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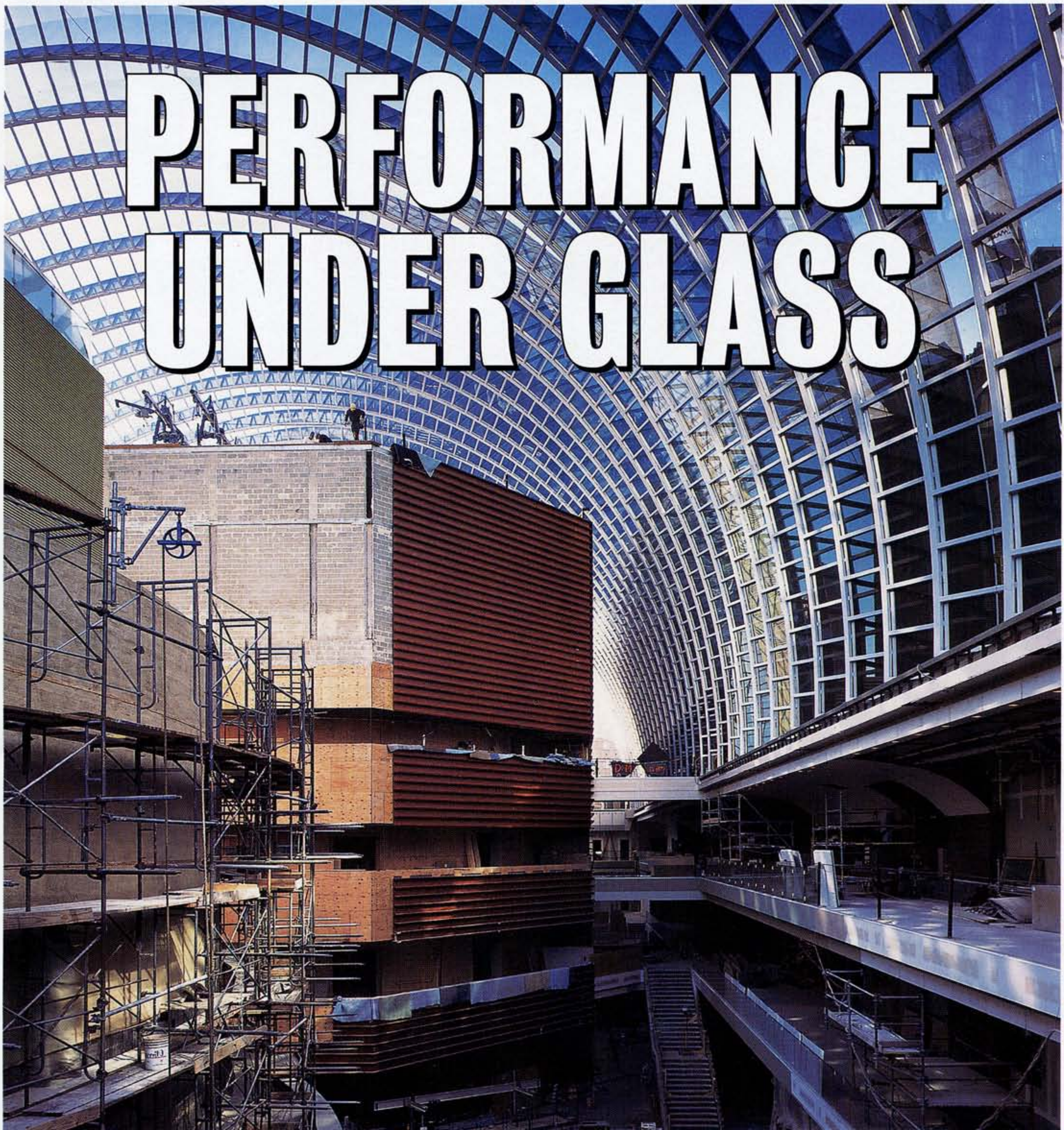
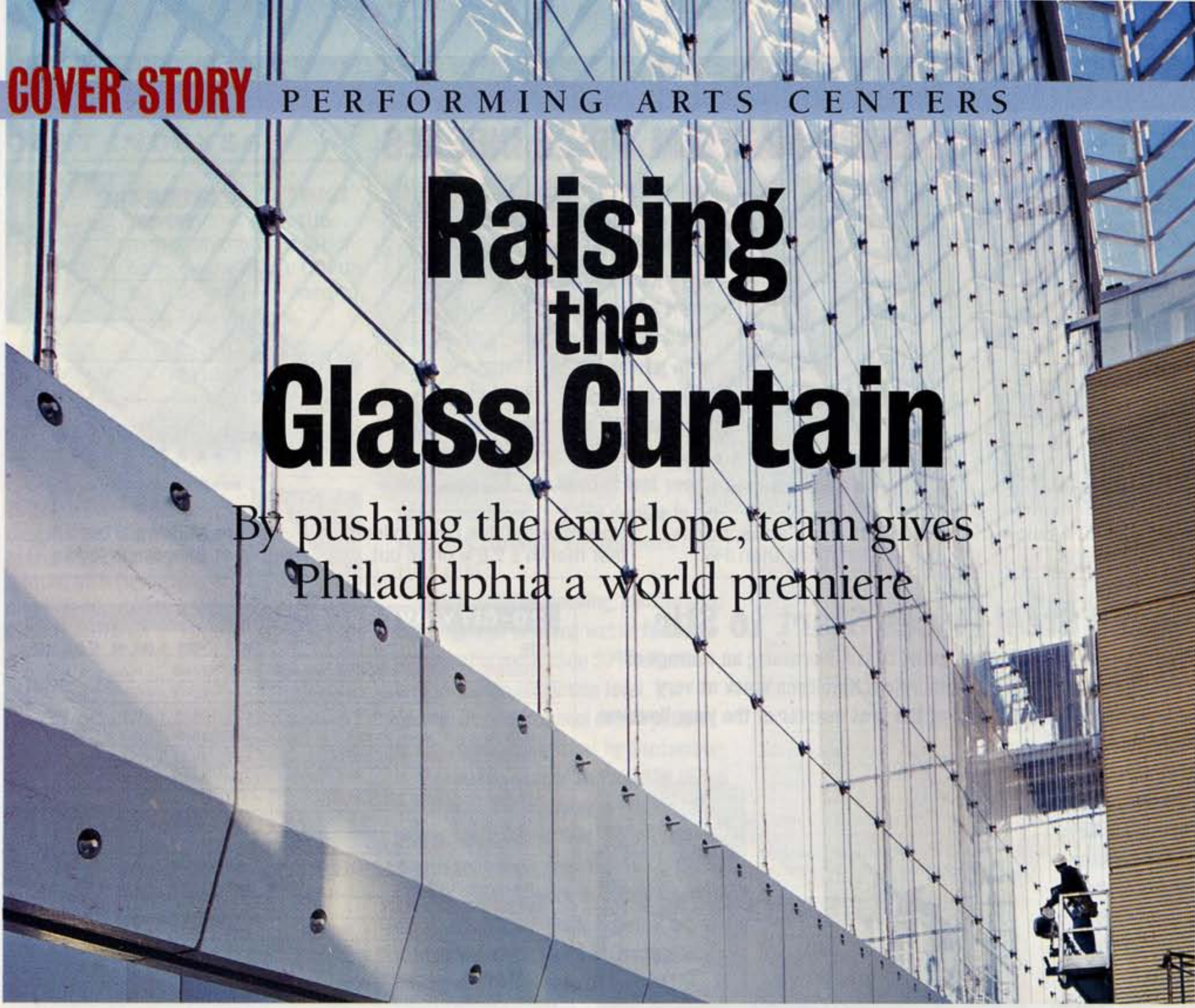
PERFORMANCE UNDER GLASS





Raising the Glass Curtain

By pushing the envelope, team gives Philadelphia a world premiere

Architect Rafael Viñoly calls the two Philadelphia buildings "jewels in a box." Others see boxes in a jewel. To them, the show-stopper at the almost-done Kimmel Center for the Performing Arts is not the concert hall or the adjacent recital theater, it is their container—a 350 x 174-ft, half-barrel vaulted skylight, nearly 90 ft tall.

The gem showcases design and construction virtuosity more common in Europe. Yet this $265-million performance under glass is a world, not just a New World premiere.

VIÑOLY

The skylid, which springs from a four-story building that surrounds the two halls, is novel by itself. But the lid's "scarily transparent" glass end walls are radical. Instead of the more typical tensioned cable net, the half-moon walls are supported laterally by a vertical-cable and cast-iron weight system. The engineering allows the glass sheet to deflect as much as 32 in. either in or out at its 87-ft-tall centerline, without a pane shattering. Glass walls aren't typically designed to move that much, says Walter Cichonski, director of fenestration for construction manager, L F Driscoll Co., Bala Cynwyd, Pa., in joint venture with Artis T. Ore, Philadelphia.

Each 174-ft-dia glass drape is a cast-fitting, single-cable-suspended, butt-glazed wall that hangs from a back-to-back, double-channel steel arch, distinct from the barrel vault. This type of wall "has never been done before," says Cichonski.

The architect's drive for maximum transparency in the lid inspired the structural engineer, scared away bidders and got everyone's juices flowing. A job like this "is no more expensive...you just need to work harder," says Viñoly, whose New York City-based office is designer and architect of record.

Viñoly and company did work harder. For example, the $4.3-million cable walls almost came "tumbling down" in a redesign after bids came in sky high. But the CM saved the day by rebidding the job, after devising a contracting scheme that split the work between the glass and steel contractors. And, instead of giving the glass contractor liability for the entire installation, it was responsible only for weatherability. That left engineering liability with the structural engineer. "We took away the fear factor and kept within budget," says James E. Verzella, Driscoll's project executive.

BLOMBERG

Suppliers were also given greater responsibility for detail design. Even so, when approached about rebidding wall, contractors had "a glazed look on their faces," says Verzella. To eliminate that, Driscoll held individual prebid meetings to explain the wall to them. The strategy worked. Second-round bids were on target.

This project has been no barrel of fun. Lots of overtime has helped keep to the set opening dates, which for the concert hall and public spaces is Dec. 14, and for the recital theater is late January or early February. But the path to completion has been filled with shards. Rebidding, fast-tracking, design changes and other issues caused delays, including a late start of six months for steel erection, says Driscoll. That pushed skylight glass installation into the cold months, making it that much more difficult.

TRANSPARENCY Vaulted skylight meets glass end wall, called unique.

Despite the sour notes, an air of mutual respect prevails. "We put the challenges out there and [the steel sector] rose to the occasion and did better than what we asked for," says Charles Blomberg, Viñoly's project manager.

Blomberg then credits Cichonksi for making the wall happen. Others credit Blomberg. Everyone pats the structural engineer on the back. And Willard G. Rouse III, chairman of the board of the client, the Regional Performing Arts Center, calls the CM's team "miracle workers."

There are some "grapes" outside the inner circle that soured during the development's 15-year course. The 450,000-sq-ft project, which includes $95.9 million in public funds, started as solely a concert hall for the Philadelphia Orchestra. Design was under way when lack of funds stalled work from 1989 to 1992. RPAC created itself and took over development in 1996, but not before getting the orchestra's buy-in for a much-expanded program that was community not orchestra-centric and would be a magnet for the city's revival. RPAC then held a design competition and selected Viñoly over the orchestra's original architect, in association with the local office of The Hillier Group (ENR 4/28/97 p. 17). RPAC then dropped Hillier, reportedly so that Viñoly could be in direct contact with the subcontractors regarding questions about the documents and the design.

Viñoly's charge was to create a weather-protected public plaza that would beckon all, from morning until late at night. The full-block complex includes a 2,500-seat concert hall and 650-seat recital theater, restaurants, a breakfast-lunch-late-night bar and space for hanging out. "We really tried hard to make it a civic space" not just an acoustical palace, says George H. Shaeffer, RPAC's project director.

The skylight was to look like a cladding system, with minimal structure and maximal transparency. To achieve this, the glass module fits directly over the roof's steel frame. Even joint widths match.

"We did hundreds of models of different geometries to get that one thing right," says Damian Murphy, senior associate in the New York City office of project structural engineer Dewhurst Macfarlane and Partners, in association with Goldreich Engineering, also New York City.

The skylight is framed by 72 folded-plate Vierendeel trusses made from 65 ksi steel tubes that span 174 ft. Trusses spring from 27-in.-deep beams on opposite inner edges of the top floor of the 420 x 250-ft perimeter building. Loads are transferred sideways through shear-stud connections to steel towers.

The folded plates, which resolve longitudinal lateral loads, outline an accordion profile, with peaks and valleys formed by 3¼-ft-wide, 7-ft-long steel frames set 45° to the horizontal. The roof is designed to deflect up to 1.5 in. sideways and 2.5 in. vertically. Though there is a flexible weather seal between the roof and each end wall, the roof imposes zero dead load on the wall.

At 750 lb per ft, the end wall's 33-in.-deep arch is like a giant curtain rod, self-supporting for vertical but not lateral loads. It is stabilized by the roof through a series of "wings" that have Teflon-coated sliding plates to allow independent roof and wall movement. Arch weight was determined with the control of wall deflections in mind, says the engineer.

CICHONSKI

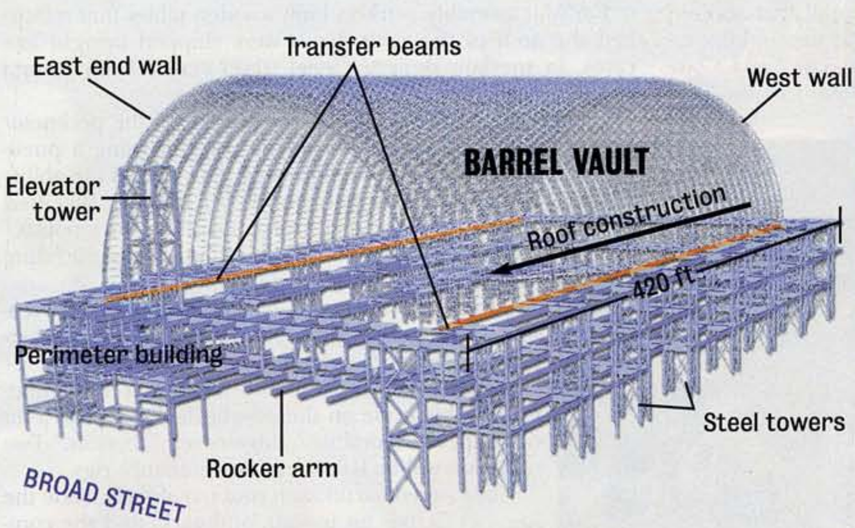
Wall structural-glass panels fit between arch channels via an aluminum channel. Along the bottom, panes fit into a groove. The glass wall connects into a frame of 38 stainless steel cables, tensioned by 38 weights, through stainless steel cast fittings. Swage fittings, common to yacht rigging, connect the ⅞-in.-dia cables to the arch above and weights below. The top connection is fixed; the bottom is adjustable via a turnbuckle.

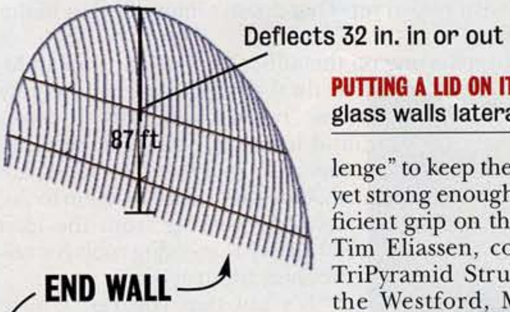
Weights weigh from six to 12 tons each, totaling 66 tons. They were cast in halves and bolted on site. They look identical but were hollowed out to vary the tonnage.

Each fitting joins the corners of four panes. "It was a chal-

MANY FACETS Steel erector used hall roofs to access vault. Arch is built on bents.

PHOTO TOP COURTESY OF RAFAEL VIÑOLY ARCHITECTS; BOTTOM COURTESY OF ©JMS CO. INC.





PUTTING A LID ON IT Roof stabilizes single-cable glass walls laterally but imposes no dead load.

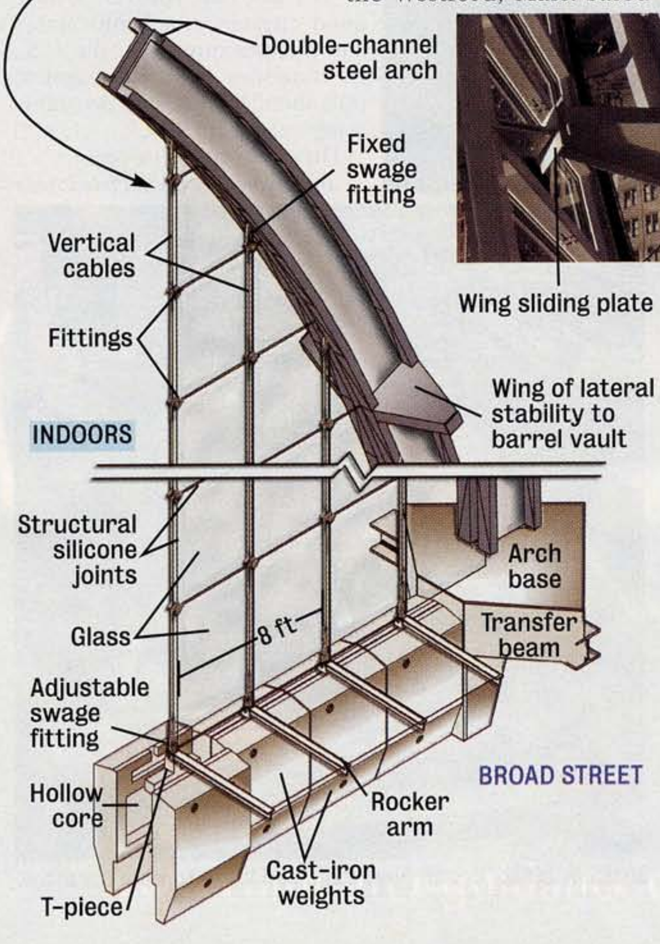
lenge" to keep the fitting small yet strong enough to have sufficient grip on the cable, says Tim Eliassen, co-partner of TriPyramid Structures Inc., the Westford, Mass.-based cable system supplier.

The fittings allow individual panels to rotate 6° off the vertical and to slide slightly and independently of one another.

The cable load remains "absolutely constant" no matter the wind condition, says the engineer. In an 80-mph wind, the longest and middle cable is predicted to deflect 32 in., as would the wall. In that condition, the center weight rises 2⅜ in.

The 9/16-in.-thick pane has two lights of ¼-in.-thick, low-iron glass, which is the most transparent.

Architectural Testing Inc., York Pa., performed mockup tests on the wall, including a section of the vault. The test also included the Broad Street elevator tower footbridge, which penetrates the east wall. Gaskets wrap the glass-enclosed footbridge like rubber bands and perform like windshield wipers, removing water from the footbridge walls.



For the roof and wall's steel contractor, the biggest difficulty was in the detailing. "The most important step was to get the shop drawings right," says Dominick D'Antonio, senior project engineer, Helmark Steel Inc., Wilmington. Baseline Drafting, Toronto, did the detailing.

MURPHY

Falcon Steel Co., Wilmington, erected the roof west to east, beginning with the west arch. The barrel vault was "a snap" compared to the walls, says D'Antonio.

For the arch, not self-supporting vertically until complete or laterally without the vault, workers first completed six shoring bents. Bent columns had been erected as continuations of perimeter columns. A beam and vertical plate assembly—bolted between arch channels—cantilevered from the bents. When the arch was self-supporting in the vertical direction, workers removed the bolts, allowing vertical movement. The remaining plate prevented lateral movement. The arch was erected in three pieces from the sides toward the middle. Crews bolted webs and welded flange splices. When complete but still shored, the arch stabilized the vaults, which became self-supporting laterally only after 12 to 16 were connected.

After erection of about 10 vaults, crews started installing the skylight units. In conjunction with that, and while the bents were still in place, workers started hanging cables and weights.

Cables needed to be adjusted sideways in both directions. Spacing was important so the glass panels would fit, says D'Antonio. Workers positioned the weights by sitting them on carts with a hydraulic lift table, and rolling them into place. The weights had to be tuned to exacting tolerances, says D'Antonio.

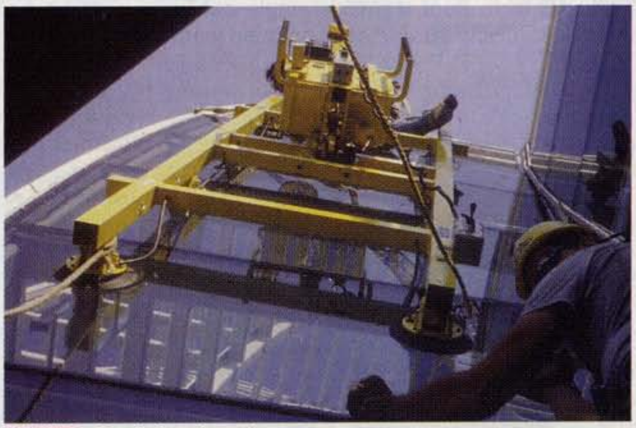
Workers began installing the end-wall glass last March. Un-

PHOTO TOP AND CENTER COURTESY OF RAFAEL VIÑOLY ARCHITECTS; DRAWINGS COURTESY OF DEWHURST MACFARLANE AND PARTNERS der Driscoll's split-contract approach, National first verified the locations of cables and weights. "This was to avoid finger-pointing" if anything went awry with the glass, says Neil J. Clabbers, vice president of National Glass & Metal Co. Inc., the Huntingdon Valley, Pa., glazing contractor.

Then, National shot marks with a laser and clamped the back end of a cast fitting on each cable, every 5½ ft. Proper position was critical, says Clabbers, because of limited ability within the fitting to accommodate any play in the glass. Tolerances were 1/16 to 1/8 in.

Next came the glass. Workers set a corner on the ledge created by the clamp. A temporary device was used to hold the assembly until all panes were in. As the glass was installed, a worker outside the wall would screw on the fitting's front plate, working in tandem with someone on the cable. Finally, workers on both sides of the wall would apply structural silicone to the joints.

National did 80% of the installation in a couple of months. The other 20% took another three or four months. "We breathed a sigh of relief in early September," says Clabbers.



UNITIZED Skylight glass installed in preglazed units.

For the 174-ft-long barrel vaults, tubes were preassembled at the shop into four truss sections, with slanted Z profiles, and shipped to the site. To better assure an easy fit, "we decided to limit ourselves" in fabrication to much tighter tolerances than contractually specified, says D'Antonio.

VERZELLA

"They built the jig for the barrel vault steel to tolerances of within 1/16 in., which is unheard of in structural steel or even architectural steel," says Viñoly's Blomberg.

At the site, center sections were bolted together on the ground. End sections were lifted first and guyed back. The middle section followed. Workers made midair splices, using simple bolted connections.

The issue was worker access. "How do you get 60 to 80 ft in the air to make the splices?" asks D'Antonio.

Falcon decided to position the high-reach equipment on tracks on the roof of the concert hall and recital theater, which could handle the loads. Falcon also erected a 40-ft-long "rail bridge" between the two halls to access the roof above.

To minimize field work, the skylight glass was shop-assembled into a unitized system of lightweight, low-profile aluminum frames each containing four preglazed panes with structural silicone caulking. "Typically, you don't glaze in the shop," says David B. Ott, project manager for Architectural Skylight Inc., Waterboro, Me. But the approach allowed workers to complete 70% of the weather joints at the shop.

For unit assembly, workers built wooden tables that mimicked the arch of the vault. Units were shipped upright like cards, in specially designed steel travel crates. Each 10-unit crate weighed 3 tons.

From a laydown area on the fourth floor of the perimeter building, workers would pick a unit using a pneumatic lifter with suction cups. The rig has the ability to power rotate and power tilt units to specified angles. "It was real critical to maintain work points," says Ott. If the steel was a bit off, workers would shim the glass unit. The glazing crew followed.

Ott says the operation, which started in a cold season, was not easy. "We spent a lot of money on overtime," he adds, to complete work on time.

Installers nicknamed the triangular work platforms, which ride on slotted wheels that fit into a fin of the peak's aluminum ridge cover, "chariots." Two of the six will be left as roof maintenance rigs.

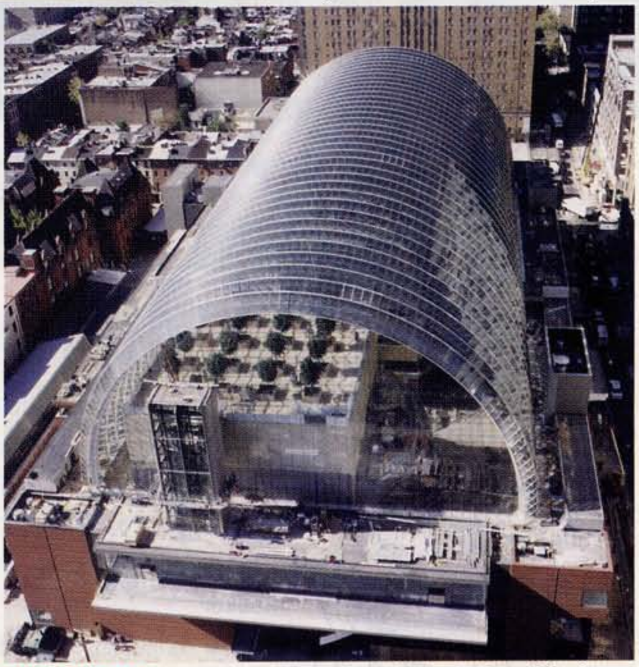
The faceted barrel vault roof has already made the Kimmel Center an instant landmark, and the complex isn't open yet. That doesn't happen often in the U.S.

In reflecting on the difficulty of creating an architectural icon in America, Viñoly says: "It takes care and attention and a love for doing something special....You need to solve the mysteries and translate them to the industry, working from the idea out rather than using tools for off-the-shelf construction.

"It's not that you don't have good engineers, subcontractors and manufacturers," in the U.S., he continues. "But you've got to pull them together to do something outside the box." □

His jewel proves the point.

By Nadine M. Post in Philadelphia



BOXES IN JEWEL Urban American icon likely to be a big draw.

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