Theater on the Roof

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There was nowhere to go but up for New York's Lincoln Center, which added a new performance space on top of its original theater building.

THE LINCOLN CENTER THEATER (LCT) in New York has long been associated with big productions.

But it serves as a showcase for lesser-known artists as well, as indicated by LCT3, a program of scaled-down productions and emerging talent.

In searching for a permanent home for LCT3's growing audience, the theater realized the need to expand its capacity within the Lincoln Center for the Performing Arts (LCPA) campus and add a small, intimate theater to serve LCT3's needs. However, historic preservation of the 16-acre LCPA complex, just northwest of New York City's Columbus Circle, had locked in the building layout and, except for temporary events, space was not available for new construction.

The LCT building, designed by architect Eero Saarinen, was originally built to house the 1,080-seat Broadway-style Vivian Beaumont Theater. The building features a column-free space spanning 175 ft, over which the New York Public Library for the Performing Arts is located; columns can only be found at the perimeter, and any expansion needed to respect this layout. Expanding downward into the ground had already been done in the past, all the way down to bedrock, to house the 290-seat Mitzi E. Newhouse Theater, LCT's second theater. Therefore, the only option was to follow the trend in city development and expand upward, requiring the insertion of new elements through existing volumes and changing the nature of exterior elements.

Preservation of the logic inherent in Saarinen's design meant that any major visual alteration to the base building was unacceptable. LCT wanted this proposed addition, which opened last May, to feel as though it had always been there. The design team responded with a light, airy 23,000-sq.-ft two-story addition on top of the original building.

Successful completion required carefully navigating and satisfying the requirements set by city agencies, the Lincoln Center Development Partnership, the New York Public Library, preservationists, artists and community boards. In addition to design, the critical issue of constructability on a beloved and architecturally recognized structure, and its added associated costs, framed the design-construct dialogue.

▲ The LCT3 addition, under construction.

▼ The interior of the space, with exposed truss elements.

▲▼ The wide-flange main longitudinal trusses, weighing about 65 tons each, are the main load-carrying elements of the addition.

Direct Landing

To limit the structure's weight, a steel frame with lightweight concrete on a composite metal deck was chosen. Since a standard column layout was impossible due to the limited capacity of the existing concrete girders, Severud Associates, the project's structural engineer of record, elected to land directly on the exterior columns and bypass the entire existing internal structural framing system. That decision would require LCT3 to become a bridge unto itself—a conceptual nod to the minimalism of the original Saarinen design.

Deep truss configurations were picked over arches and plate girders to minimize weight, optimize the architectural layout and allow clear runs for the mass of conduits, lighting, data, ductwork and the systems associated with theater design. Two 30-ft-deep wide-flange main longitudinal trusses, weighing about 65 tons each, would become the main load-carrying elements that would vault the 175-ft span of the original building. Two additional cross trusses would be 75 ft long and each end would cantilever an additional 15 ft. Together they would also become the lateral force resisting system. A third long truss would tie it all together.

The exact location of the trusses played an important role in balancing the reactions to the chosen columns below, since it was imperative that the load being delivered to the columns was exactly what the columns had in "reserve." The reserve itself was a number conjured up by the structural engineers, who combed through the existing structural system, paring down theoretical excess, reducing allowances and precisely accounting every weight that was in position rather than allocating weight by floor area. A series of non-destructive tests determined the actual material strength of the various existing structural elements, and the reserve increased.

Since the architectural motif was a light box hovering over the existing building, 36-in.-deep wide-flange steel girders were used to transfer the load from the trusses into the columns below via isolating bearing pads. The idea was that if there had to be isolators, then they were going to do double duty and they were designed to allow the new structure to slide over the tops of the old columns, thereby subjecting the existing columns to vertical loads only. In addition, a careful and thorough distribution of the various


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The new structure provides increased capacity for the growing LCT3 program.

force combinations eliminated the need for an overall seismic retrofit of the entire building.

Headroom clearance requirements and architectural walkways necessitated the incorporation of Vierendeel panels into the truss configuration. The three long trusses could not be hidden, so the architects chose to show them off as architecturally exposed structural steel (AESS). Since aesthetics precluded gusset plates, the engineers answered by designing and detailing fully welded truss connections in all the visible zones.

Access to the new space is provided by an elevator tower, which carefully pierces through the existing structure from the foundation up to the rooftop. Constructed of square hollow structural steel (HSS) and channel glass, the elevator tower was designed for strict tolerances of wind and seismic movement. Structurally, it is completely independent from the original building and the new rooftop theater, a slender steel and glass tower unto itself.

Relieving Stress

Staging the installation of the curtain wall façade presented several challenges. The glass had to be attached to the trusses before the concrete floors could be formed and the interior finishes added. But forming the floors and adding the finishes would make the trusses deflect, which would likely cause the glass to stress and crack. To prevent the glass from cracking when the floors were formed, the team designed joints into the curtain wall to accommodate those deflections. To prevent cracking during installation of the finishes, the team applied temporary weight to the trusses prior to attaching the curtain walls; doing so ensured that the glass was in the appropriate position to handle those deflections. It was a balancing act between the jointing in the glass, the sequencing of the finishes and the weight that could be added at any given moment in time. Cambers were calculated so that in their final loaded configuration, the trusses would stay flat over their entire span.

Another challenge: The theater could not be stick-built because the roof of the original building was incapable of handling the weight of the raw material. Instead, the structural framing, including the large trusses, was prefabricated, assembled in the shop to ensure the fit, deconstructed and shipped to New York. It was divided into sections so that a crane could lift each section and hold it in place over the roof during construction. Crane reach and lift capacity decided the size of the spliced segments (the furthest reach was 220 ft with 13.5 tons, while the heaviest was 50 tons at 105 ft).

Weight Issues

As construction began, additional challenges related to weight arose and the engineers became wary that the foundation of the original building had not been constructed in accordance with the building's design and became concerned over the associated differential settlement issues this would cause. Test pits and core samples were required to expose the theater's foundations, which rest directly on bedrock, and the engineers' fears were confirmed; the foundation was smaller than depicted on Saarinen's drawings. Worse, there was no discernible pattern to the deviation in the four column foundations. While the columns worked, the foundations did not.

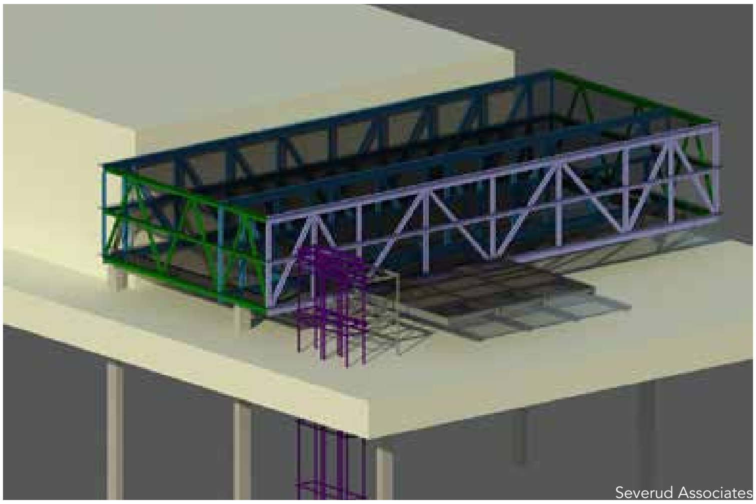
The ostensibly obvious solution—enlarge the foundation—would have required evacuating the building and displacing a number of people from their offices within LCT. It would also delay the project. This led the structural engineers to conduct an even more sophisticated analysis of the new theater as well as the original building. The analysis confirmed that the foundations were not evenly loaded, and once the new theater was constructed some of the columns would settle more than others. Concerned that the differential settlement would cause unpredictable micro-cracking in the original building, the engineers analyzed the structure yet one more time, this time with the focus on differential deflection and crack control. From there, they determined that they could accommodate a slight amount of differential settlement between the columns.

Disciplined Theory

Structural engineers are responsible for the general welfare and safety of the public in and around their structures. As such, we can be a conservative bunch. We tend to be even more conservative when modifying and adding to structures that are not ours but were designed by others. But how much of that conservatism is genuine and how much of it is a fear of the rigorous application of engineering theory?


Mercedes I Armillas, AIA/H3 Hardy Collaboration Architecture

One of the lifts performed by the Manitowoc 16000 crane.


Severud Associates

A 3D model showing the trusses of the new addition and the elevator, which is structurally separate from the new and old buildings.

Great structures are possible when that fear is leashed, when disciplined theory rules, when architect, engineer and builder are perfectly in synch and believe in the end product. LCT3 perfectly illustrates this. MSC

The authors would like to note the contributions of Lou Occhicone, P.E., Daniel Surrett, P.E., and Gustavo Amaris to the successful completion of the project.

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