Barclays Center Green Roof

On hold for years, plans for the arena's green roof come to fruition with a structurally innovative, improvisational addition to the existing steel superstructure.

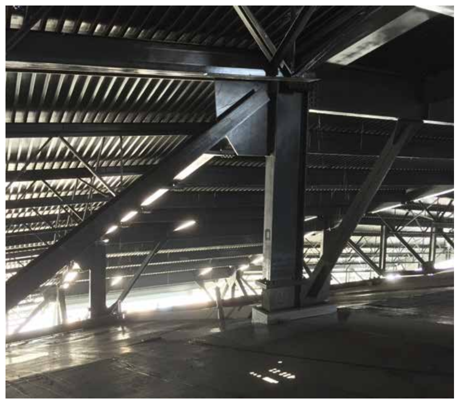
THE BARCLAYS CENTER WAS COMPLETED in 2012 as the first component of Pacific Park, a 22-acre mixed-use commercial and residential development in Brooklyn. Situated at the intersection of Atlantic and Flatbush Avenues, the iconic, undulating weathered steel skin of the arena reflects the industrial history of the surrounding neighborhood.

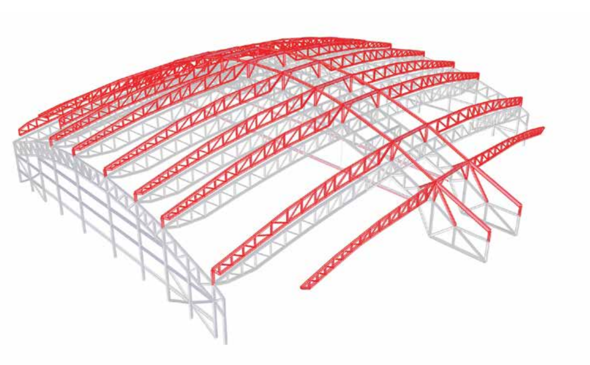
Initial plans for the arena had also included a green roof to further integrate the design into the surrounding environment. Although the green roof component was ultimately eliminated from the design, the arena was still able to achieve LEED Silver certification, becoming the first sports venue in the New York metropolitan area to achieve that status in recognition of its sustainable design. (See *Metals in Construction* Winter 2013 issue to read features about the facade and structure of the arena.)

One year after completion of the Barclays Center, Forest City Ratner Companies and Greenland Group entered into a joint venture for development of Pacific Park, a multi-use project formerly known as Atlantic Yards. This agreement also provided the necessary resources to allow the original vision for a green roof to become a reality. A green roof would help to reduce noise levels from the busy sports and entertainment complex while also enriching the views from the surrounding neighborhood and the planned residential towers.

The revival of the green roof presented a unique challenge for Thornton Tomasetti, who provided structural engineering design for the original arena and were brought back, along with the rest of the original team, to develop a design for support of the new green roof. "Although the foundations of the arena had been designed with an allowance for a green roof as a vestige of the original concept, most of the superstructure—including the long-span roof—was not designed to support the additional weight," explains Thornton Tomasetti associate Michael Bauer, P.E.

To minimize the extra weight that would need to be supported, SHoP Architects selected a lightweight sedum for the green roof. Sedum is a flowering plant that does not require watering or routine maintenance and can be limited to a maximum weight of 30 pounds per square foot—considerably less than other common types of roof plantings. To facilitate installation, the sedum was grown in 2-by-2-foot





This page, clockwise from top left View of truss and joists flying over the existing arena roof during construction. A slide bearing assembly at the end of a secondary truss. The completed structure as seen from below after a rainstorm. Diagram illustrating green roof primary truss structures (red) overlaid on the existing roof truss structures (gray). View of trusses and joists from below the green roof, showing the small gap between the truss bottom chord and the crossbeam to the existing arena roof. **Facing page** Trusses and joists during construction, facing toward the rail yard and Pacific Park development.

This page photos: Mike Bauer, Thornton Tomasetti; diagram: Thornton Tomasetti; opening spread: Forest City Ratner Companies

trays off-site in Connecticut and then transported to the arena for installation in the spring of 2015, with over 34,000 trays required to cover the 135,000-square-foot green roof.

An initial analysis determined that the added weight of the green roof system would require substantial reinforcement to the trusses, purlins, and steel connections throughout the roof, as well as additional reinforcing and secondary support for the roof deck. Furthermore, performing all of this work within the arena while maintaining an occupiable venue for dozens of monthly events would be next to impossible. It became clear that any viable solution would need to minimize the work required on the inside of the arena.

The main support elements of the existing arena roof are a pair of central tied arch trusses spanning 350 feet in the east-west direction. On the north and south sides of the roof, a series of eight secondary trusses, spanning 170 feet in the north-south direction between the central tied arches and the perimeter, provide support to allow for a column-free seating bowl. Girders and purlins spanning between the secondary trusses frame the remainder of the roof.

The design solution developed by Thornton Tomasetti for support of the green roof augments the existing pair of central tied arches with an additional chord 14 feet above the existing arch chord. The new arch chords are tied into the existing arches with a vertical element at each major panel point, along with diagonal bracing elements at the ends of the span. In doing so, the effective depth of the arch under live loads and the weight of the new roof is increased from 50 feet to 64 feet, with a proportionate decrease in member stresses. Moreover, the resulting heightened green roof surface is more visible from the street, and the resulting gap between the new and existing roof surfaces provides added benefit in curtailing noise emission.

Mirroring the original design, a series of new secondary trusses span from the new arch top chord to new stub-ups on the perimeter, directly overhead of the existing secondary trusses below. "With this arrangement, over half the weight of the new roof is supported entirely on the two central arches, while the remainder is supported at the perimeter," says Bauer. To avoid excessive thrust transfer into the existing structure from outward deflection of the new roof structure, nearly all perimeter support connections incorporate elastomeric slide bearings. "The end result is that a vast majority of the existing roof framing, including all existing secondary trusses and infill framing on the north and south sides, does not carry any load from the green roof."

While it was determined that the perimeter structure had sufficient excess capacity to accommodate the additional loads, the central pair of arch trusses required some local member and connection reinforcement. More crucially, the engineering team found that the existing wide flange tension tie members within these tied arches would be overstressed under the added load.

To avoid overstressing the existing tension tie members, each arch was retrofitted with a pair of 3 ¾-inch diameter 300-foot-long steel cables—a type and size of cable more commonly used in bridge construction. To provide a means to connect the cables and transfer the load into the existing structure, new 3-inch-thick cable gusset assemblies were welded to each side of the existing 3-inch-thick arch node

gusset plates. After completion and inspection of the reinforced nodes, the reinforcing cables were lifted into place during a two-day window between scheduled events, and several weeks later, a series of hydraulic jack assemblies were used to draw each reinforcing cable into over 300 tons of tension.

By tensioning the reinforcing cables, the force in the existing tension tie was reduced by a sufficient amount to allow for installation of the new roof. Key locations within the existing arch and tension tie were fitted with strain gages that could be monitored during the tensioning of the cables to verify the amount of force reduction in the existing tie and to confirm that the overall structural behavior was consistent with analysis model predictions. The strain gages were left in place and used to monitor changes in force levels in key members for the duration of construction.

Designing a long-span steel structure that could be erected over an active arena required an alternate approach to conventional shored construction techniques. Crane locations around the site were limited due to adjacent construction projects and the arena's location between two heavily-trafficked streets. Thornton Tomasetti worked closely with the steel fabricator and erector to develop a lightweight structure that could be quickly erected using three cranes situated around the perimeter of the arena.

To reduce their weight, ASTM A913 Grade 65 steel was used for all truss members, and mid-span shoring posts supported on the existing roof trusses below allowed each of the 170-foot secondary trusses to be erected in two segments with weights under the limiting pick capacity of each crane. Lightweight joists were used to provide infill framing, further reducing the weight of the overall structure and increasing the speed of erection. Exterior steel erection began in late 2014 and was completed by June 2015, with minimal impact to the arena's busy event schedule. Installation of the sedum trays was completed shortly thereafter, and the roof quickly became a popular destination for local bees, which made quick work of pollinating the vast field of flowering plants. From the street, amid the buzz of daily life in Brooklyn, the new expanse of green atop the Barclays Center provides a refreshing sense of openness amid the dense urban surroundings the arena calls home. □

Above View from the peak of the green roof towards downtown Brooklyn and Manhattan.
Above left Flowers spring from the deck along the edge of the green roof.

This spread: Mike Bauer, Thornton Tomasetti

BARCLAYS CENTER GREEN ROOF

Location: **620 Atlantic Avenue**, *Brooklyn, NY*
Owner/Developer: **Forest City Ratner Companies**, *Brooklyn, NY*
Lead Architect: **AECOM**, *New York, NY*
Design Architect: **SHoP Architects**, *New York, NY*
Structural Engineer: **Thornton Tomasetti**, *New York, NY*
Mechanical Engineer: **WSP Flack & Kurtz**, *New York, NY*
Construction Manager: **Hunt Construction**, *Brooklyn, NY*
Curtain Wall Consultant: **Front Inc.**, *New York, NY*
Structural Steel Erector: **James F. Stearns Co., Inc.**, *Pembroke, MA*
Curtain Wall Erector: **Egan Architectural**, *Yonkers, NY*