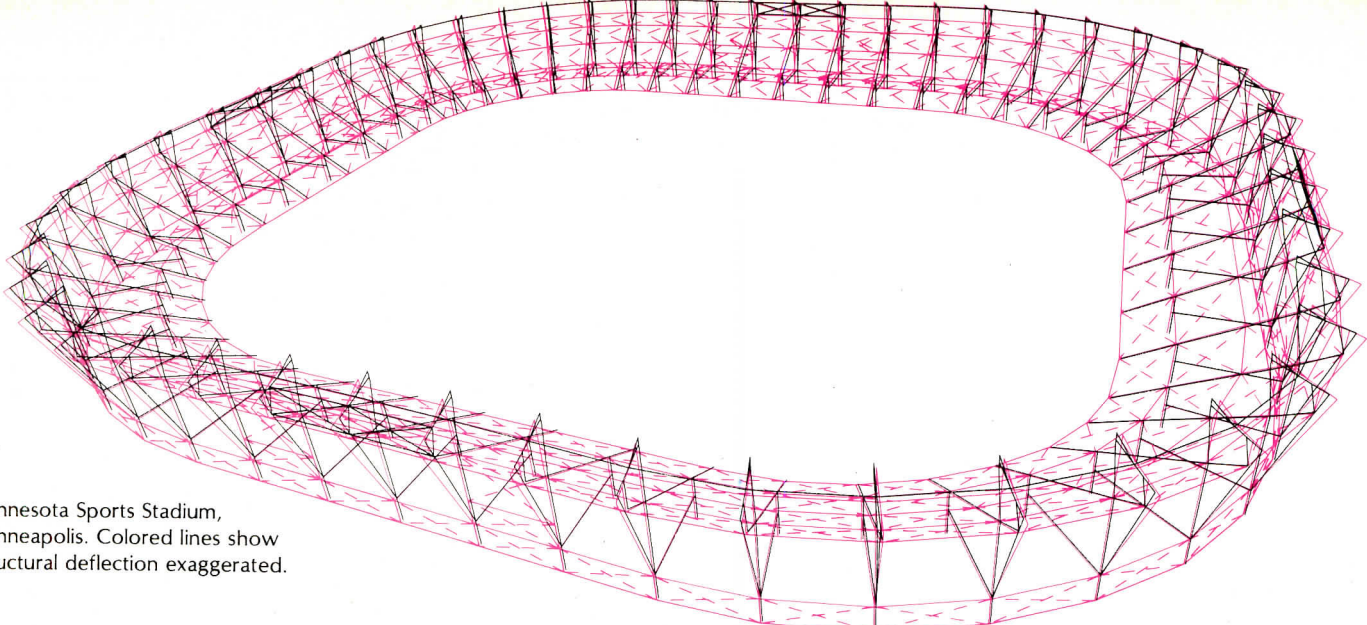




▲ Only minimal site preparation—i.e., footings and a curb—is required ahead of time. Once at the site, the trucker/rigger takes less than an hour to hoist units from the flatbed and deposit them atop the footing. The units are then bolted together. A 1-ft section left exposed for tightening bolts is later infilled and the joints sealed. All in a day's time.

▼ During the day, the kiosk is full of daylight from the front glass and from the side lights. At night it is well illuminated inside by fluorescent fixtures. For security and promotional purposes, the exterior is floodlighted with six quartz-halogen fixtures at ground level.





Minnesota Sports Stadium,  
Minneapolis. Colored lines show  
structural deflection exaggerated.

# SOM's computer approach

The Chicago office sees the computer helping with three key issues of the 1980s: 1) enhancing employee skills to deal with increasingly complex buildings, 2) keeping a competitive position by increasing productivity, and 3) developing staffing flexibility to react to changing business conditions.

Computer applications are becoming an integral part of the practice of Skidmore, Owings & Merrill in Chicago. That they have been successful in this, says computer group head Douglas F. Stoker, stems from "being able to identify pertinent problems and constructing appropriate solutions, instead of coercing problems to conform with available solutions." The systems do not require computer people to run them, but can be used by architects working as architects.

As long ago as 1963, the firm installed an IBM 1620 in the Chicago office to assist in engineering design. Since then, the office has tripled in size to 875 employees, and now has extensive computer hardware comprising three computers, two plotters, and over 70 terminals. The computers are a pair of Digital Equipment Corporation PDP 11/70 computers and a brand new VAX 11/780 also made by Digital. This one is a "virtual" computer that "thinks" it has a million times more memory capacity—which means it can accept an input overload and defer decision-making until the capacity is available.

The firm's approach in utilizing the computers is oriented toward the design professional, with applications responding to the needs of the 14 design studios and the four different disciplines of engineers comprising the firm. SOM started the design studio concept in 1972, when the firm had 300-400 people, as a means of solving an organizational, and "identity" problem. Each studio operates as an independent design office, undertaking its own projects, servicing them from start to finish. The computer group, also organized like a studio, treats design studios as if they were 14 customers.

Because the studios have at least 10 and as many as 100 professionals, and because the studios are diverse in building-type capability and interests, developing computer solutions could "get a little free form," Stoker muses. But, he says, the computer group tries to be efficient by applying the computer tools to specific problems, and solving them generically.

The SOM Chicago computer group combines training in architecture and engineering with computer programming skills, and is staffed by eight architects and engineers, three financial-oriented programmers, four operations people and one secretary. Its skills in the vocabulary of design permit close coordination between programming and design.

The key to using a computer on a project, SOM's computer group believes, is having a continuum of information to utilize for a variety of end applications. "You want to avoid," says Stoker, "the discrete event approach where you do a drawing, take it out and throw the data away. Then you do a different drawing, take it out, and throw that data away, and so on." What you want to do, he says, is to build up a complete description, the ultimate goal being "every nut and bolt in the world." The data then can be used as the basis for a perspective, a set of working drawings, or modified to assist in structural analysis, or for calculating energy loads, or simply making a quantity estimate.

"An extreme test, a tough nut to crack," is how members of the firm describe the use of computers to produce 400 plan sheets for King Abdul University in Saudi Arabia. The first phase of the project, totaling one million square feet of space, required 80 different

basic plan sheets which, multiplied by five different architectural and engineering disciplines, yielded 400 sheets the computer was involved with. About 80 per cent of the work on the plan sheets was done by computer and the remaining 20 per cent was hand-drafted on overlays. The computer drafting approach allowed the architects to easily reissue base sheets to other disciplines as changes were made.

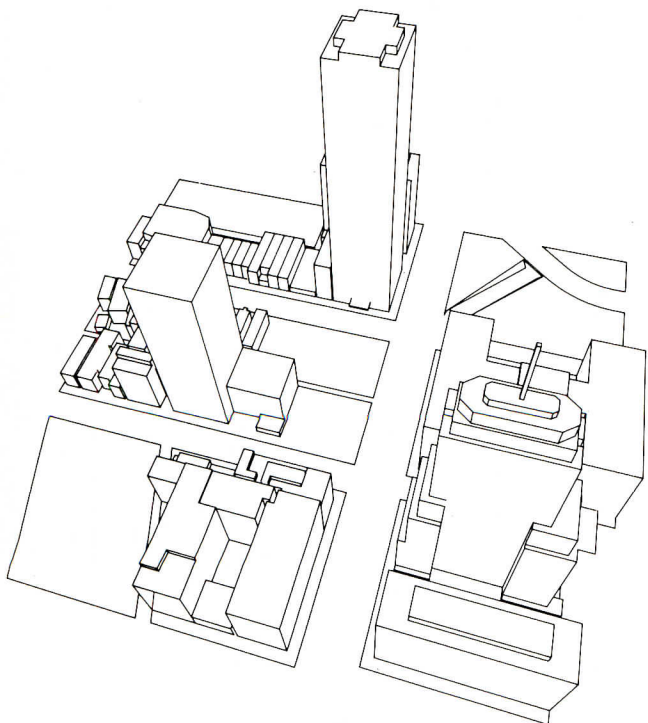
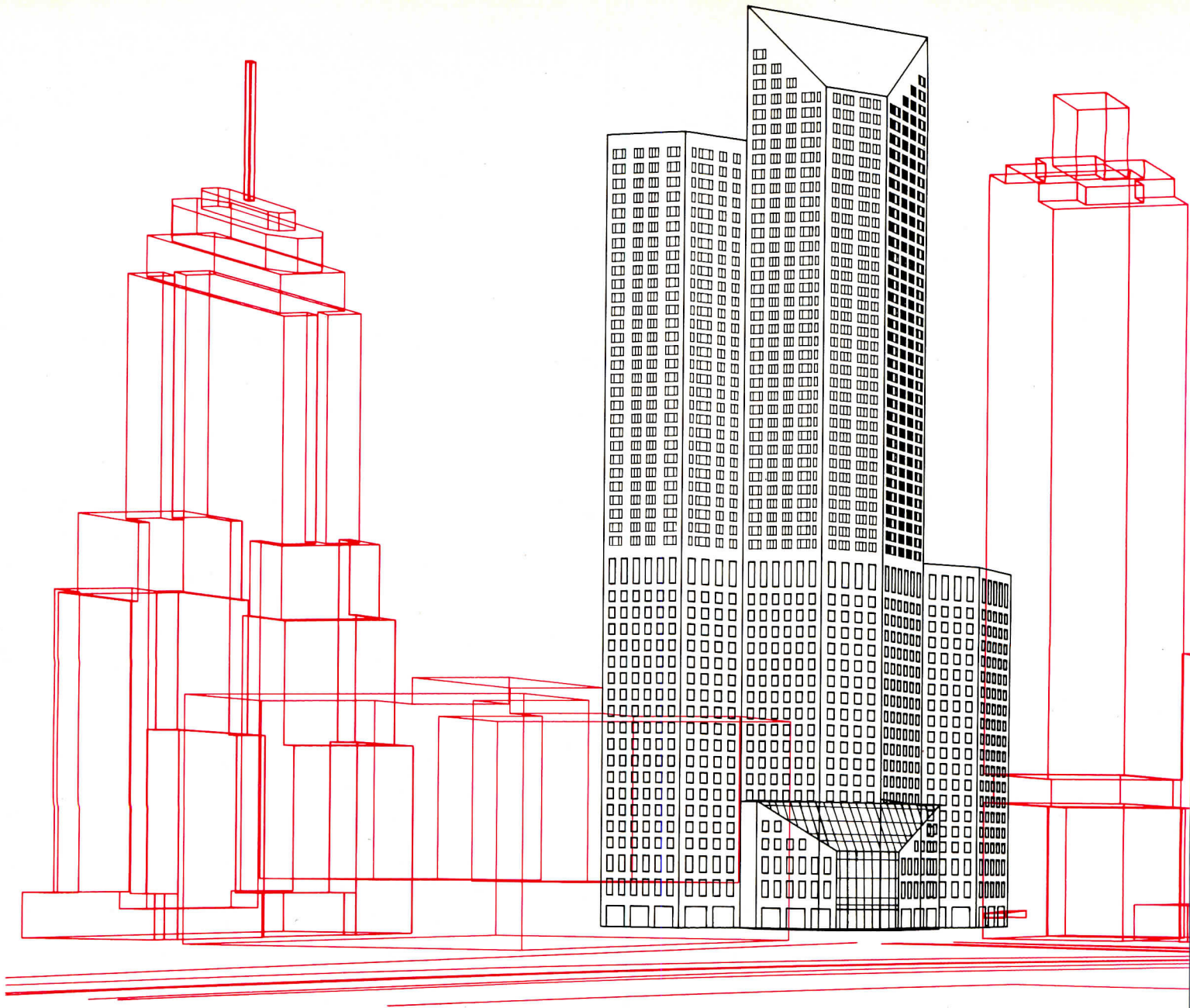
Experience with this project demonstrated that for the computer to be effective it has to be integrated into the studio so that people connected with design development and evolution of the project are involved with the actual input of information. Not only does this put them in a better position to make decisions, but they feel they are part of the process.

Beyond current applications, the use of computers at SOM is being encouraged by the firm's belief that the number of people available to do drawings is going to drop; thus the need to give really good tools—especially the computer—to those people in the drawing activity. Further, if an architect can produce twice as many drawings with the computer, he can switch more of his time to design.

"It's important at SOM to keep the systems 'friendly,'" says Stoker. We want the systems to be easy to use, not hostile . . . reasonable to deal with . . . English language back and forth . . . a friendly and warm environment. If the architect is not threatened, he's happy. The fact that the information is from the computer should be completely incidental. But we're not completely there yet because computers are still computers."

For the first phase of the King Abdul Aziz University project (1 million sq ft) near Mecca, the SOM studio assigned the project developed over 400 computer-coordinated and -drawn plan sheets. Separate disciplines were able to share data and overlay information in any desired combination. The architectural, mechanical, and structural base sheets were completely computer-generated. Common data of columns, centerlines and walls were stored in separate data "files" in the computer, and overlaid on each of the sheets when plotted. Finish schedules also were generated.



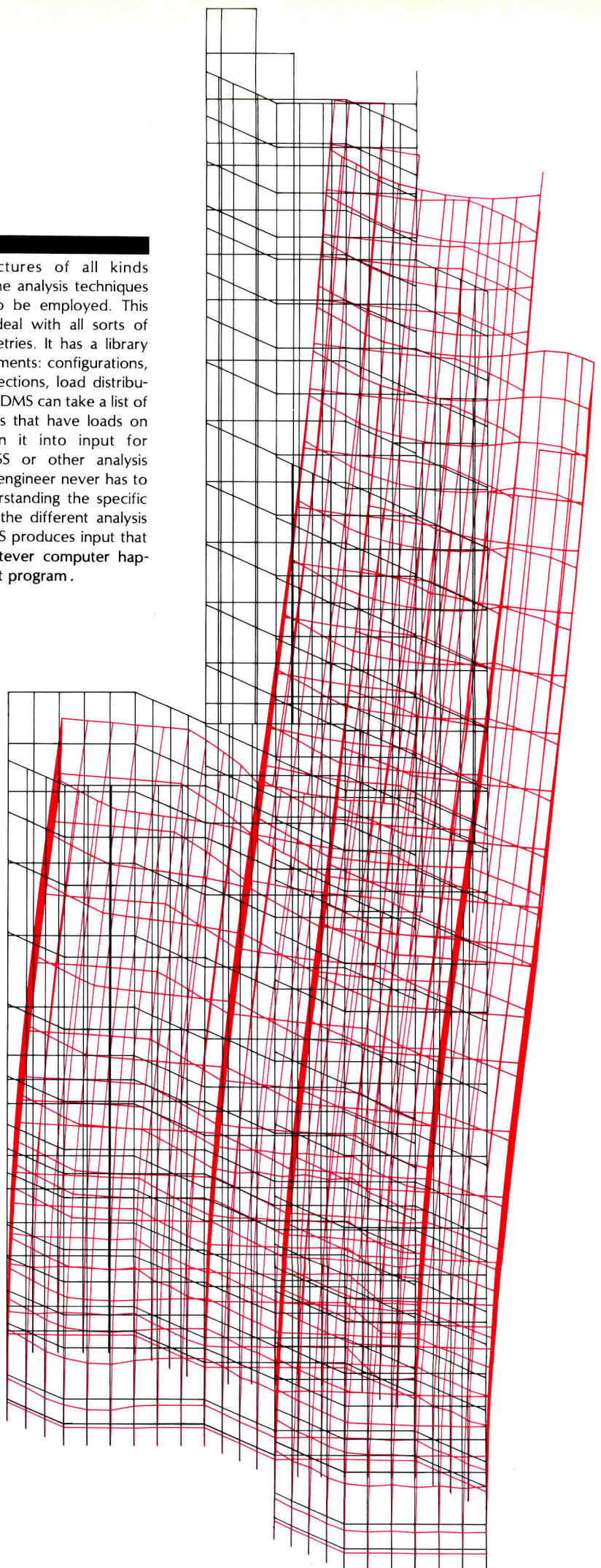
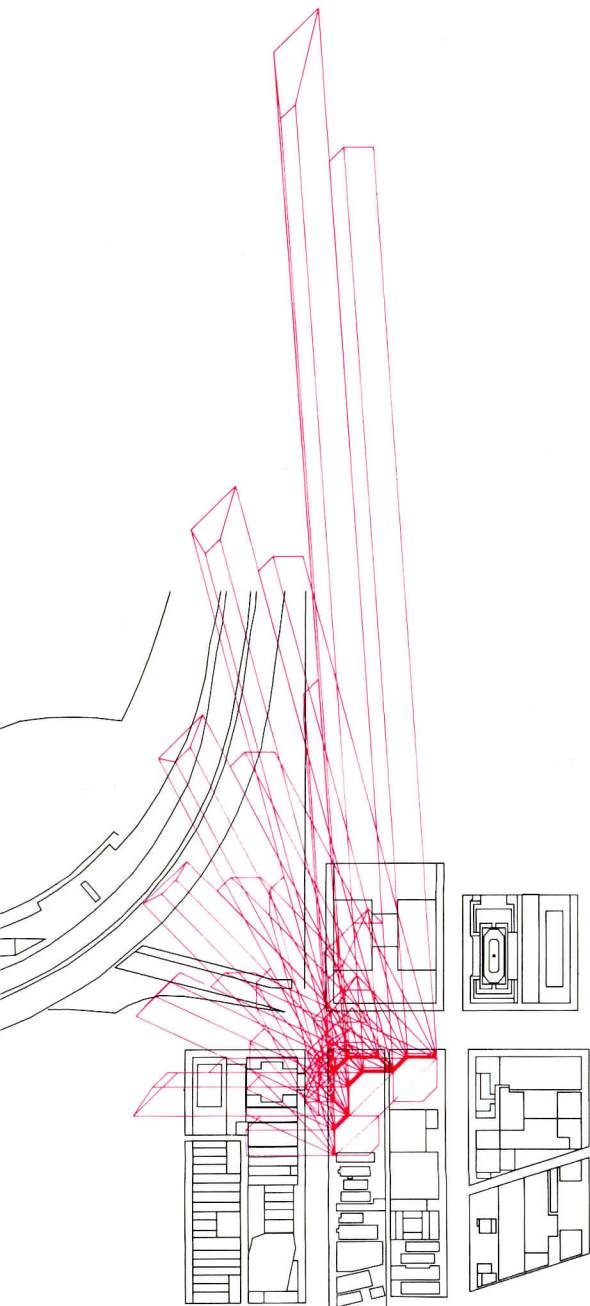


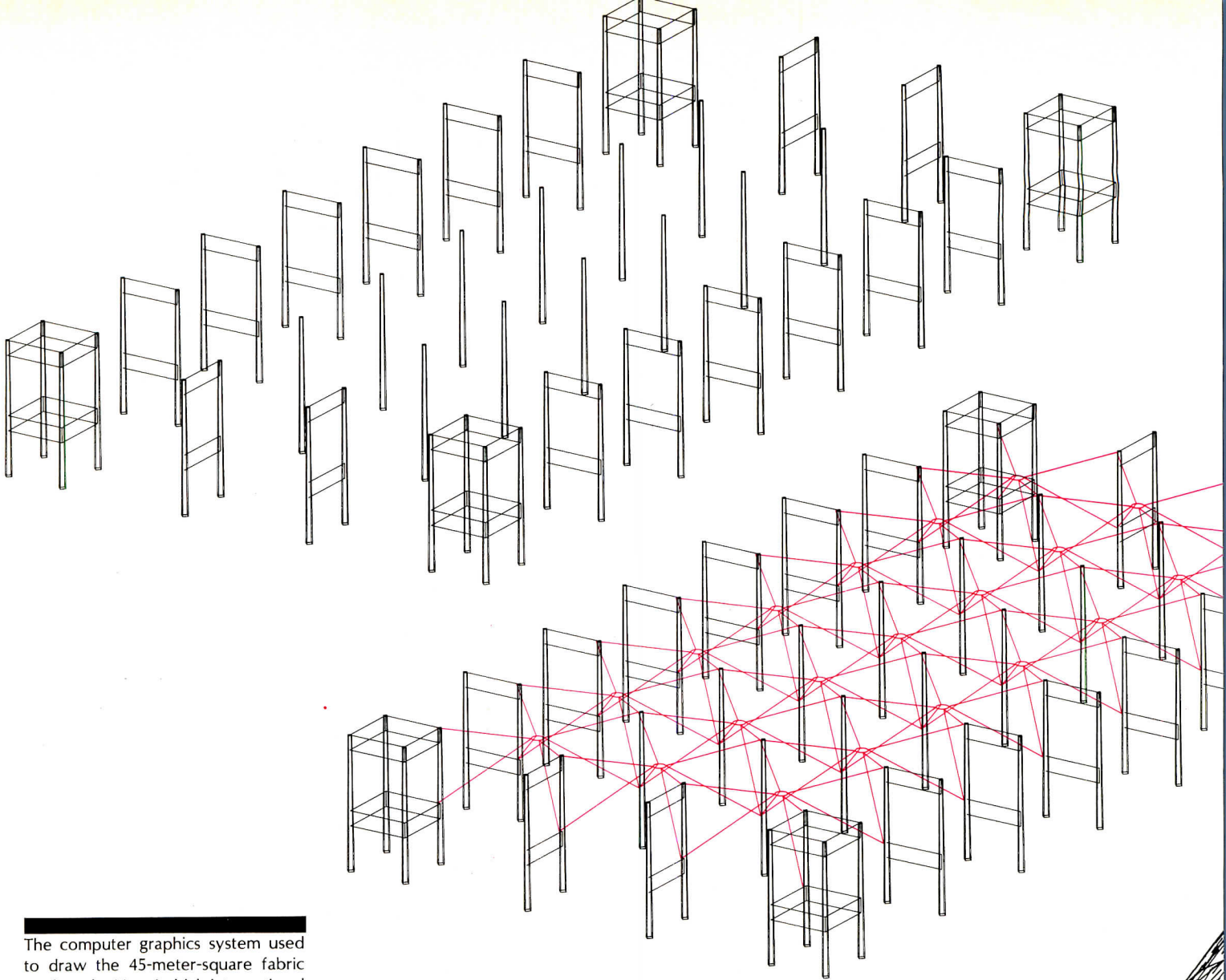
"The more you use the computer on a job [with the same data base], the cheaper and cheaper it gets," says SOM. Example: design and engineering studies for One Magnificent Mile, a 57-story multi-use tower at the head of Michigan Avenue on Chicago's near North Side. A proposed site was viewed from many angles to study the effects of building massing (left). Then the proposed form of the building was described to the computer and merged with the site description to construct pedestrian views (above). To convince the city that the building would not cast undesirable shadows on Oak Street Beach, the same data base was used but extended to include positions of the sun at various times of the day and year. A program was used that "went into the data base, looked at where the sun was, took positions of the sun, and generated shadows," (drawing across page).

One Magnificent Mile comprises three hexagonal concrete tubes bundled together for structural stability. Using the same computer graphics system as for the other studies shown here, the structural engineers were able to display the deflected shape (exaggerated) of the building under wind loading.

The drawing was created utilizing SOM's Structural Data Management System (SDMS) that was initiated 10 years ago. With the system, a data base is developed that describes the structure, its elements, and the loadings placed upon them. A standard language was developed to

describe structures of all kinds regardless of the analysis techniques or programs to be employed. This language can deal with all sorts of "goofy" geometries. It has a library of standard elements: configurations, properties of sections, load distributions, etc. The SDMS can take a list of all the members that have loads on them and turn it into input for STRUDL, STRESS or other analysis programs. The engineer never has to deal with understanding the specific formats for all the different analysis programs. SDMS produces input that is sent to whatever computer happens to run that program.

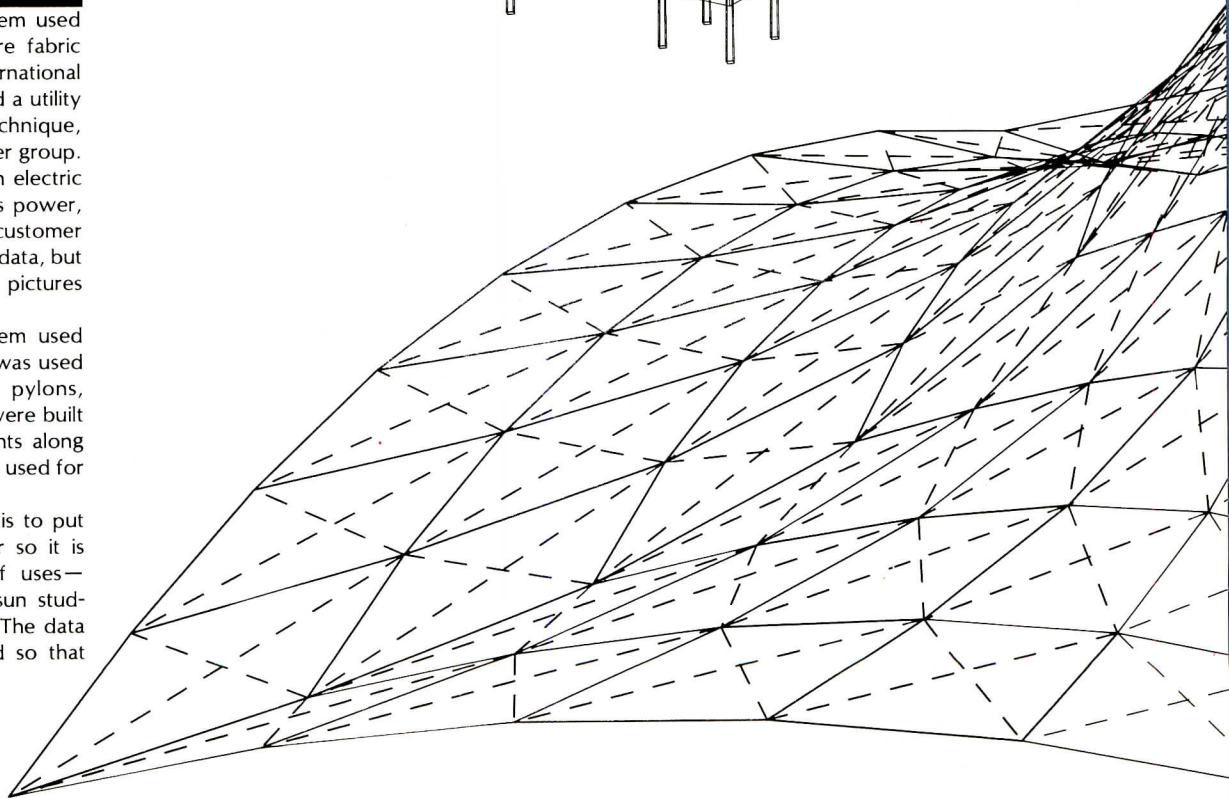


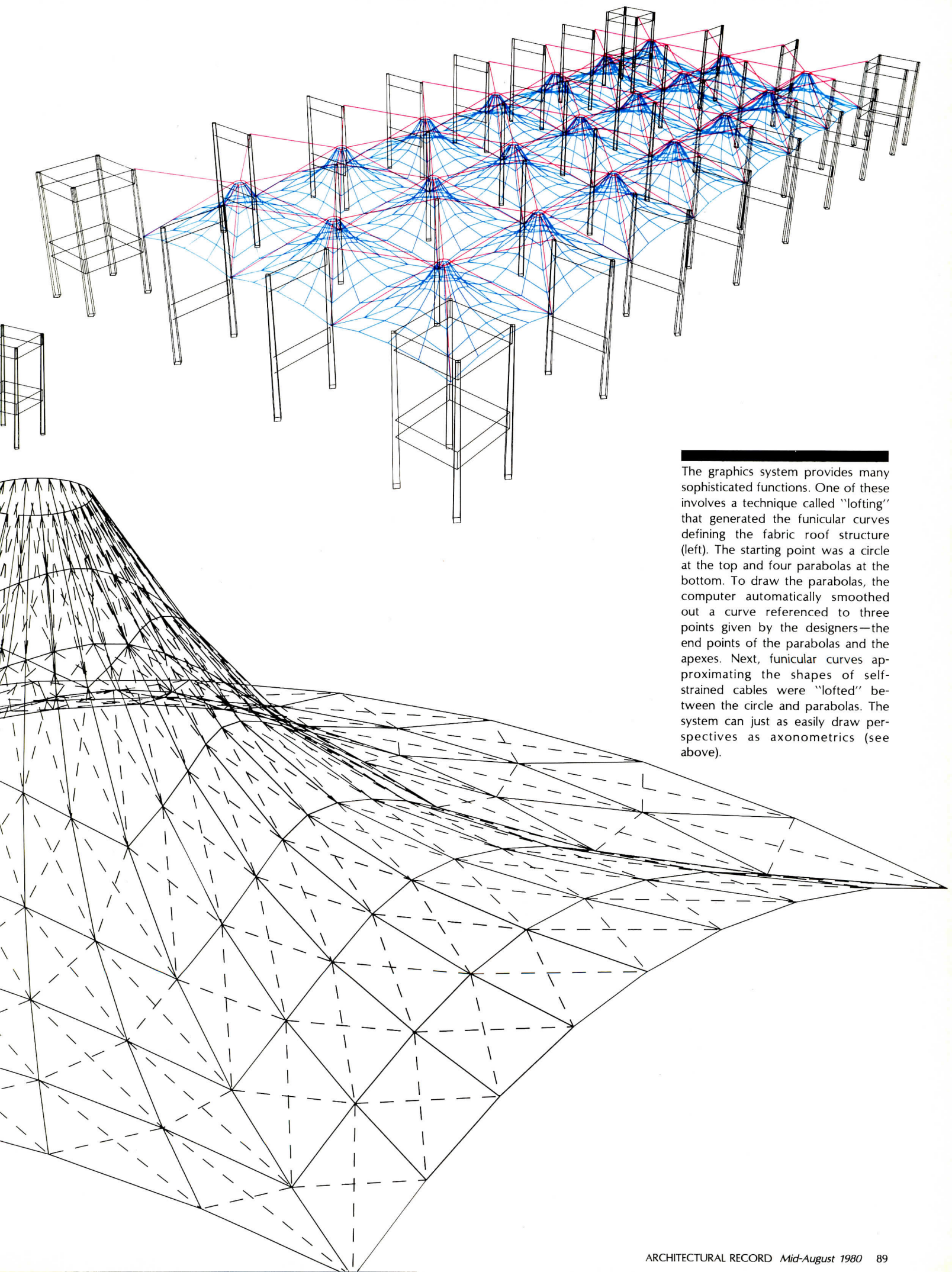


The computer graphics system used to draw the 45-meter-square fabric roofs at the New Jeddah International Airport should be considered a utility rather than a specific technique, according to SOM's computer group. They draw a parallel with an electric utility: the electric utility sells power, but does not care how the customer uses it. The computer stores data, but does not care what kind of pictures are drawn using it.

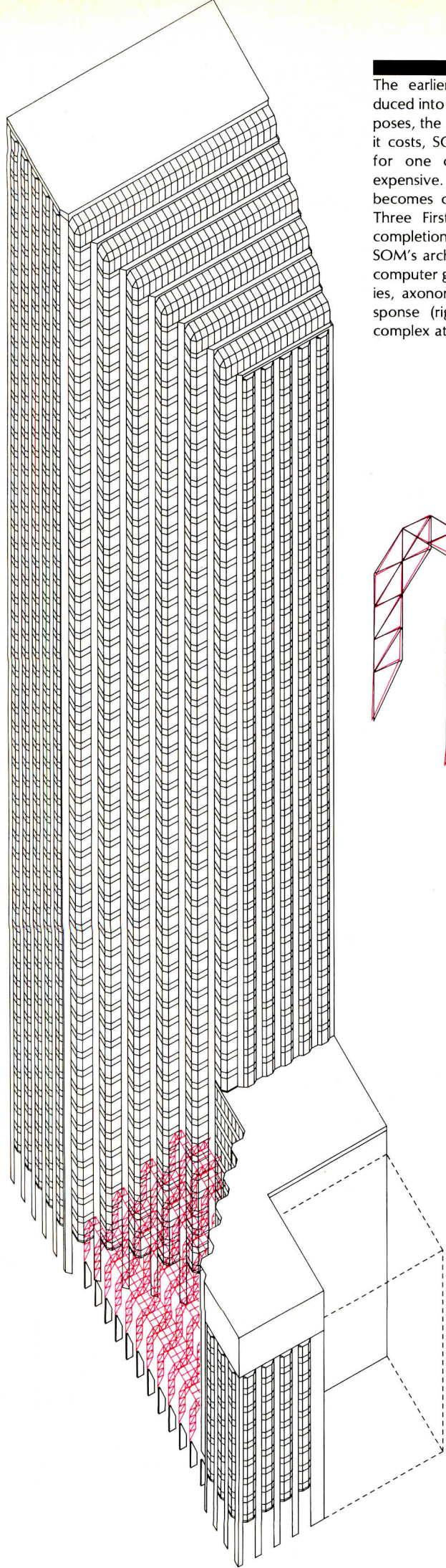
The same graphic system used for the plans shown earlier was used for these drawings. The pylons, cables and fabric elements were built up using graphic check points along the way. The composite was used for dynamic structural analysis.

The approach at SOM is to put the data into the computer so it is accessible for a variety of uses—drafting, structural design, sun studies, mechanical design, etc. The data is assembled and organized so that one can get at rationally.

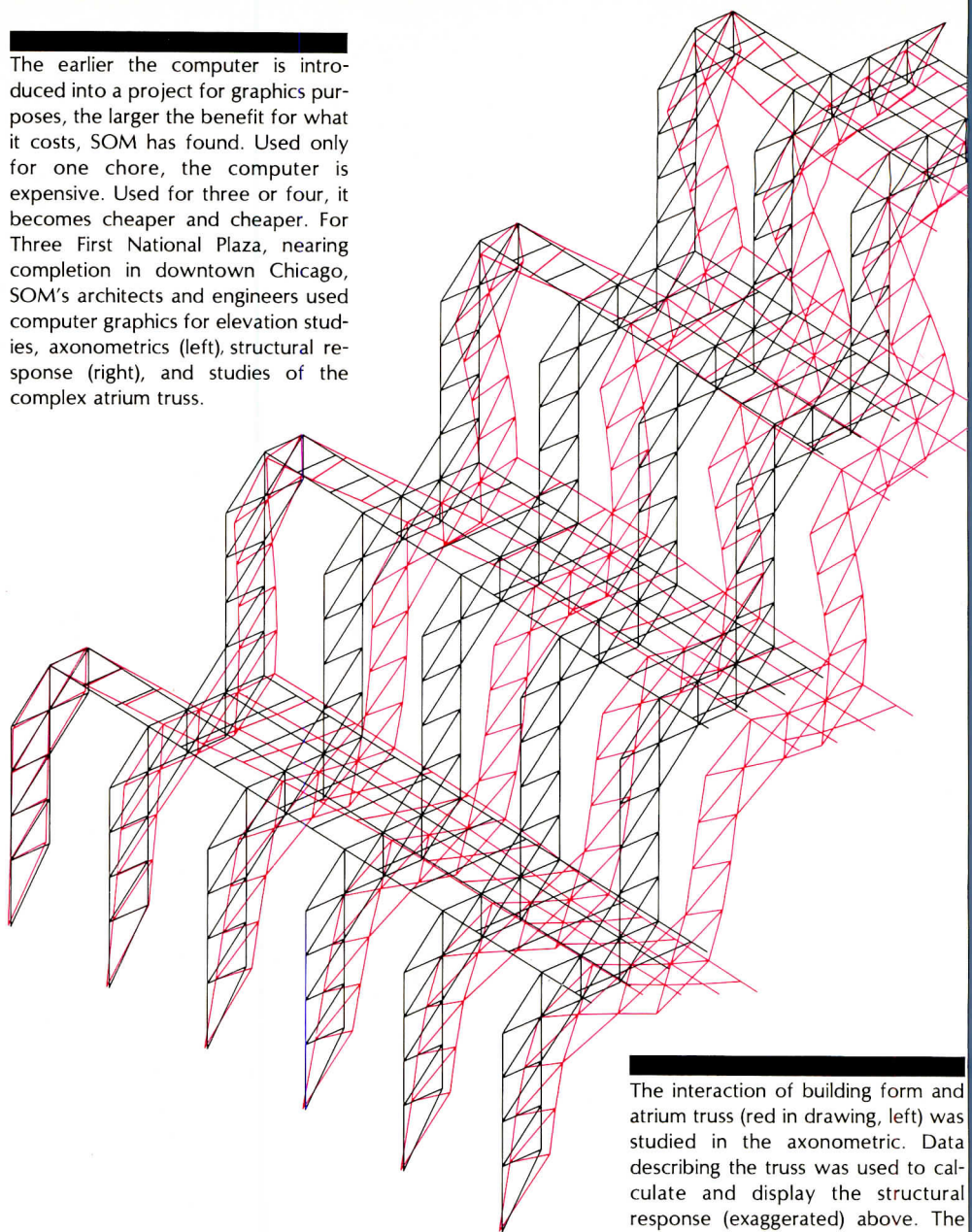




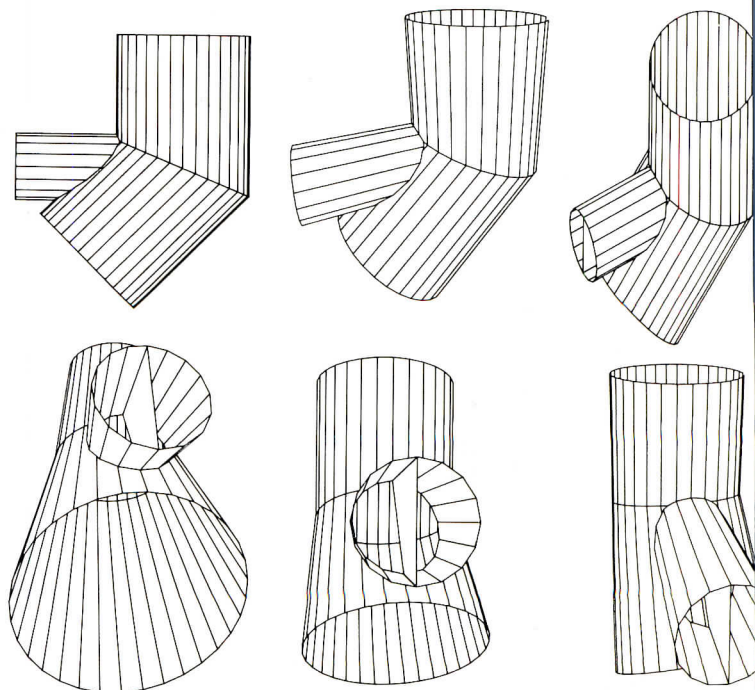
The graphics system provides many sophisticated functions. One of these involves a technique called "lofting" that generated the funicular curves defining the fabric roof structure (left). The starting point was a circle at the top and four parabolas at the bottom. To draw the parabolas, the computer automatically smoothed out a curve referenced to three points given by the designers—the end points of the parabolas and the apex. Next, funicular curves approximating the shapes of self-strained cables were "lofted" between the circle and parabolas. The system can just as easily draw perspectives as axonometrics (see above).



The earlier the computer is introduced into a project for graphics purposes, the larger the benefit for what it costs, SOM has found. Used only for one chore, the computer is expensive. Used for three or four, it becomes cheaper and cheaper. For Three First National Plaza, nearing completion in downtown Chicago, SOM's architects and engineers used computer graphics for elevation studies, axonometrics (left), structural response (right), and studies of the complex atrium truss.



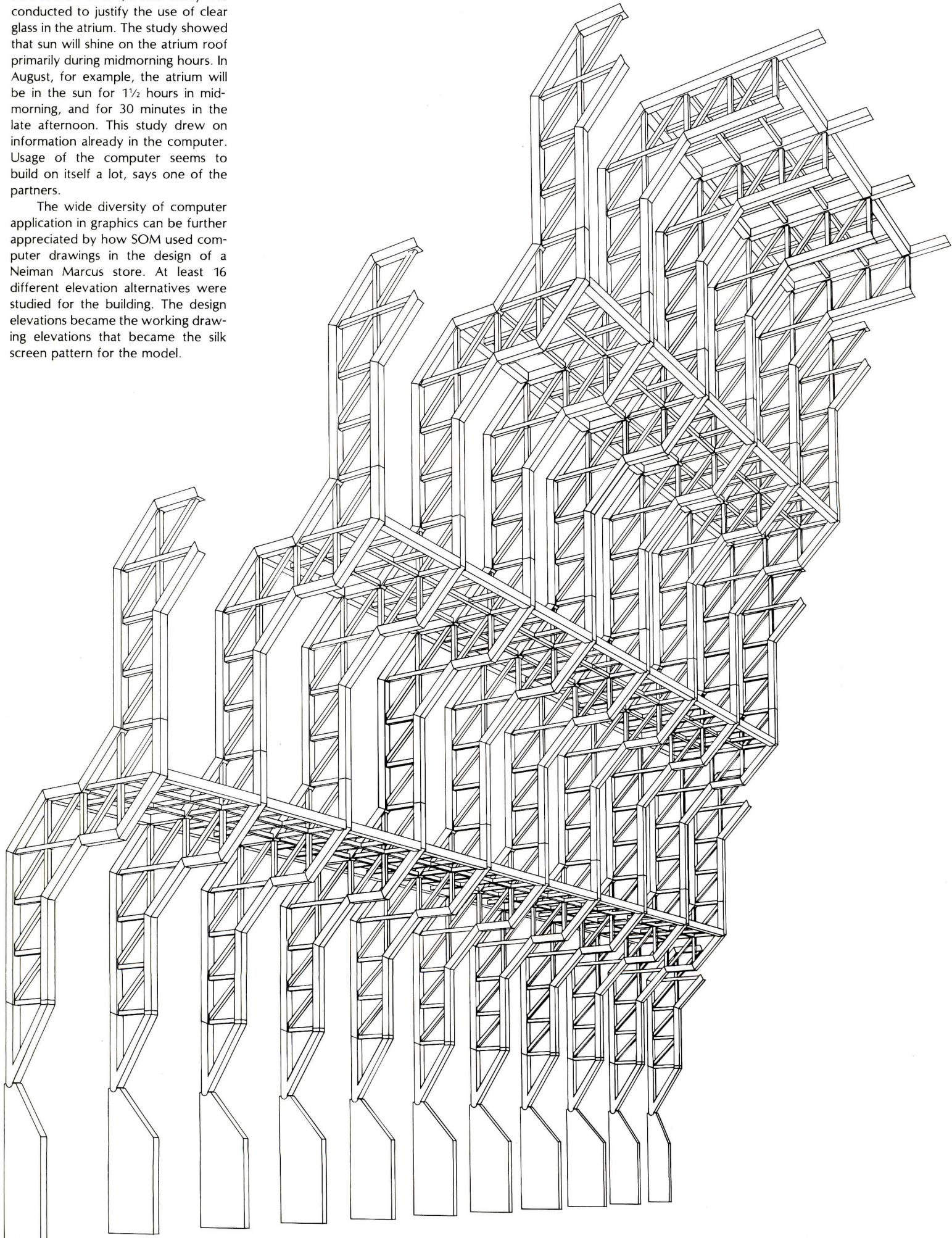
The interaction of building form and atrium truss (red in drawing, left) was studied in the axonometric. Data describing the truss was used to calculate and display the structural response (exaggerated) above. The typical connections used in the tubular members of the truss were modeled to study the intersection of members from a variety of angles. Though round, the truss members were shown square (across page) to simplify computer work.

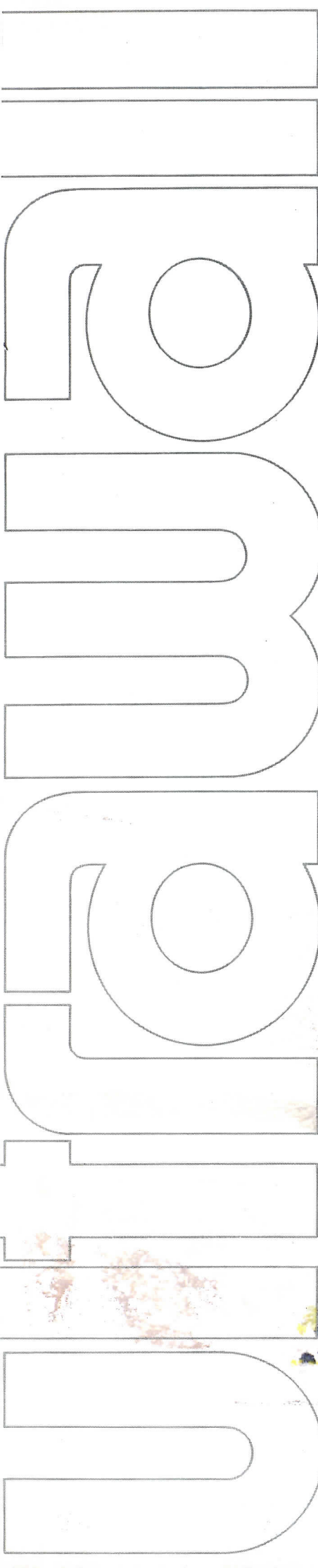




In addition to the graphic computer studies shown here, a solar study was conducted to justify the use of clear glass in the atrium. The study showed that sun will shine on the atrium roof primarily during midmorning hours. In August, for example, the atrium will be in the sun for 1½ hours in mid-morning, and for 30 minutes in the late afternoon. This study drew on information already in the computer. Usage of the computer seems to build on itself a lot, says one of the partners.

The wide diversity of computer application in graphics can be further appreciated by how SOM used computer drawings in the design of a Neiman Marcus store. At least 16 different elevation alternatives were studied for the building. The design elevations became the working drawing elevations that became the silk screen pattern for the model.





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