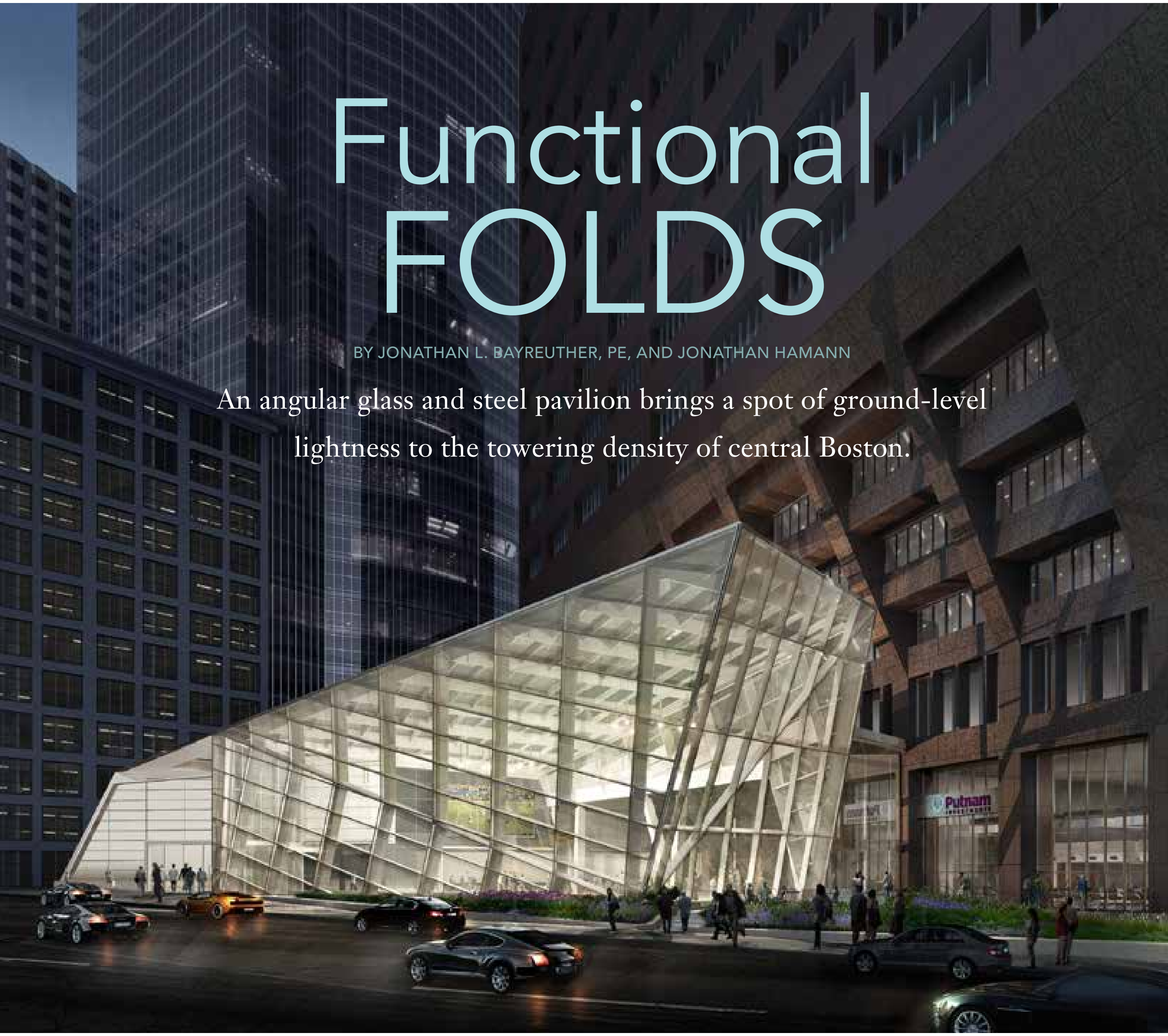
Functional FOLDS

BY JONATHAN L. BAYREUTHER, PE, AND JONATHAN HAMANN

An angular glass and steel pavilion brings a spot of ground-level lightness to the towering density of central Boston.



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RISING NEXT TO CONGRESS STREET in the heart of Boston's Financial District, a plate steel and glass prism seems to have been pushed from the earth.

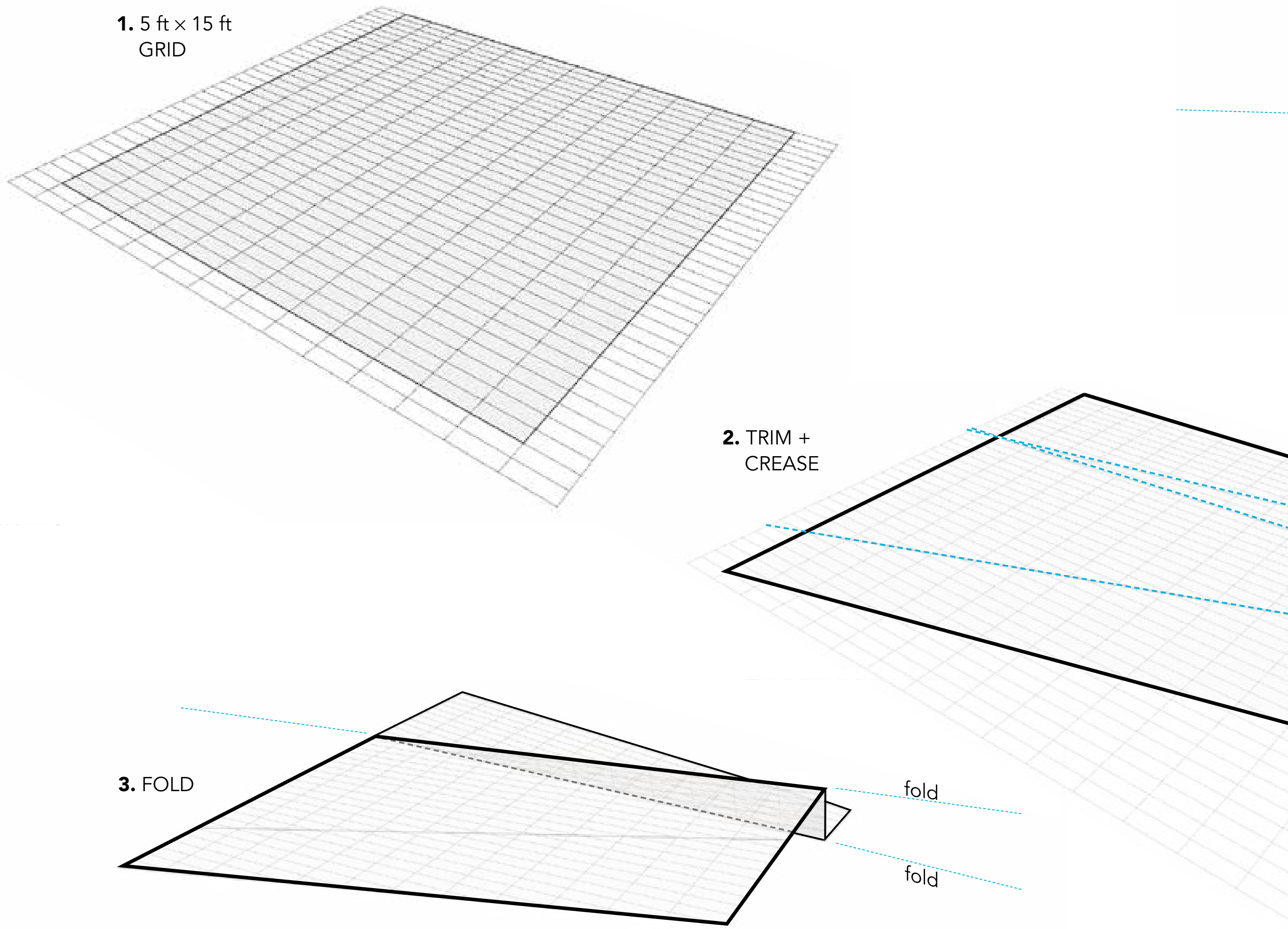
The project serves as a new entry pavilion for 100 Federal Street, a 591-ft-tall office building that opened in 1971 and is defined by its angled design near the base. The final form of the pavilion, known as The Exchange at 100 Federal Street, is the result of a highly collaborative, iterative design process with a clear focus on design intent while also balancing cost and constructability.

The new steel-framed entry pavilion for 100 Federal Street, a 591-ft-tall office building that opened in 1971 and features several floors protruding out over the street near the base.

Inspired by Paper

Initially visualized with a folded piece of graph paper, the design intent was clear (and angular): a sharply faceted form with an exposed steel structure. A series of conceptual working sessions between architect Perkins+Will and structural engineer McNamara·Salvia yielded multiple options for steel piece sizing and shapes, including W-shapes, hollow structural sections (HSS), built-up boxes and cable-trusses. However, none of these options could be cost-effectively sized for the 75-ft main spans and still achieve the architectural vision of narrow members (less than 6 in. wide) with sharp edges. Leveraging a longstanding relationship with Cives Steel Company's Augusta, Maine, facility, McNamara·Salvia reached out for pricing and size guidance on a new, simpler idea. Cives presented a design using solid plate members with exposed bolted connections and this approach became the design language for the entire exposed volume.

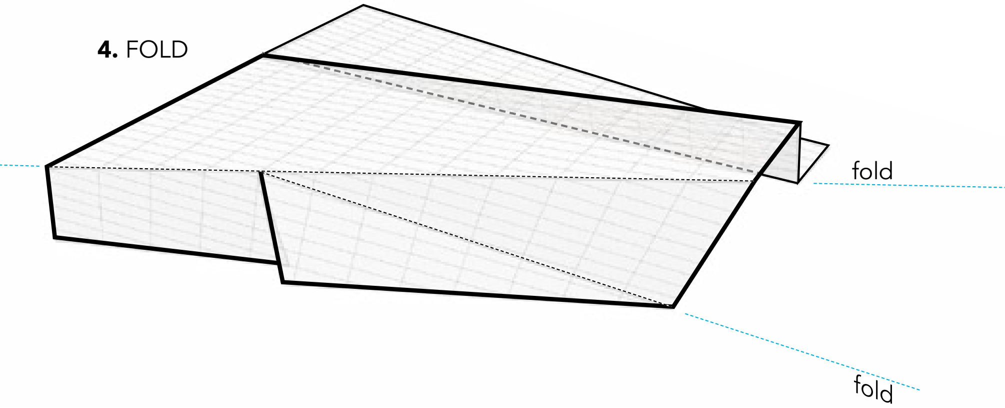
Though not as efficient as rolled W-shapes or HSS, solid-plate steel was able to meet the desired look where these other options could not. And while the built-up shape option was viable from an aesthetic standpoint, the solid-plate design was significantly lower in terms of fabrication costs. While it did present a structural stability challenge in that the plates required frequent lateral bracing, this problem was solved by adding sufficient additional steel bracing plates and matching the panel spacing of the curtainwall system, thereby eliminating additional aluminum mullions in the process.



Once the decision to use solid plate steel shapes was made, the next question to answer was clear: Field weld or bolt? The answer would have significant cost and erection time implications. With input from Cives, McNamara·Salvia proposed a concept for using a simple double shear plate, slip-critical connection, located at the inflection point of each plate. The owner (Boston Properties) was amenable to having exposed connections, and after some compromising on splice location to provide uniformity, Perkins+Will was on board as well. The bolted connections allowed stubs and tabs as needed to be shop welded, providing connections sized to meet shear and moment demands, and reduced field-welded splices to just a few locations. To increase uniformity, only 30 connection arrangements were used for the nearly 300 plate-to-plate connections. In some cases, slightly larger plates than strictly required by design were used to reduce noticeable differences in adjacent connections. In other cases, bolt diameters were increased to reduce bolt quantity. In addition to the loading requirements, the typical plate-to-plate connection also accommodated a penetration for a sprinkler supply line and electrical conduit. A full-scale wood mockup of a typical connection, including bolts, was built and painted for review and later used in checking sprinkler and conduit runs.

After finalizing steel member shapes and connections, the last piece of the design development puzzle was optimizing steel tonnage. The main volume slopes from 35 ft tall up to 50 ft and leans over 10 ft at the "prow" in two directions, in addition to changing width from 75 ft down to 35 ft. The geometry resulted in significant variation in steel depth and thickness requirements.

As a baseline tonnage, the structure was optimized with minimum depth and thickness for all pieces. From there, depths and thicknesses were adjusted with architectural input to limit noticeable jumps in depth or thickness between adjacent members. Thickening of the main members was avoided as much as possible, since ¼ in. of added thickness on the deepest 28-in. main rib plate would add one ton of steel. The adjustments resulted in a tonnage increase of less than 10% over baseline, and cost increases were mitigated by limiting the bracing plates to just three depths and thicknesses to allow for repetition.



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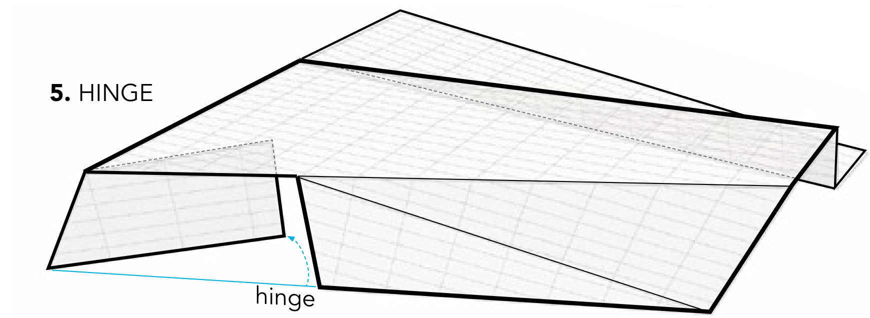
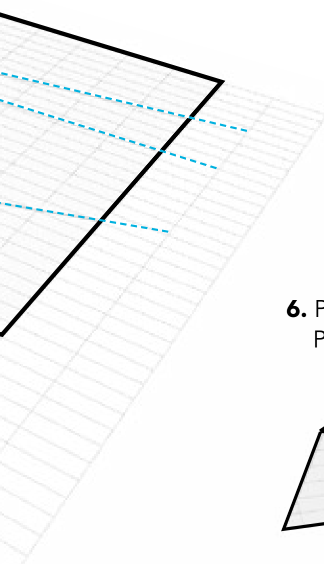
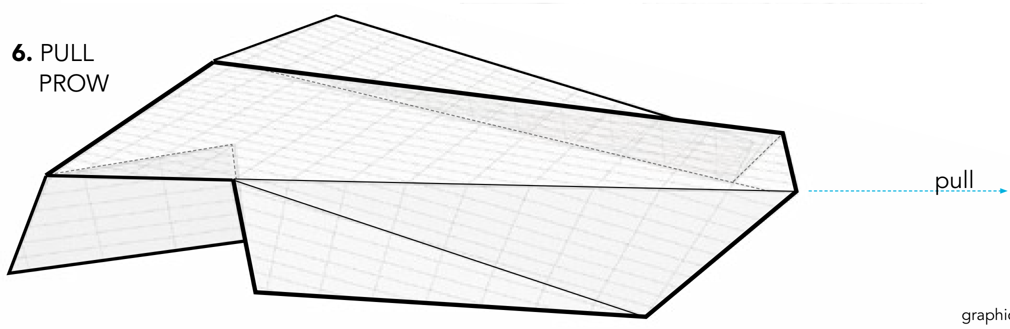






graphics on this spread courtesy of Perkins+Will

From All Angles

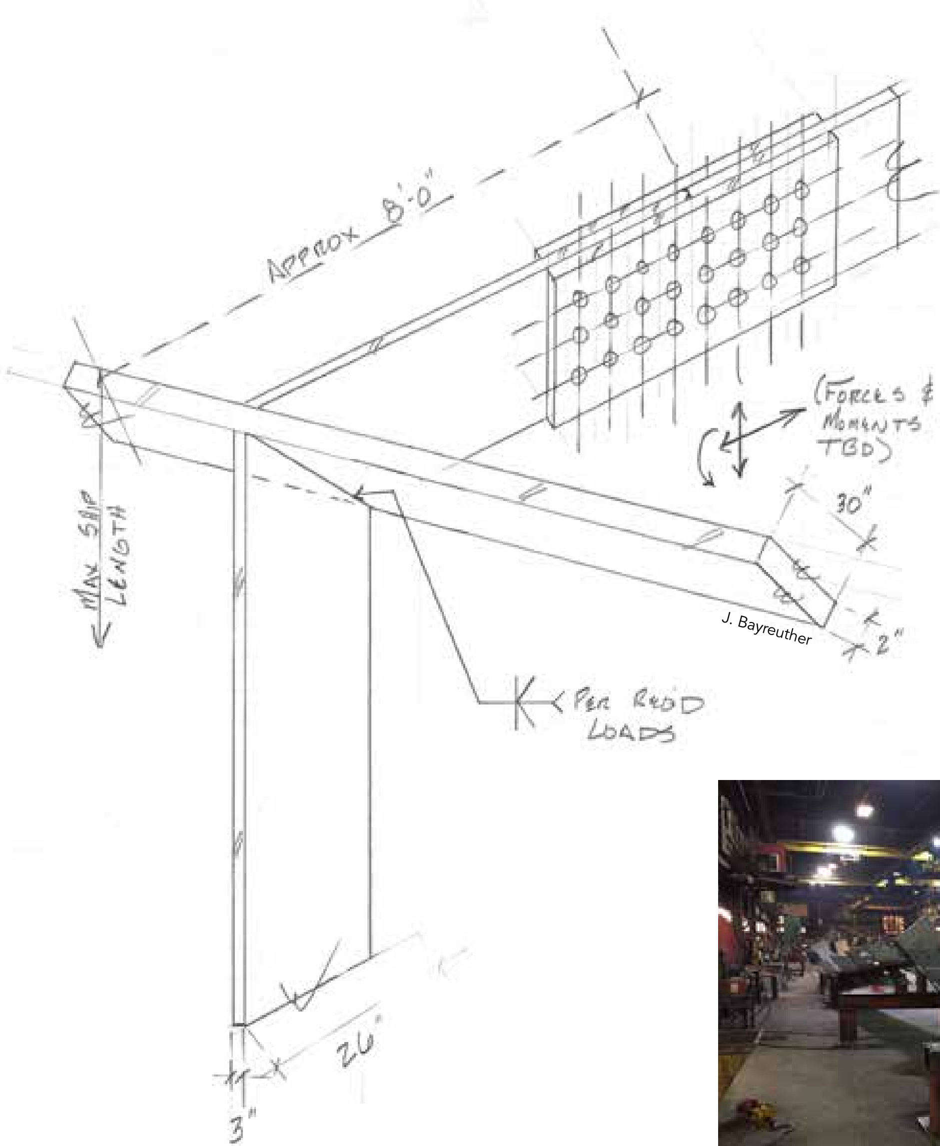
The exposed, mitered shop connections, and the fact that the steel would serve as the curtainwall mullions, meant that many small tweaks to the steel geometry were required before finalizing the steel locations and orientations. Typically, a detailer would begin the modeling process with fully dimensioned drawings and a Revit model from the architect and engineer, but the team realized that the typical document issuance would significantly slow down production of the shop drawings. To simplify the workflow, the structural drawings provided member sizes, but member locations were determined solely through 3D model coordination.

A Revit model was issued by McNamara·Salvia with member sizes and approximate member positions. Perkins + Will simultaneously supplied a precise Rhinoceros model of the curtainwall system and mitered steel joints, which was imported through Revit into the SDS/2 steel model. Cives then located and oriented all plate members to accurately maintain the 5⅜-in. offset required by the curtainwall system. Where the vertical rib members were not oriented perpendicular to the plane of

A Note on the Prismatic Form

The pavilion at 100 Federal Street is a prismatic form that subtly echoes the angular geometry of the building from which it grows, unfolding from the tower's base to envelop a triangular site and reaching toward Boston's Post Office Square Park. Its faceted glass and metal surface alternates between reflecting the sky, the street and the park, and revealing the life inside the building. The pattern of the skin and structure, a simple 5-ft by 15-ft grid synchronized with the tower, is manipulated like a sheet of graph paper that has been folded, producing an energetically directional skin. Articulating the structure in solid plate steel gives this skin a depth that baffles daylight and views, and that can appear simultaneously heavy and light as one moves around it. The detailing of the exposed steel structure emphasizes the continuity of the folded surface while integrating structural connections and essential building components such as lighting, fire protection and curtainwall support into a unified system.

—Matthew Pierce, Senior Project Designer/ Senior Associate, Perkins+Will



A splice sketch.

A complex rib plate assembly in the shop.

the glass, this required chamfering the outside plate edge parallel to the glass plane.

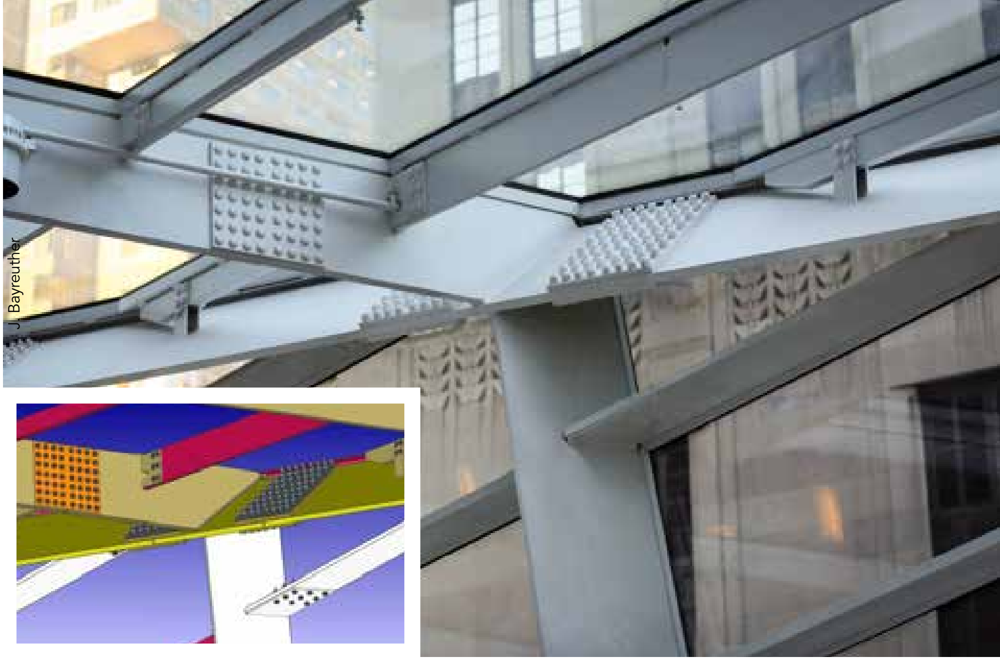
Creating 2D shop drawings from the 3D model proved to be a difficult task for even an experienced detailer. The main rib plates, particularly on the east and north walls, required up to five 24-in. × 36-in. drawings to fully illustrate the dimensions and bevels needed for assembly. The most complex assemblies were detailed with each main plate on a separate drawing, and the main assembly drawing then detailed the exact bevels for each connecting plate. All of the joints between rib plates were welded with complete joint penetration welds.

Even with multiple shop drawings and dozens of section views per piece, it was often necessary to consult the SDS/2 model during fit-up of the rib plate assemblies via 3D PDFs that were loaded on the QA inspectors' tablets. These digital views could be zoomed and rotated to enhance understanding of difficult joints and geometries. In a number of instances, a custom steel jig was modeled and fabricated to maintain member positions during fit-up and welding.

As all of the pavilion steel would be architecturally exposed structural steel (AESS) in the final condition, great care was taken to maintain the crisp, square edges of the plates. Groove welds were of the highest quality and were not required to be ground smooth. Shop splices, where necessary, were typically full-penetration welds, and these welds were ground smooth so as to become invisible in the finished member. A table of AESS requirements specifying only those items that would have significant visual impact in the final condition for each piece was included in the contract documents to reduce AESS costs and ensure the correct levels were applied to the specified pieces.

Proper Position

The main rib plates form the main lateral load resisting system for the pavilion. As such, the structure was not self-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➤ Fabricator Cives' approach, using solid plate members with exposed bolted connections, became the design language for the entire exposed volume.

supporting during erection. Field-bolted connections simplified fieldwork and reduced erection time, but the angular shape still required extensive shoring and bracing for stability until fit-up was complete. The erection engineer, using the SDS/2 model and proposed erection sequences, analyzed the potential wind loads on the structure based on the portion of the structure that would be erected by the end of each day of the anticipated six-week erection schedule. Shoring towers with custom-made cradles supported the main rib plates at the roof, while a lattice of ½-in.-diameter cables secured to the grade-level slab provided lateral bracing.

In order to maintain the proper position and elevation of each of the main rib plates during erection, nearly 150 survey points were stamped onto the outside edge of the wall and roof rib plates during fabrication. An erection drawing provided X, Y and Z coordinates to each of these points from a project control point for verification in real time as each piece was installed by the raising gang. The as-built tolerance for support of the curtainwall mullions was limited to ⅜ in. in any direction (including all fabrication and erection tolerances). Only minor adjustments to the plates were required just ahead of glass installation.

At once bold and yet naturally fitting into its surroundings, the angular steel structure of the pavilion at 100 Federal Street showcases how steel in its simplest form can lend dynamism and life to the built environment—and also serves as a model for creative collaboration in integrating the design and construction teams. ■

Owner
Boston Properties

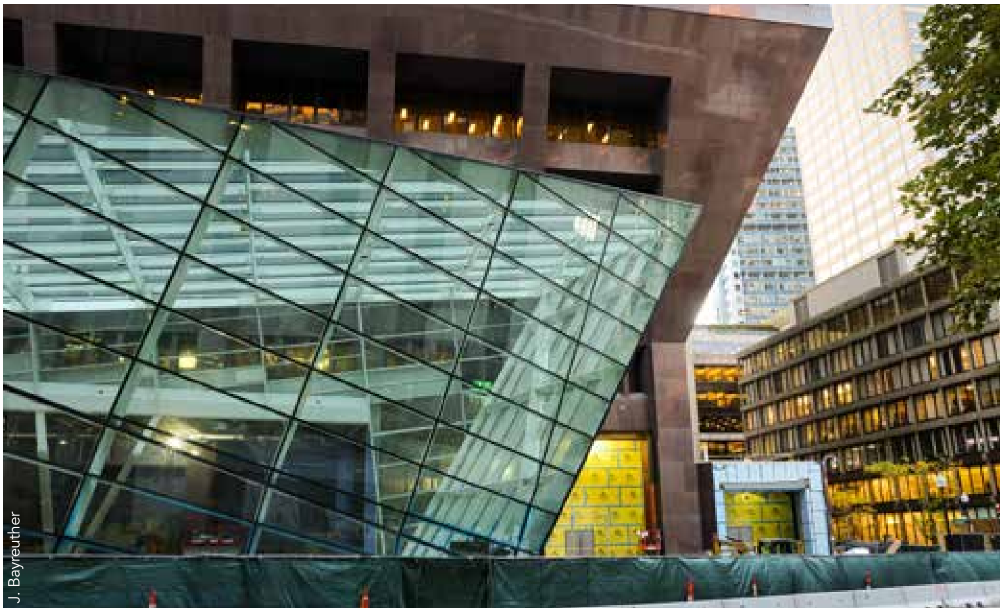
Construction Manager
Turner Construction Company

Architect
Perkins + Will, Boston

Structural Engineer
McNamara Salvia, Boston

Connection Design/ Erection Engineering
Meyer Borgman Johnson

Steel Fabricator
Cives Steel Company—New England Division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▼ The framing required extensive shoring and bracing for stability until fit-up was complete.


Jon Hamman