

Steel This Book

BY EDWARD J. ROBERTS, PE



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COMPETING CONCEPTS can sometimes join forces to work together.

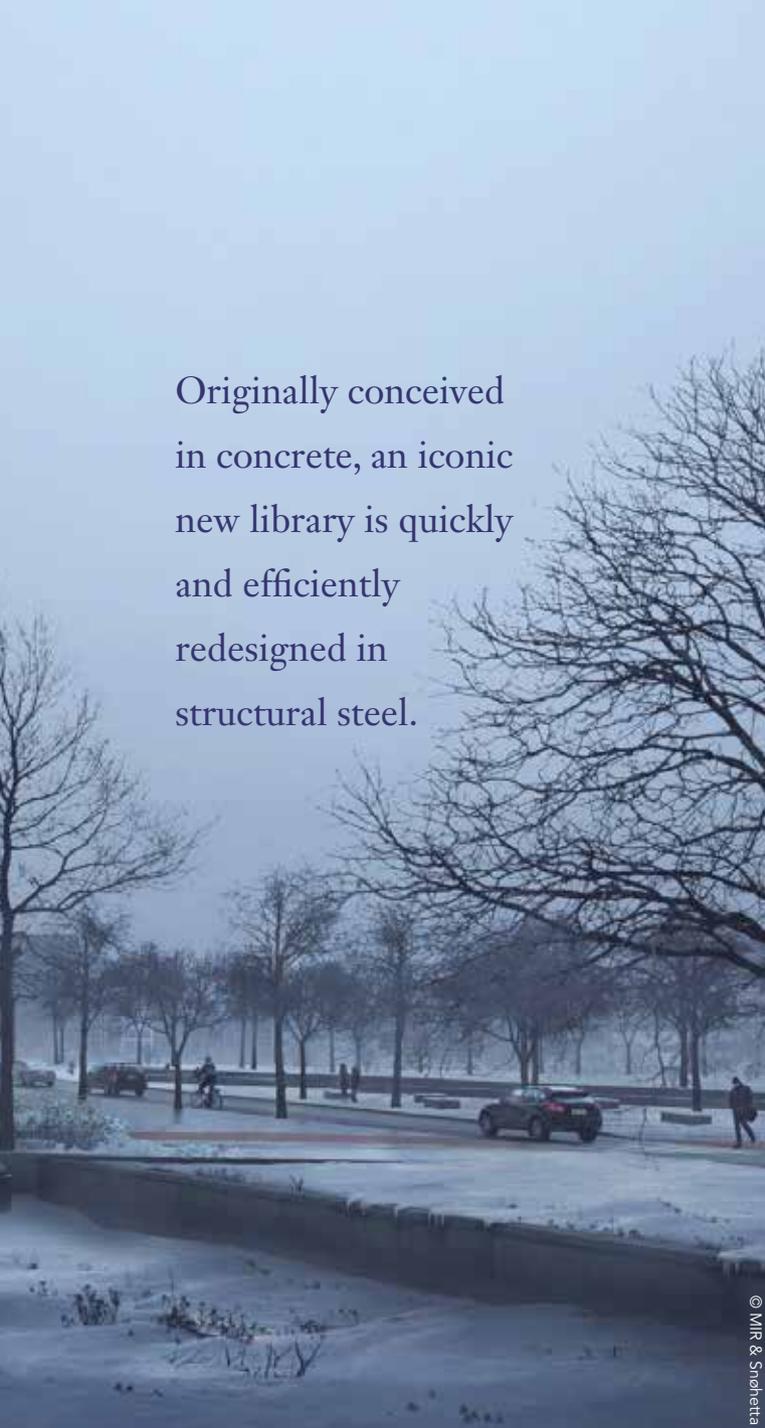
When developing the architectural vision for the new Temple University Charles Library, designed by a joint venture between Snøhetta and Stantec, two very different concepts emerged early on: one containing a series of large cantilevers, the other long-span arches.

In true architectural flair, the two concepts were ultimately combined, demanding a structural system that was both innovative and efficient. The new library building on Temple's Philadelphia campus, measuring approximately 420 ft long, 160 ft wide and 70 ft tall, will serve as an elegant addition to the campus when it opens in fall of 2019, becoming a new focal point for students and faculty alike.

A Nimble Structural System

Overall, the architectural layout follows two different sets of grids. The northern side of the library follows a regular steel column grid of 30 ft by 30.5 ft. The fourth floor and the southern side of the building follow a different steel column grid of roughly 30 ft by 28 ft. These two grids are slightly skewed with respect to one

Originally conceived in concrete, an iconic new library is quickly and efficiently redesigned in structural steel.



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opposite: Temple's new Charles Library measures approximately 420 ft long, 160 ft wide and 70 ft tall.

below: The project uses approximately 1,800 tons of steel in all.



Chad Carpenter/Snohetta

another. Beams or sloping columns serve to transfer loads from one set of column grids to the other. At the southern side of the building, the large atrium lobby is covered by a wood-clad dome. The structural columns in this section, which follow the regular column grid at the fourth floor, slope through the atrium, puncturing the wooden dome and providing a large open space lined by leaning columns.

Out of approximately 120 total column locations throughout the building, 50 columns are transferred, either via deep transfer girders, as sloping columns or by long-span "spanning wall" trusses. Having to transfer more than 40% of the column load posed many structural challenges, the most significant of which were accounting for resultant forces, engineering appropriate details and delivering a cost-effective structure. The various leaning columns and trusses required special consideration, not only with regard to the final building but also for each stage of erection. Accordingly, the design team reviewed the load paths of the build-

ing's finished state while the steel erector studied the erection sequence of the steel, which was not self-supporting.

The building's lateral load-resisting system consists of concrete shear walls, which also carry the horizontal components of the gravity loads of the various leaning building systems. These shear walls are located around the building's elevators and egress stairs. In addition to the lateral loads of wind and earthquake, certain shear walls are designed for loads from lateral earth and water pressures. The basement is located approximately 20 ft below-ground at the southern end and 34 ft below-ground at the northern end of the gently sloping site. The deep basement is partially due to the automatic storage retrieval system (ASRS) used to house the library collection, which stores approximately 1.8 million books in bins stacked in high-density shelving, with robots retrieving books upon request. The 50-ft ceiling height of the ASRS required concrete fin walls, spanning from the basement to the third floor, to resist the lateral earth and water pressures acting on the basement.

Flipping the Script

At most locations, the floor framing consists of concrete slab on metal deck acting compositely with the steel floor beams. However, this was a departure from the project's original design. Although Philadelphia is often considered a "steel town," the building was originally conceived and designed—through the end of construction documents and into bidding—as a predominately concrete building. The floor system was intended to be concrete voided (bubble) flat slab or flat slab with drops at most locations, with some local steel framing at the cantilevered trusses. The concrete floor framing was, at the time of design, considered economical by cost estimators, and preferred architecturally where the flat soffit of the floor was to be exposed to view.

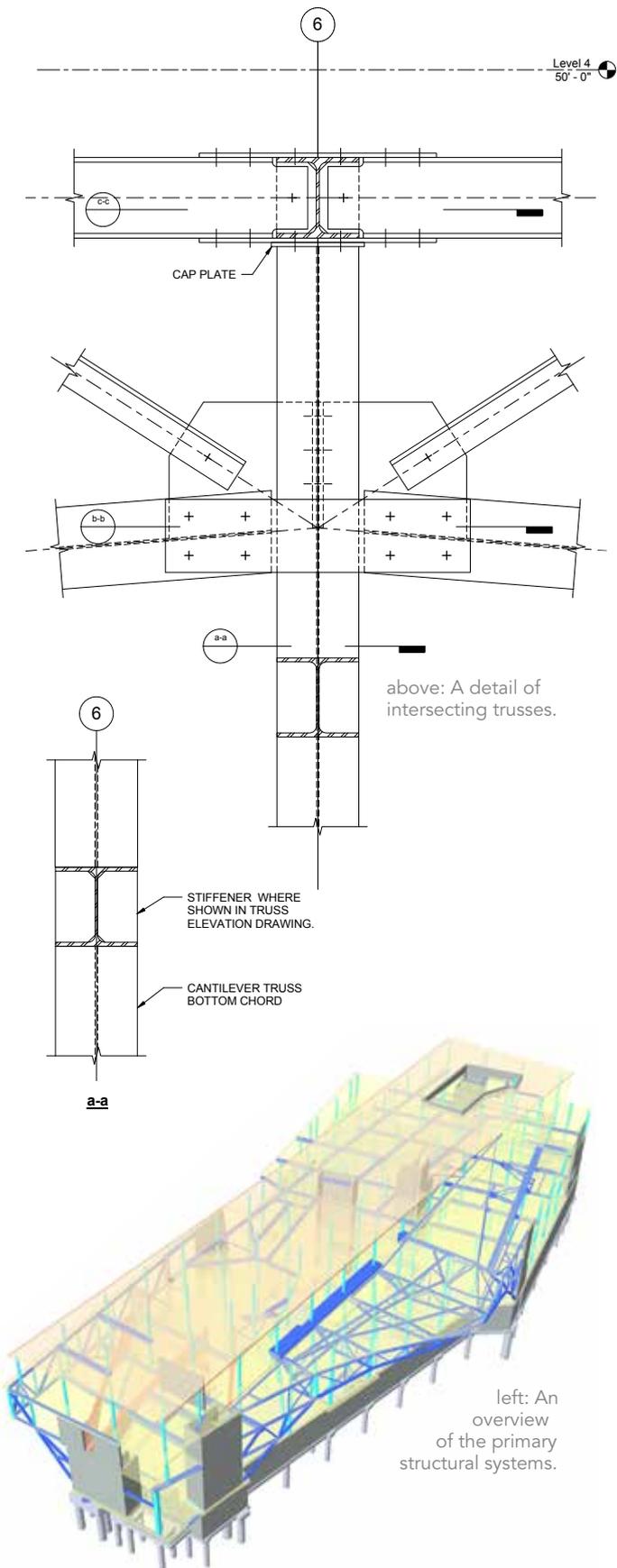
By the time the project was bid, shifts in regional economics altered the relative cost of the building materials, and steel became more economical than concrete, even where the costs included architectural modifications to accommodate the steel framing. As a result, the structural design team was tasked with redesigning the building to be predominately steel—and issuing the revised bid documents—in only four months. To maintain the pace of construction, a portion of the northern side of the building, including the ASRS vault, was kept as concrete, with the roof of the ASRS vault consisting of flat slab with drop panels. The concrete construction started first, providing time to complete the detailing and fabrication of the new structural steel (in all, approximately 1,800 tons).

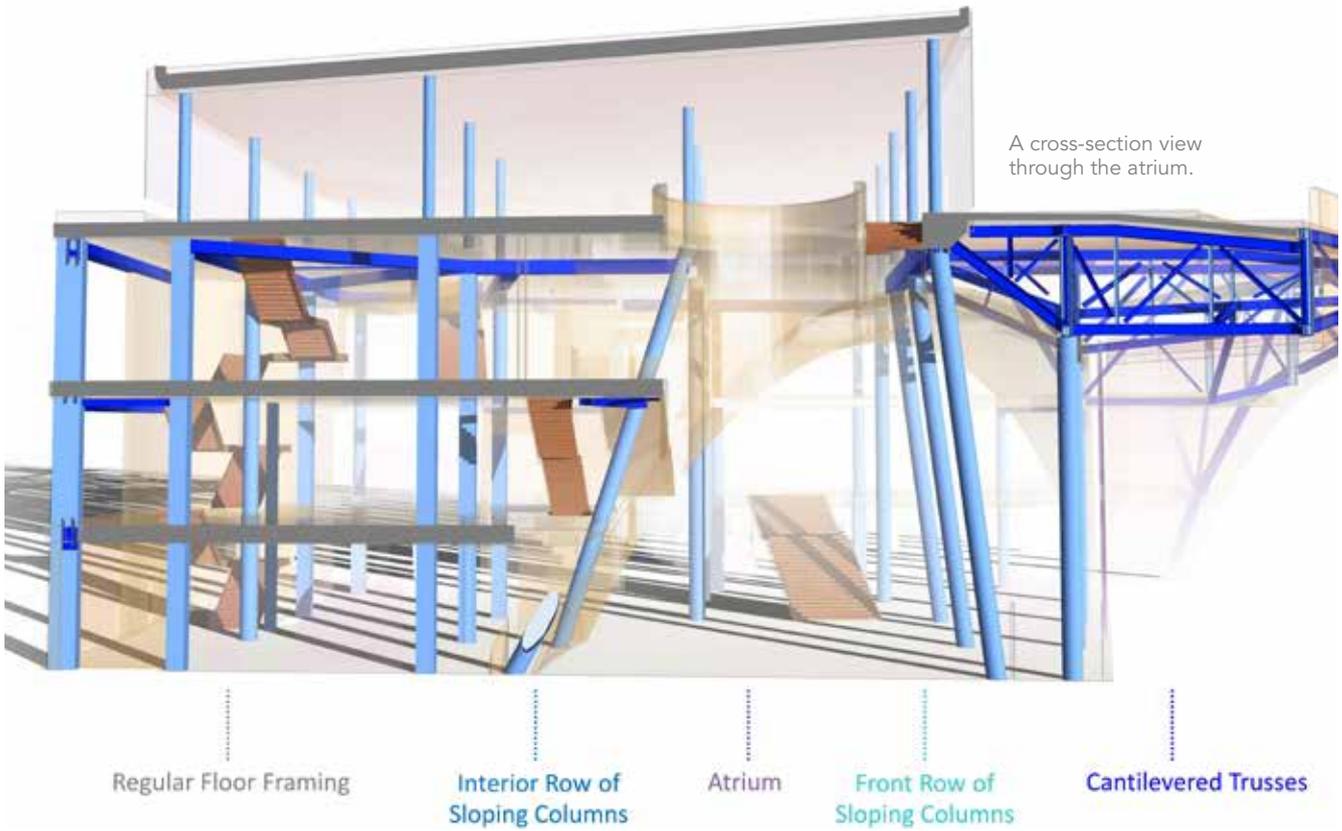
Some aspects of the original concrete building design were difficult to change. The basement level is located 20 ft below ground and is below the water table. This basement elevation was determined as the optimal location whereby the weight of the original concrete building would counteract the uplift produced by hydrostatic water pressures. While the steel building was more economical, it was also lighter, resulting in portions of the foundation (the caissons and the pressure slabs) being in net uplift. In parallel with the effort to redesign the building in steel, a concerted effort was made to review changes to the caissons while they were being installed.

Although the majority of the building structure was changed to steel, the concrete shear walls remained largely unaltered. To allow the steel to be erected in advance of the construction of the concrete shear walls, 5-in.- to 6-in.-diameter steel pipe columns were placed at the corners of the concrete shear walls and the concrete walls were cast following completion of the steel erection. Shear studs, shop-welded to the columns, were provided to transfer loads from the steel framing into the concrete walls.

To achieve the monumental open spaces, a series of "spanning wall" trusses span as long as 100 ft across the interior of the building. Originally designed as concrete arches, the spanning walls were revised to become deep steel girders, with sloping steel diagonal columns and tension tie beams. (Although the term "spanning truss" would be a more accurate description of these long-span steel structures, "spanning walls" was still colloquially used throughout the construction.) The largest of the steel girders, visible at the underside of the third floor, is a built-up steel I-section, 60 in. deep, with 3-in.-thick flanges.

It is also worth noting that project was one of the first to take advantage of IMMERSIFY, a virtual reality (VR) software





right: Looking into the new library.

package developed by LERA, the project's structural engineer, that allows users to easily import models from Revit and Rhino directly into a VR interface. Although the building's design was substantially completed by the software was available for the LERA team to use—and it is not just in-house software but can be licensed by outside companies as well—the designers translated the 3D model into IMMERSIFY to experience how it would look and feel firsthand, as well as to double-check that everything was in place. This gave the team a better understanding of the model going into the construction phases.

Iconic Architecture, Unique Structure

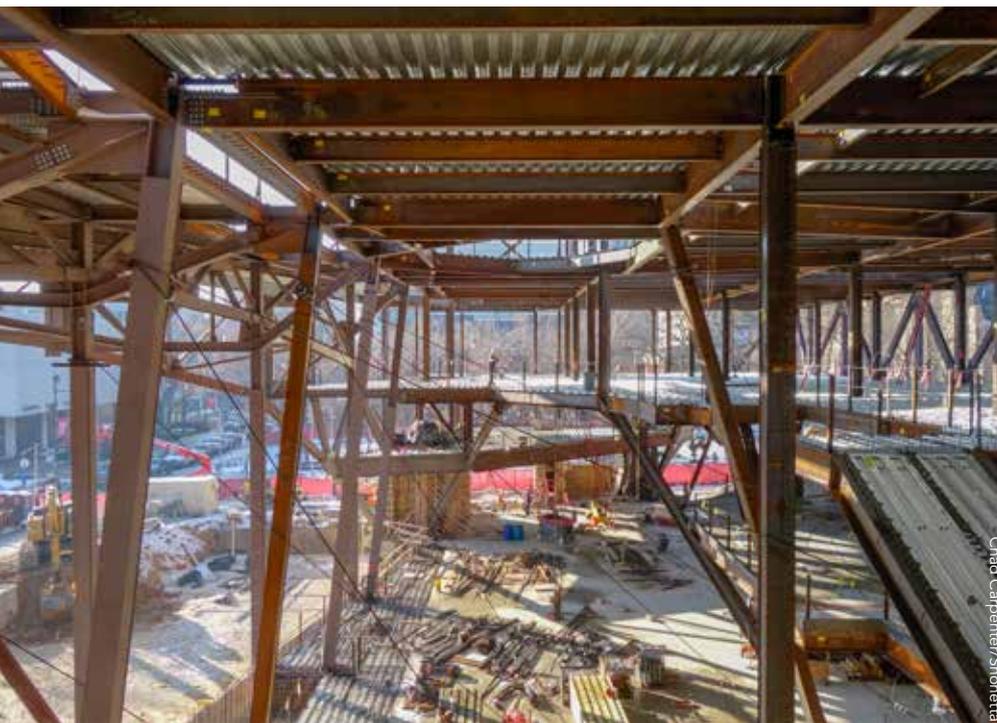
The iconic architectural shape of the building, with some regions cantilevering far beyond the footprint of the first floor, presented an opportunity to create truly unique structural elements. The main entrances contain cantilevered components at the eastern and southwestern sides of the building, while at the eastern side the cantilevered floor extends approximately 45 ft beyond the column support at the lower floors. A series of trusses, one story in height and extending into the building, are used to balance these cantilevered spans. The back-span of each cantilevered truss

is tied down with a sloping column, resulting in additional loads that must transfer through the adjacent floor diaphragm, with load paths directed to nearby shear walls.

At each connection of the cantilevered truss to the adjacent floor, a horizontal component of load from the column and truss is transferred through the connection to the adjacent floor framing. At some cantilevered trusses this transfer is not feasible, due to a large opening in the adjacent floor that blocks a direct connection to the floor diaphragm, so the horizontal load component is instead transferred through a wide-flange shape rotated on its side, which in turn transfers the horizontal load to floor framing beyond. These trusses, and many of their details, were carried over from the original building design, though the columns and back-span structures had originally been designed in concrete to help

counteract the overturning of the cantilevered trusses.

In order to provide robustness and redundancy to the structural system, the design for the cantilevered trusses considers the potential for a disproportionate collapse event. If there is a loss of a truss member, the trusses and the building as a whole will remain intact. This redundancy is accomplished through the use of bridging trusses between the cantilevered trusses, which transfer load from one truss to the adjacent trusses. The geometries at the intersections of the cantilevered trusses, bridging truss and canopy truss result in connections that are non-orthogonal and certainly anything but run-of-the-mill. Accordingly, the design focused on facilitating bolted connections and allowing the members with the largest loads to continue uninterrupted through the nodes. In addition, the truss connections were detailed to avoid cross-grain tension in the steel sections, and the



Chad Carpenter/Smithetta

above: Construction of the atrium, with "spanning wall" members visible in the distance.

below: Pipe columns in the future concrete wall allowed quick steel erection; some pipe columns are leaning to match the wall shape.



above: Building the trusses.



Mike Thompson/Staritect



wide-flange truss chords were oriented to simplify the connections, with tapered fill plates being used at skewed connections.

The southwest corner of the building stretches over the entrance, with a 40-ft cantilever on the south elevation and a 100-ft cantilever on the west elevation. Trusses are provided at the west and south elevations of the building, and a braced frame at the north end of the truss acts as a back-span, helping to reduce the weight of the truss members. A temporary erection column at the southwest corner supported the trusses and remained in place until the system was self-supporting following completion of the concrete shear walls and slabs up to the fourth floor.

Due to the university's ever-present student population, the walkways and roads immediately adjacent to the site were mostly left unimpeded, leaving the construction of the new library largely

confined to its site plot. The library takes up a large footprint relative to its plot size, and handling storm-water runoff required large drainage basins in the ground complemented by a green roof over the full extent of the building. These drainage basins are located at the southwest and southeast corners of the building, further condensing the laydown area. The laydown area was actually relocated around the perimeter of the building or within the building's footprint during various construction stages, requiring a careful scheduling effort that was handled well by Temple and the construction team.

Steel Symbol

Much of the structure of the Temple University Charles Library was effectively designed twice—once as a concrete building

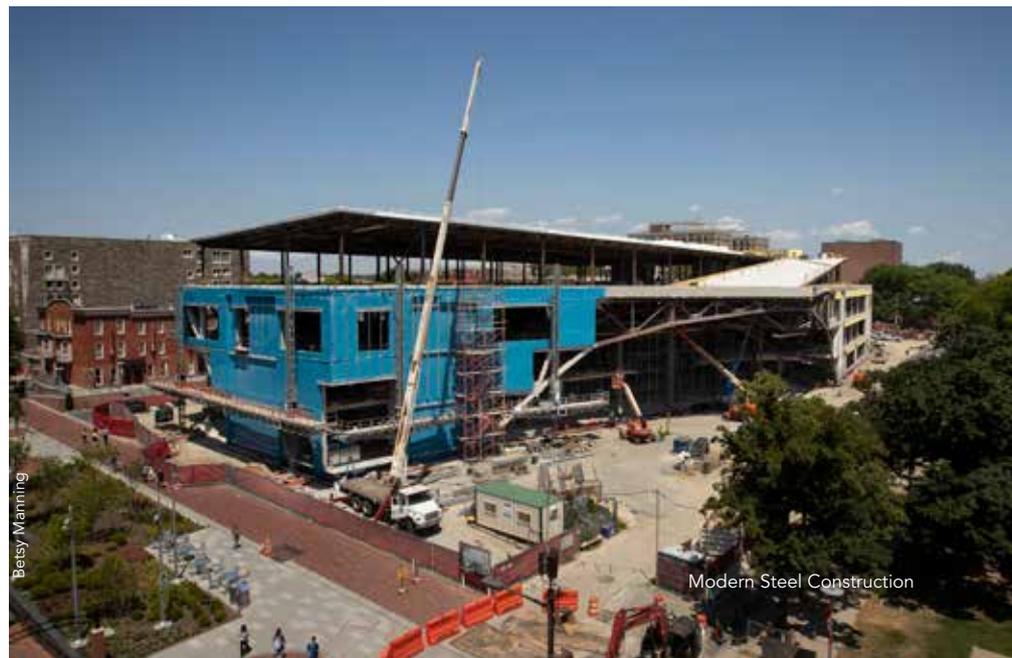


below: Truss erection at the southwest entrance. The corner column at the far right is a temporary support.



above: The building during steel erection.

below: The project following steel erection, with some envelope elements added.



and again as a steel building. As a result, the design team was tasked with not affecting the pace of construction while at the same time retuning the structural systems for the new building materials. An open dialogue and close coordination between the architectural team, contractors and the university proved crucial to ensuring that the original architectural vision would not be compromised. In the end, the state-of-the-art Charles Library will stand as a new symbol for Temple University's campus, elevating it with a 21st century architectural focal point. ■

Owner

Temple University, Philadelphia

General Contractor

Daniel J. Keating Company, Philadelphia

Architect

Snøhetta and Stantec, a joint venture

Structural Engineer

LERA Consulting Structural Engineers, New York

Steel Team

Fabricator

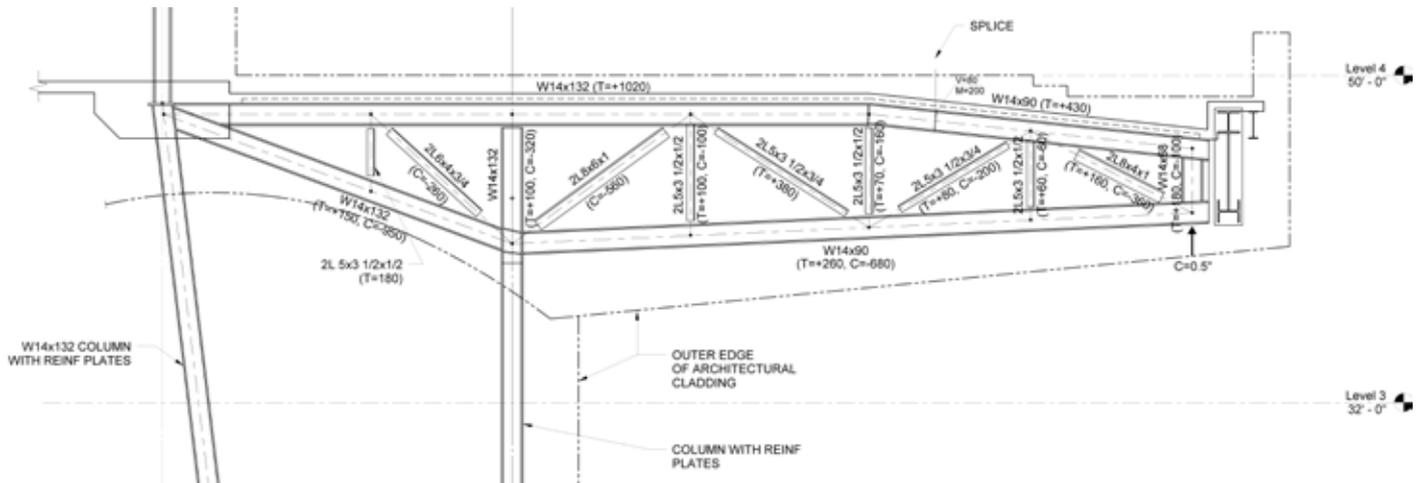
Owen Steel Company, Inc., Columbia, S.C. 

Erector

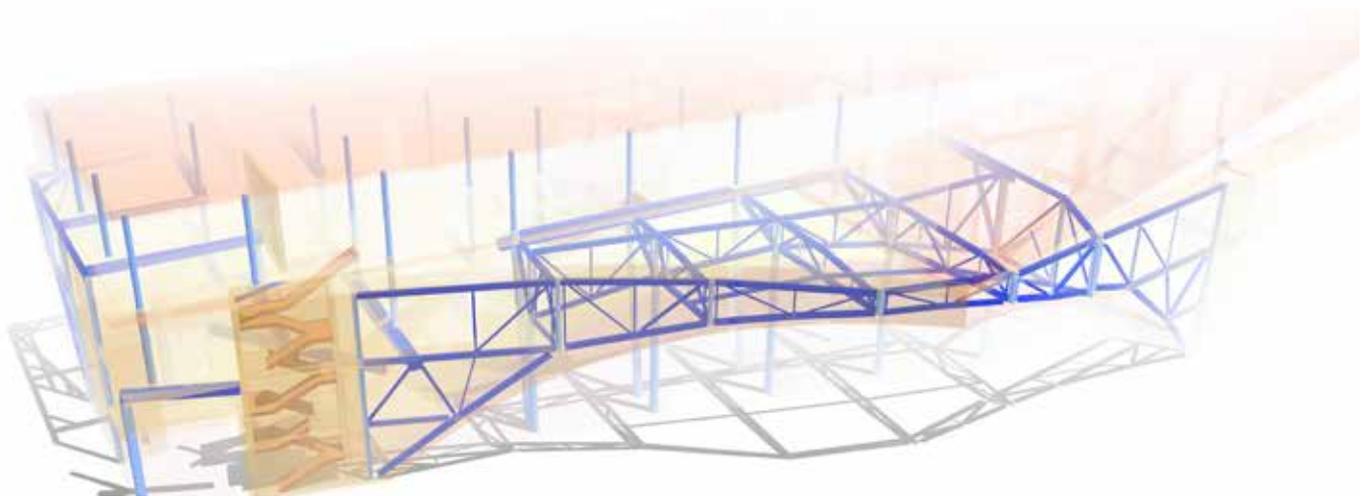
Steel Suppliers Erectors, Inc., Wilmington, Del. 

Detailer

MoldTek Technologies, Inc. USA, Cumming, Ga. 



A sloping-column-to-truss connection.



An overview of the cantilevered trusses at the east entrance.