MERGING Arts and Sciences

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Steel overcomes construction and serviceability challenges in a multi-building expansion at Columbia University.

COLUMBIA UNIVERSITY is expanding its Manhattan footprint.

Located on 17 acres of New York's old Manhattanville manufacturing zone in West Harlem, the university's new mixed-use campus project will house up to 6.8 million sq. ft of space for academic, research, residential and support services for the university, as well as civic, cultural, recreational and retail spaces. The four-block development is located between

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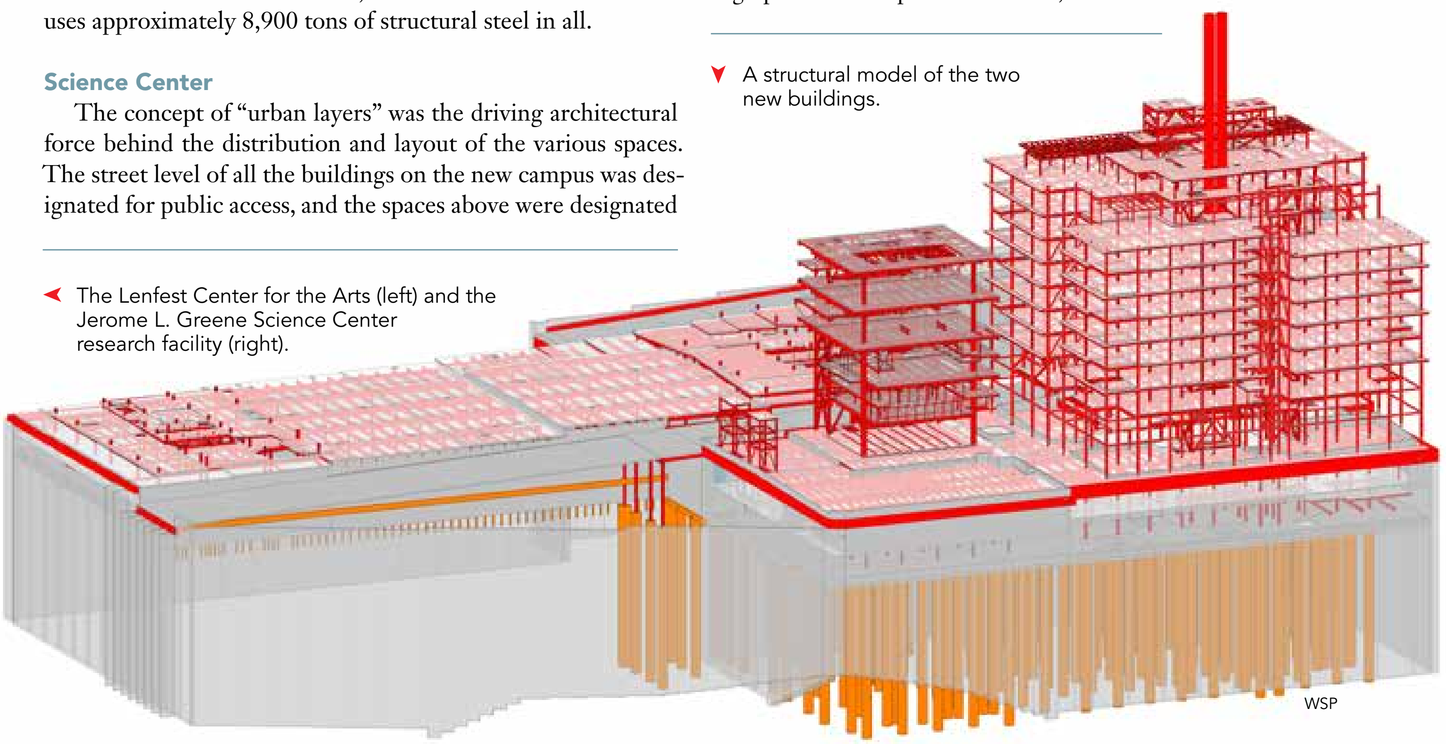
129th and 133rd Streets, and delimited by Broadway and 12th Avenue to the east and west, respectively, with some sites located to the east of Broadway.

Renzo Piano Building Workshop and Skidmore, Owings & Merrill designed a master plan for this ambitious project, working together to create a rich urban landscape that emphasizes accessibility and openness with seamless integration into the existing street grid and surrounding community. Davis Brody Bond served as the architect of record for the initial phase of the project, and WSP provided structural engineering services for several aspects of the project, including the Jerome L. Greene Science Center, the Lenfest Center for the Arts and the underground Central Energy Plant, in addition to the below-grade areas designed and built during Phase 2 of the project. Phase 1 of the project, discussed here, comprises the Greene Science Center, which is home to the Mortimer B. Zuckerman Mind Brain Behavior Institute, and the Lenfest Center—and uses approximately 8,900 tons of structural steel in all.

Science Center

The concept of "urban layers" was the driving architectural force behind the distribution and layout of the various spaces. The street level of all the buildings on the new campus was designated for public access, and the spaces above were designated to university programs. In line with the architectural intent, the structural design incorporated architecturally exposed structural steel (AESS) members, including special shapes for columns and connections, engineered castings, notched connections for braces and distinct links between structural and nonstructural elements at mezzanines and common spaces. The use of AESS was extended to the rooftop terraces, which are surrounded by trellises and house the support framing for cooling towers. Smoke stacks extending from the energy plant in the basement to the rooftop of the science center pay architectural homage to the neighboring structures. All exposed steel was coated with shop-applied intumescent fireproofing paint, which required extremely careful handling during transit.

The science center is a nine-story, 450,000-sq.-ft research facility housing core research spaces, state-of-the-art laboratories and world-class conference accommodations with gathering spaces at the penthouse level, and will serve as the intel-



A structural model of the two new buildings.

The Lenfest Center for the Arts (left) and the Jerome L. Greene Science Center research facility (right).

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The new buildings are located in the old manufacturing zone of Manhattanville.

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Exposed exterior steel of the science center.

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The Lenfest Center for the Arts comprises 56,000 sq. ft over eight stories.

The project is next to an elevated subway line.

lectual home for the university's Mortimer B. Zuckerman Mind Brain Behavior Institute. The building has been designed to maximize creative collaboration by placing open stairways and bridges at the axis and four corners of the building, unobtrusively linking common spaces, individual offices and research and lab groups to form a coherent and vibrant community.

Choosing steel for the structural framing system aligned with the client's requirement for large spans and open spaces and expedited construction synchronized with top-down foundation construction. (The structural alternative of using cast-in-place concrete was explored, though the tall floor-to-floor heights on most levels would have resulted in costly formwork and reshoring systems.) In addition, the steel framing solution provided column-free for conference rooms and laboratory spaces and also blended harmoniously with the architectural intent, resulting in a significantly lighter building in comparison to a cast-in-place concrete solution, thereby decreasing both the gravity load demands upon the foundation and lessening the seismic load demands upon the superstructure lateral system.

The lateral load-carrying system of the structure is comprised of a core of seismic braced frames, perimeter moment frames and exposed structural steel frames braced by diagonal tension rods located on the exterior sides of the building façade. An interesting feature of the system is that the first floor served as a diaphragm transferring all lateral loads to the perimeter slurry walls.

The exposed tension rods, which met the aesthetic intent and are part of the lateral load-carrying system, connect to the main frames by an elegant solution of notched ends. The structural solution provided by WSP, which was based on using exposed steel members to highlight the elegance and beauty of the system, was consistent with the architectural intent of tying the building aesthetics with the elevated structures bordering two sides of the new campus.

In order to provide the public spaces required by Columbia, additional pickup trusses were introduced at the mechanical level of the second floor, which created an unobstructed double-story open space on the ground floor. Special attention was given to the design of the vibration-sensitive laboratory areas, especially in light of the use of a structural system based on light steel frames, where reduced mass and stiffness are linked to potentially excessive vibrations. An extensive, dynamic study focused on vibration sensitivity was carried out to meet the stringent vibration requirements of the project, while optimizing member size, member location and connections. Required adjustments to mass and stiffness of structural elements throughout the building were made to meet the vibration criterion required for research and medical equipment. For instance, all floors housing sensitive laboratory equipment had 5-in.-thick slabs cast over 3-in.-deep metal deck, and the primary support members of the floor framing had moment connections to the supporting columns. In summary, the building meets the stringent vibration threshold criterion required for research equipment, including the creation of isolated testing booths for very sensitive equipment.

The design for structural integrity went above and beyond the minimum requirements of the *New York City Building Code*. The enhancement of structural redundancy and resilience, in line with the sensitive occupancy of the building complex, was paramount to the design process.

Art Center

The second building in Phase 1 of the project, the Lenfest Center for the Arts, has a smaller footprint than the science center, with a total building area of 56,000 sq. ft spread over eight stories. The structure stands prominently on a small public plaza and houses venues for the School of the Arts, including a state-of-the-art film screening room and two spaces for flexible performances and presentations, as well as the Miriam and Ira D. Wallach Art Gallery.

For this building, the designers' biggest challenge was to find a structural steel framing system with the smallest number of structural columns in order to maximize the open space area with added flexibility for use. The most efficient structural solution was the use of cellular beams, which allowed spans up to 54 ft and also became part of the architectural expression by remaining exposed. Another advantage of using these perforated elements for the floor framing is that they allow mechanical equipment to pass through the beams without increasing the inter-story height, thus maximizing available headroom.

In addition to the strict requirements to limit vibrations, which were shared with the Greene Science Center building, the Lenfest Center was designed to stringent acoustical criteria, particularly the theater and performance spaces. The task became even more challenging as the building sits on top of the underground energy plant.

From the Ground Up—and Vice Versa

The foundation of the Manhattanville Campus serves multiple purposes. It provides adequate support to the superstructure houses the extensive central energy plant and provides access to

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Exposed steel stairs and bridge in the science center.

a loading dock, as well as spaces for storage and maintenance. The entire development has a common basement that extends the entire site, with depths ranging from 50 ft to 60 ft. The energy plant is located in the now-finished Phase 1 area.

The soil conditions at the site and the accelerated construction schedule required by the client posed significant structural design and construction challenges for the project, including sloping ground levels, highly varying depths to rock and a high groundwater table. Furthermore, the proximity to the elevated portion of the MTA subway line on the east side and the presence of the elevated Riverside Drive viaduct on the west side imposed further constraints to the design and construction procedures and required mitigation of sound and vibration on the sensitive facilities in the building.

The structural solution for the foundation and support of excavation was a perimeter diaphragm/slurry wall system, which provided water cutoff and the required structural stiffness to distribute vertical loads to the soil and rock layers. It also provided adequate restraint to adjacent soils, thereby minimizing the settlement of neighboring infrastructure, in particular the elevated subway and the viaduct. The system also enabled the use of a top-down construction process, which dramatically increased the speed of construction by permitting the erection of the vertical elements of the superstructure simultaneously with the site excavation. While top-down construction is common in London and Boston, given their unique subgrade conditions, it is rarely used in New York, especially on such a large-scale site.

One interesting challenge imposed by the top-down construction sequence and multiple phases of foundation construction was the temporary condition of unbalanced lateral pressures due to the presence of soil around the basements, which were constructed first while excavation proceeded on other areas of the project. This situation was mitigated by designing slurry walls at the perimeter of earlier phases to serve as interior shear walls during later phases.

The foundations of the interior columns were installed from ground level using load-bearing elements (LBEs), which were built by embedding a structural steel shape into a concrete shaft. As construction proceeded downward to the basement, the structural shape was exposed. In Phase 1 of the project, 95 LBEs comprised of 6-ft-diameter caissons with an embedded wide-flange steel shape, some of them reaching depths in excess of 150 ft, were installed.

The tolerances for the location of the caissons and the corresponding embedded steel shapes were very stringent since the shapes were to connect directly to the superstructure steel frame. The connection details between the LBEs and the superstructure were envisioned to allow limited yet reasonable adjustments, notwithstanding the requirement for even tighter tolerances around the elevator cores.

The permanent monolithic connection between the basement slabs and the perimeter slurry walls, which were cast at a much earlier stage of construction, required an innovative solution based on shear keys built into the walls by means of block-outs, where dowels with couplers were placed for rein-

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A notched braced connection.

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Cellular beams top the Wallach Gallery in the Lenfest Center.

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➤ Excavation during the top-down construction process.

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▲ Proximity to the elevated subway line required enhanced sound and vibration mitigation.

➤ Open stairways and bridges at the axis and four corners of the science building unobtrusively link common spaces.

➤ Bracing in the science center.

▼ Cellular beams allowed for column-free spans of up to 54 ft in the Lenfest Center.

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forcement. Since the basements are used to house the energy plant, it was imperative for the foundation to be as impermeable to groundwater as possible.

The project was developed using Autodesk Revit 3D, which enhanced coordination between all design and trade consultants and minimized field coordination issues, especially for the structural members and extremely tight and complex MEP services.

The United States Green Building Council (USGBC) has awarded a LEED Platinum rating (Phase 1) for Neighborhood Development (LEED-ND) to Columbia University's Manhattanville Campus plan, making it not only the first LEED-ND certification in NYC but also the first for a university plan in the U.S. ■

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