USTA Arthur Ashe Stadium Roof

The more than 23,000 seats at the largest tennis stadium in the world were not originally designed to have a roof overhead, but after rain hindered the US Open for five consecutive years, the United States Tennis Association sought a solution.

CROWDS ROARED WITH APPROVAL when the United States Tennis Association (USTA) realized Arthur Ashe Stadium in Flushing Meadows-Corona Park in 1997. "New York has not produced as energized a public space since Lincoln Center," wrote *New York Times* architecture critic Herbert Muschamp of the campus, which since 2006 has been known as the Billie Jean King National Tennis Center. Of the 23,771-seat structure by Detroit-based architect Rossetti and engineering consultant Cantor Seinuk, Muschamp cheered, "There is excellent architectural action … where steel framing, the saw-toothed underside of the concrete bleachers and the movement of people up and down stairs and escalators create a vibrant intermediary experience."

Yet every winning streak must come to an end, and in Arthur Ashe Stadium's case, a roofless design was its shortcoming. Because bad weather could disrupt the US Open and its Nielsen ratings, in 2004 USTA began reaching out to architect-engineers to develop a retractable roof whose weight would not overwhelm Flushing Meadows' marshy soil, which subsides half

an inch per year. Several years later, as solutions failed to materialize and rain delays befell the US Open annually, the All England Club addressed similar problems by constructing a folding fabric-and-concertina-truss roof over Wimbeldon's Centre Court.

USTA had not asked Arthur Ashe Stadium's creators to devise a solution for the delicate situation, even though in 2010 it retained Rossetti to master-plan the wider Billie Jean site. As the design studio watched its client reject others' proposals, it decided to partner with WSP Cantor Seinuk and submit an unsolicited roof concept. "We had initially devised a way to unload capacity on the existing foundations by replacing the precast concrete stadia with lightweight composite stadia," recalls Rossetti principal Jon Disbrow, who led the charge. The substitution would allow the foundations to support a lightweight roof structure, which would then connect to the existing structure via giant ring beam. The scheme ultimately did not meet USTA's criteria for speed and durability—"the solution fulfilled the structural need, if not the operational demand," says Ahmad Rahimian, director of building structures at WSP USA—but it did persuade the organization to reunite the original Arthur Ashe team and contract it to work on a second serve.

In order to achieve a seven-minute opening time and withstand hurricane-level winds, Rossetti and WSP developed a bi-parting fixed fabric shell concept that minimizes bearing points. The scheme is supported on eight tripod assemblies that surround the stadium's octagonal perimeter: Each tripod comprises a pair of HSS 38-inch-diameter steel braces connected to a vertical HSS 44-inch-diameter column, atop a concrete base supported by 20 piles driven 175 to 200 feet below grade. Disbrow likens the superstructure to an umbrella. "A much more sophisticated, $100 million umbrella," jokes Rahimian, who notes the parallels between the roof scheme and the branching structural vocabulary of the stadium's upper seating. "They both start from our principle of finding the most economical means of transferring load."

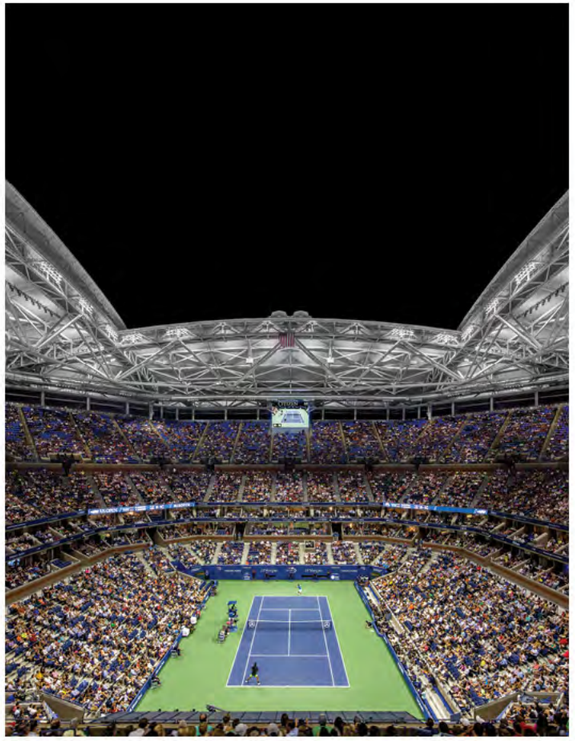
The assemblies transmit lateral and gravity loads from the roof, whose structural shell includes four catenary trusses that each span 460 feet to frame the opening of the retractable surface. The catenaries, which employ a lenticular truss configuration, are enveloped by a perimeter truss and connected by secondary one-way trusses configured in a radial direction to support the fabric roof. Tertiary X braces coupled with circumferentially running beams frame the gutter around the perimeter of the roof.

The umbrella is completely independent of the stadium, which comprises a concrete-topped composite steel structure combined with precast hollow core slabs at the superstructure level, a cast-in-place slab at court level, and steel frames spaced radially around the stadium. By concentrating the foundations in eight discrete locations, Rossetti and WSP also avoided much of the underground workings of the Billie Jean campus, as well as the infrastructure that dates to the World's Fairs held at Flushing Meadows. Potential interferences at each location were investigated beforehand to expedite steel erection and fabrication.

The fabric roof, installed by Birdair, today hovers 205 above the site. It measures 236,000 square feet in all, of which 191,400 square feet is polytetrafluoroethylene (PTFE). Within this area, two 38,000-square-foot PTFE panels open and close according to digital controls linked to sensors that monitor everything from wind and motor speed to torque, temperature, and humidity. "Tennis is an outdoor sport, so it needs to feel like the outdoors as much as possible," Disbrow says of the aperture, "We were able to far exceed the area of the court below, and to create the largest opening of any of the retractable roofs in tennis." Arthur Ashe is the sport's largest stadium.

This spread, clockwise from above
Four catenary trusses form the framing system that supports the roof, each spanning 460 feet to form the opening of the retractable panels and weighing 1 million pounds each. The trusses use a lenticular truss configuration that spans between eight column supports. The final scheme of the stadium's bi-parting fixed fabric shell in closed and open positions.
Opening Spread The new structure of the stadium roof supports 190,000 square feet of polytetraflouroethylene (PTFE) fabric, a Teflon-coated membrane installed by Birdair that is lightweight yet effective in keeping out the elements.

This spread: Rossetti; opening spread and following pages: Rafael Gamo



With its record-breaking retractable roof, the facility is dominating the tennis scene once again. Besides offering relief to US Open ticketholders and media buyers, the year-old project has earned new love from the architecture community. In revisiting the stadium, The *New York Times* exclaimed, "Now, the outward slope of the bowl is met with a graceful, ethereal lid." Disbrow says the design team indeed took great pains to "respond to the original building," noting how the retractable roof structure's gutter framing aligns with the raker beams that have supported the precast concrete stadia for two decades.

Rossetti continues to execute its master plan of the Billie Jean campus. And although its next major project, a replacement Louis Armstrong Stadium, cannot top the Arthur Ashe Stadium in scale, Disbrow says the all-new facility will exceed its larger, rejuvenated neighbor in terms of atmosphere. Whereas a tremendous air-conditioning system now must mechanically cool Arthur Ashe Stadium to prevent condensation from forming when the roof is closed, the new Armstrong venue pairs natural ventilation to a retractable roof. "We've designed it from the onset as an open-air breathing stadium," Disbrow says. Thanks to north- and south-facing rain screens that will allow breezes to filter through their terracotta louvers, "you won't even know you're in an enclosed space." That junior champion should be ready in time for the 2018 US Open.

The roof gives the appearance of being an integral part of the original stadium, which was built in 1997. In reality, the roof structure is completely independent of the stadium.
Left Engineered to open and close within 7 minutes, the roof's design and technological components allow Arthur Ashe Stadium to continue to feel like an outdoor venue.

USTA ARTHUR ASHE STADIUM ROOF

Location: **USTA Billie Jean King National Tennis Center in Flushing Meadow-Corona Park, Queens, NY**
Owner: **United States Tennis Association**, *White Plains, NY*
Architect: **Rossetti Architects**, *Detroit, MI*
Structural Engineer: **WSP USA**, *New York, NY*
Mechanization Engineer: **Geiger**, *Suffern, NY*
Mechanization Engineer of Record: **Hardesty & Hanover**, *New York, NY*; in partnership with **Morgan Engineering**, *Alliance, OH*
Retractable Roof Fabricator and Erector: **Birdair, Inc.**, *Amherst, NY*
Structural Steel Erector: **Derr and Isbell Construction, LLC**, *Euless, TX*