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Author: Julieta Boy, Design Manager, LBR&A Arquitectos

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Mexico's New Tallest is an "Open Book"

Julieta Boy

Author

Julieta Boy, Design Manager
LBR&A Arquitectos
Rubén Darío 28
Bosques de Chapultepec, Mexico City
Mexico
t: +52 55 5279 1800
e: jboy@lbr.com.mx
www.lbrarquitectos.com

Julieta Boy
Architect Julieta Boy is currently the project manager at LBR&A Arquitectos, where for the last eight years she has been leading the development and construction of Torre Reforma, Mexico City's tallest building. She holds two Master's degrees, one on Ephemeral Architecture from the Universidad Politécnica de Cataluña, Spain in 1996, and the second in Architecture Design from the Universidad Nacional Autonoma de Mexico in 2008.

For more than 20 years, Boy has been a key contributor to the work of Rivadeneyra Arquitectos, Becker Arquitectos and LBR&A Arquitectos, in which she has specialized in development of corporate, urban and residential projects. As an independent practitioner, she has developed single and multifamily living projects. Boy has been a frequent contributor to publications specializing in construction and architecture, including *Enlace y Obras*.

Torre Reforma is not only the tallest building in Mexico City, but is also representative of innovation and leadership in the high-rise building industry, which has begun a shift away from a generation of all-glass façades. Here, high seismic conditions and the presence of a historic building on the site resulted in a highly distinctive hybrid "open-book" form, comprising two exposed concrete shear walls and floor plates enclosed in a dramatically cantilevered steel diagrid. Torre Reforma received a Finalist recognition in the Best Tall Building Americas category of the 2016 CTBUH Awards.

Context

It is important to understand Torre Reforma within the arc of Mexico's brief but dynamic high-rise history. The modern story starts with the Torre Latinoamericana, completed in 1956 at 204 meters and 44 stories, overcoming many engineering challenges in the process, as it is sited in a seismic zone with soft soil. For many years the tallest building in Mexico and Latin America, it was surpassed – almost 30 years later – by the Torre Ejecutiva Pemex (1982, 212 meters, 54 stories) and the Torre Mayor (2003, 225 meters, 52 stories). In 2016, the Torre Reforma surpassed all others in the capital, at 246 meters and 55 stories, including the recently finished Torre BBVA Bancomer (235 meters, 50 stories), signaling a turning point for vertical urban growth in Mexico City.

Figure 1. General view of the new tall buildings on Paseo de la Reforma, with the Torre Reforma at the right. © Alfonso Merchand

Torre Reforma is one of the most prominent skyscrapers in a developing area, in which many others are expected to be built. Currently, there are several skyscrapers of more than 200 meters under construction in Mexico City, most of them on Paseo de la Reforma (see Figure 1). Demographics is the main driver: 8.9 million people reside in the central city and 21 million people total live in the metropolitan area. With 26.3% of Mexicans aged between 15 and 29, almost two million young people enter the Mexican economy every year. The bowl shape of the city's enclosing valley limits the potential of horizontal sprawl. Thus, Mexico City's downtown will definitely have to build upwards as it grows.

> "The building is organized into 14 four-story clusters, 'buildings within the building' that allow users to interact with the city on a larger scale, and within their workspaces on a smaller scale."

The Site and the Skyscraper

Located on Paseo de la Reforma, one of Mexico City's most renowned avenues, Torre Reforma is part of a cultural, historical, and financial district, and is restricted to a 2,800-square-meter site – extremely small for a high-rise building containing 87,000 square meters of space.

Diverging from the standoffish-icon model for skyscrapers, Torre Reforma embraces its surroundings. The existing historic house on the site was integrated, becoming part of the main lobby (see Figures 2 and 3). The commercial areas at the ground floor and the first basement allow for the street activity to flow into the building. Reflecting an understanding that a skyscraper is a vertical continuation of the city, the building has an array of services that includes sporting facilities, open spaces and terraces, bars and restaurants, gardens, an auditorium, and common meeting rooms.

Torre Reforma is also accessible in a practical sense, as it is well connected to urban infrastructure and services. Its strategic location is surrounded by important avenues such as the aforementioned Paseo de la Reforma, Avenida Insurgentes – the longest avenue in Mexico City – and the Circuito Interior – an urban freeway connecting the city's central neighborhoods. At the ground level, the sidewalks are expanded and made accessible for all users, giving priority to pedestrians over vehicles. The existing infrastructure of the neighborhood includes two subway stations, public buses, and multiple public bicycle stations. The historic house retains its urban value, serving to transfer from human scale at pedestrian level to a high-rise building scale. Torre Reforma therefore not only improves the visual quality of the city's skyline, but also the street level experience for pedestrians.

Figure 2. The historic hacienda-style house at the base of the tower has been incorporated as part of its lobby.

Figure 3. Torre Reforma, Mexico City rises above the hacienda.

> “The exposed concrete walls of the tower are not just powerful symbols – they are the structure, the architecture and the construction process synthesized.”

An Uncommon Geometry

Torre Reforma's unique shape, derived from the architectural-structural parti, takes into consideration many social, financial and environmental factors. The 55-story building, distinguished by its triangular form, is composed of two 246-meter-high exposed concrete walls, resembling the form of an open book that is closed by a third "hypotenuse" of a steel diagrid over glass, affording a panoramic view to Chapultepec Park (see Figures 3 and 4). Its shaded façades, hung from the diagrid, allow for versatile column-free interiors and have a great impact on the reduction of energy consumption, representing a remarkable shift from the all-glass façade aesthetic common to contemporary skyscrapers.

The "open book" of the tower supports and manages the loads of the building. A diagonal exterior steel mesh crosses along the main façade as a substitute for columns. This transfers the loads to the structural concrete walls, and then along the wall to the foundations through the basement slurry walls. The solid concrete structural and architectural façades are influenced by Pre-Hispanic and colonial Mexican architecture, in which tectonic materials such as stone are predominant, reinterpreted in the contemporary Mexican architectural context (see Figure 5).

The exposed concrete walls of the tower are not just powerful symbols – they are the structure, the architecture and the construction process synthesized. They function both as a backbone and a supporting element, but also as dynamic elements that allow the building to move safely in an earthquake. These massive, perforated walls are inserted in the subsoil to a depth of 60 meters below grade to bedrock, giving the necessary stability to the building.

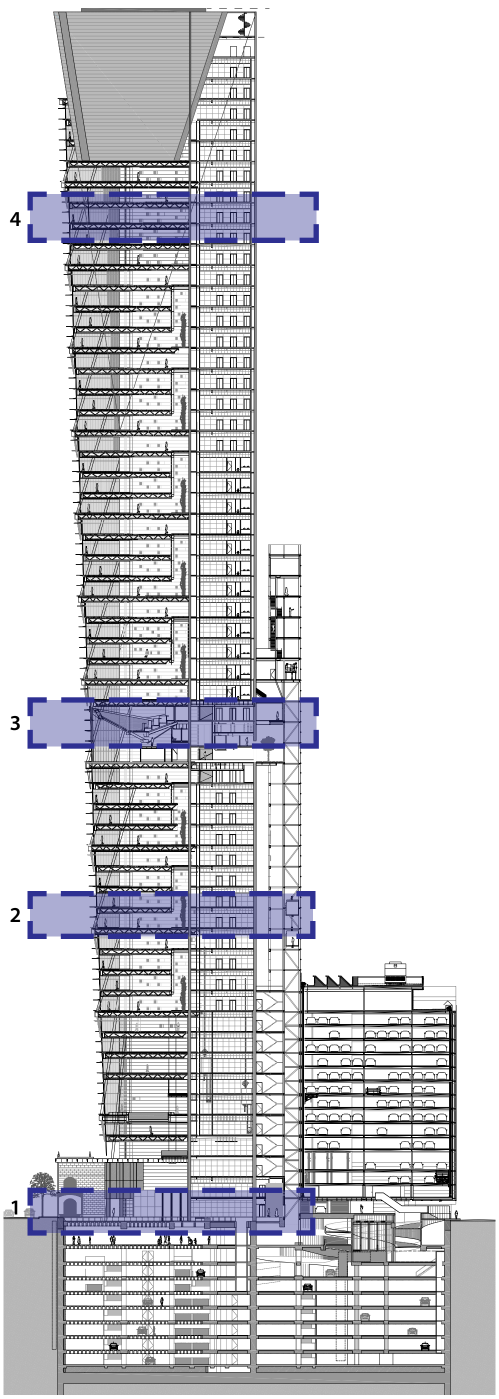

Figure 4. General plans and section showing the "open book" scheme.

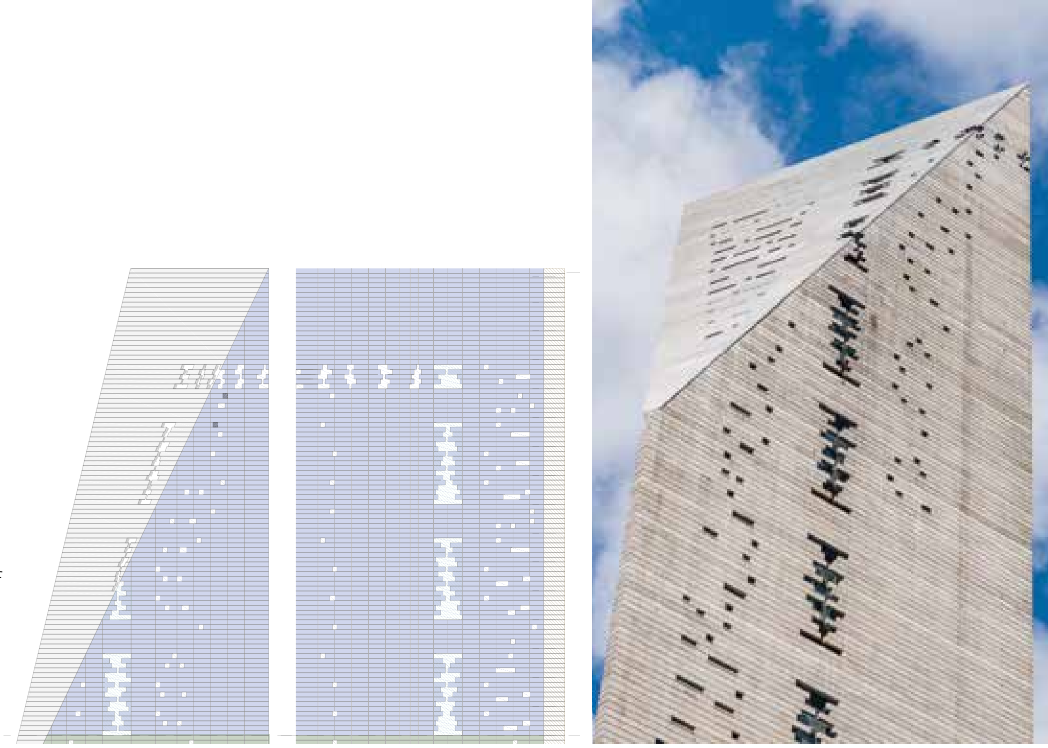

Figure 5. Torre Reforma concrete façade, influenced by Pre-Hispanic and colonial Mexican architecture.

Figure 6. The historic house provides a link between the high-rise, Mexico City's past, and the pedestrian scale.

According to city regulations, the allowed height for the building is twice the width of the street in front of the property, in this case, Paseo de la Reforma. However, although there are façade height restrictions, the regulations applicable to the property allowed for a higher density. Per the Mexican norm, an imaginary line is traced at 1.80 meters in height from the opposite side of Paseo de la Reforma, passing through the highest point of the façade. The potential height of the building is the limit of the imaginary line. This allowed Torre Reforma to achieve 246 meters in total height and a sloped façade starting upwards from 200 meters.

Torre Reforma's faceted shape was devised partially to accommodate a 660-square-meter historic house that already existed on the site. The early twentieth-century house is historically protected by the National Institute of the Arts (INBA) and cannot be demolished or modified (see Figure 6). In order for the building to be economically feasible, the house was integrated into the main lobby (see Figure 2), and the space beneath was used for the foundation, underground parking, and services. As a result, the house was moved. It was reinforced by thickening its walls and pouring a concrete slab underneath, which was placed on top of rails and moved temporarily, 18 meters away from its original position. After the foundation was completed, the house was returned to its original position, and the underground levels were dug. The old, damaged limestone has been restored and the house is currently rented as retail space. The glass façade of the tower turns 45 degrees to face the best views of the city, supported by a 14-meter cantilever over the historic house.

The Exterior Layer

Considering the AIA 2030 commitment for energy performance, Torre Reforma's structural efficiency and architectural design has obtained USGBC LEED Platinum pre-certification. The overall building envelope generates good energy performance, representing a 24% reduction in energy use against a conventional building of the same size, according to American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) standards. The reduction of energy consumption is due to the interplay of the façade and the structural design: the concrete shear walls work in tandem with the double-layered glass façade and its fixed horizontal shades, allowing natural light to penetrate to all office spaces. This dramatically benefits the occupants by providing aesthetically appealing, comfortable interior spaces, environmental characteristics that have been shown to enhance employee performance. In addition to providing shading and thermal protection to the interior spaces, the concrete shear walls are architecturally exposed and do not require any additional cladding materials (see Figure 5).

The glass façade system improves the minimum solar coefficient (SC), solar heat-gain coefficient (SHGC), *u*-value, reflection values and light transmission levels that ASHRAE recommends. Each insulated glass panel exposes a single layer of low-*e* glass to the exterior side, with a double layer of laminated glass on the interior. This double façade also serves as an acoustical damping feature. The façade has 1.2-meter-deep horizontal aluminum shades, at 2.1-meter intervals along the glass face, giving the tower a strong horizontal language (see Figure 7). The other two

Figure 7. Horizontal aluminum shades.

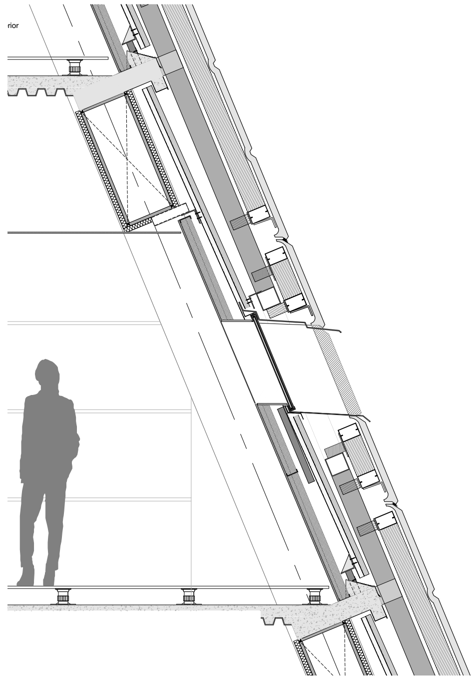

Figure 8. Prefabricated concrete panels on the sloped façade.

façades of the main tower are exposed in-situ concrete shear walls with punched windows, following a pattern based on the interior space use, the structure, the ventilation and the construction process. On the upper floors, the shear concrete walls give way to prefabricated glass-fiber-reinforced concrete (GFRC) panels. This sloped façade also includes deep-set insulated windows (see Figure 8).

On Level 23, the glass façade system opens up to a dramatic outdoor sky lobby space. The triple-height sky lobby offers unobstructed views of the surrounding city and nearby Chapultepec Park. A glass screen protects occupants from wind without obstructing views, but the remainder of the space is open to the elements (see Figure 9).

Directly above, an interior auditorium interacts with the outdoor area via a triangular extension featuring angled glass that looks down on the city and space below (see Figure 10). This also serves to provide exceptional natural lighting to the auditorium. The architectural expression of the triangular extension is clearly visible from the exterior and references the cantilevered geometry of the tower.

Interior Flow

The key word that defines the interior design of the Torre Reforma is "flow;" of people, fluids, loads, energy, etc (see Figure 11). The building is organized into 14 four-story clusters, "buildings within the building" that allow users to interact with the city on a larger scale and within their workspaces on a smaller scale (see Figure 12). In a city with high seismic activity, the concrete walls were designed to bend at the punched openings, which are repeated at every cluster along the tower. These have the added effect of providing natural light to interior gardens in the triple-height spaces. These gardens are an extension of the horizontal public space at street level along a vertical axis, creating indoor micro-spaces (see Figure 13).

The building is designed to optimize the flow of occupants within the building, but also in relation to the city. Within the building, the elevators for low-, mid-, and high-rise zones are separate in order to optimize service for different users, but they share the same shaft space for efficiency (see Figure 11). From the conception of the project, the team has pursued the advice of the best international experts in high-rise

Figure 9. A triple-height sky lobby provides open-air, unobstructed views of the city.

Figure 10. The auditorium features dramatic triangular viewing glass that provides natural light to the interior.

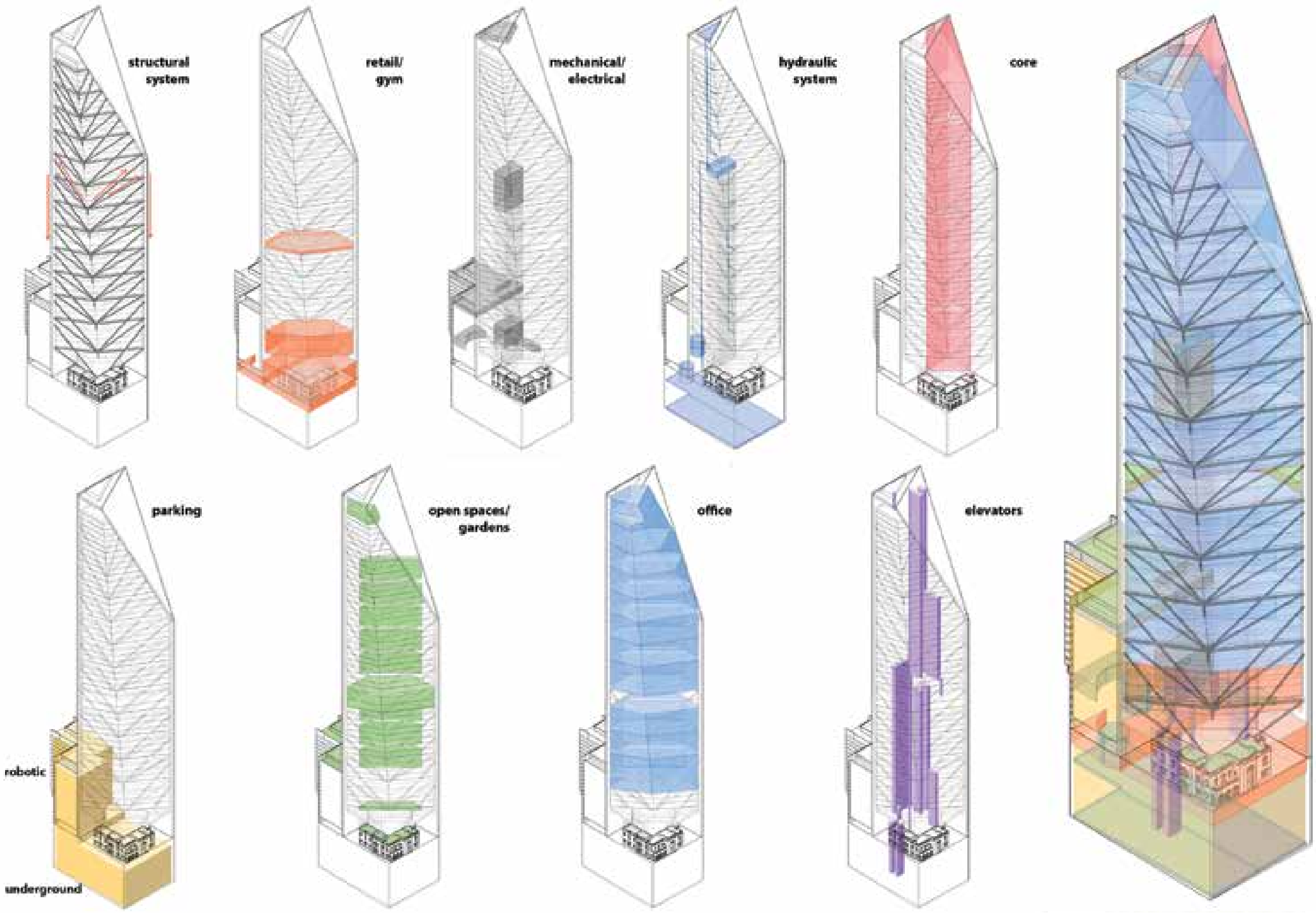

Figure 11. Flux diagram.

buildings, with the safety of all users being the most critical objective. By using an Emergency Elevator Evacuation System (EEES), elevators can be used during a fire when shafts are pressurized and refuge areas are provided on each floor. This is not a common practice in Mexico, which has relatively few high-rise buildings, so some user education is required.

Compared with other big cities, where parking requirements are minimal, Mexico City's regulations require one parking space for every 30 square meters of office area and one parking space for every 40 square meters for commercial space. Thus, Torre Reforma required a 1,000-car parking facility, which posed a special challenge on a small site. As a result, the building has an eight-level underground parking ramp for 600 cars, accompanied by two robotic parking

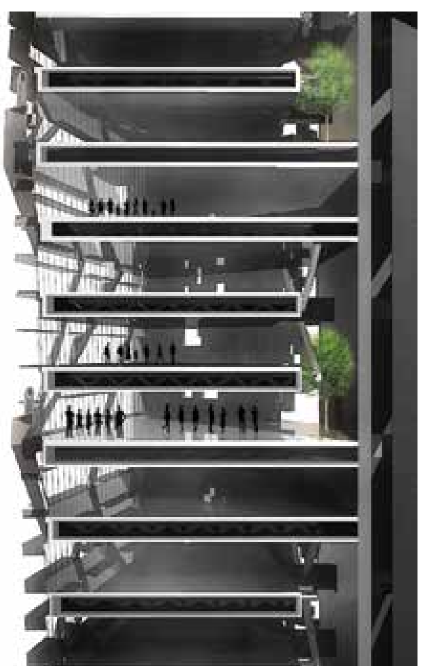

Figure 12. Section cluster.

Figure 13. Indoor micro-spaces with triple-height patios.

buildings for 400 cars in the back of the main tower. The robotic system has a low impact on the environment compared to a conventional garage, because no toxic fumes are emitted while parking, and the space doesn't need to be lit or ventilated. In order to have the lowest possible impact on neighboring streets, the underground parking garage has a third access ramp that can change its direction from entering in the morning to exiting in the afternoon.

Tall and Green

Sustainability is no longer optional. The global marketplace requires companies with global reach to demonstrate their commitment to preserving the planet's natural resources, and their facilities must reflect this. Torre Reforma is an exciting project for Mexico City. Its sustainable features and well-considered construction practices make a global statement about state-of-the-art construction in Latin America. This showcase project is expected to help encourage more green building in Mexico City and surrounding regions. The owners realized during the design process that meeting the code and regulations would result in 33 LEED credits. Beyond this, they realized that a demonstrably sustainable design would improve the payback on their investment; thus, it was agreed to seek the Platinum certification by going beyond code and incorporating innovations into the design. In 2016, the building received the LEED Platinum Core & Shell (V2.0) certification with 45 credits.

Rain and wastewater are 100% reused in Torre Reforma's water treatment plant, mainly for bathrooms and air conditioning. Water tanks, dispersed along the tower for more effective local distribution, rely on gravity rather than electric pumps, a particularly useful feature in a fire emergency. The building has a primary set of water pumps, which deliver water from the basement to a mid-level tank at the 30th floor, and from there to the top of the building. From the 30th floor and top tanks, water is delivered to all services by gravity, including the fire-protection system for hose valves and sprinklers (see Figure 11).

The water treatment plant makes this building an exemplar in Mexico. The system will allow 100% of wastewater to be treated and reused on-site, mainly in the cooling towers and in all sanitary fixtures of the low-rise and the retail areas. This treated water will serve all street-level and low-rise irrigation needs. The storm drain at the lower basement will harvest 100% of the rainwater and reuse it in multiple fixtures throughout the building.

In addition to water treatment, the building actively manages natural air flow. Automated controls open windows before dawn to allow cool air into the building and release warmer air to the outside. Additionally, naturally ventilated triple-height atria throughout the building contain interior gardens with tall trees and other vegetation, which improve air quality as well as airflow between the core to the tenant areas (see Figure 14). Floor-to-ceiling glazing will allow the gardens to be viewed from the outside (see Figure 15).

Seismic Safety

Because Mexico City is a high seismic area, the tower achieves high levels of seismic performance, demonstrated through advanced analytical techniques and innovative structural solutions. The structure exceeds the requirements of the building regulations of both Mexico City and the US state of California to provide maximum safety. The seismic systems in the tower are required to address the unique geometry of the building. Structural cross-bracing membranes on the upper levels help stabilize the tower in case of an earthquake.

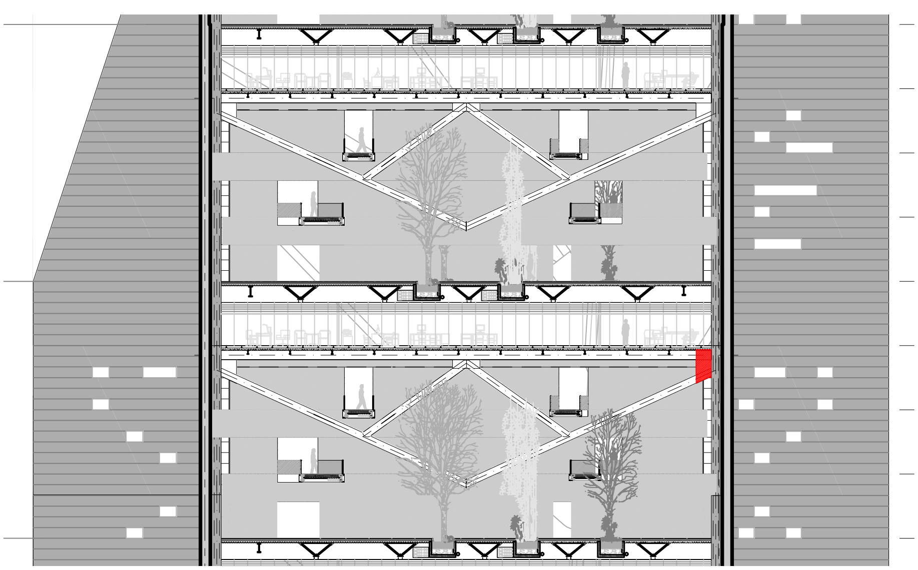

Figure 14. Triple-height atria containing vegetation and trees.

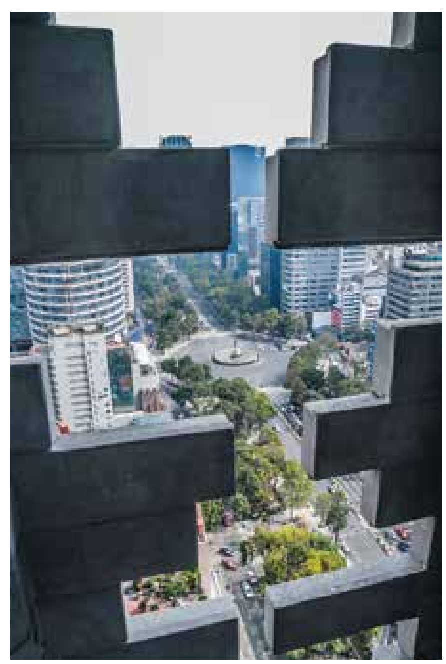

Figure 15. Openings in the concrete shear wall frame views of the city.

Figure 16. Detail view of 700-millimeter-high concrete horizontal strips.

The analysis undertaken to support the building's structural scheme utilized non-linear material behaviors to explicitly measure the dissipation of seismic energy. It confirmed that the structure would be undamaged during a service-level seismic event (43-year return period), and that life safety would be preserved, even under the extreme case of a maximum considered earthquake event (2,475-year return period).

Additionally, the concrete shear walls have strategically located openings in the center of the length of the wall. The remaining concrete bridging across the openings, referred to as coupling beams, allow the walls to remain stiff during low-intensity seismic events and limit deflections. Under very rare seismic events with high-intensity ground motions, the coupling beams yield, thus softening the building and dissipating the seismic energy through controlled and localized cracking. This energy dissipation is critical to protecting the life safety of the occupants.

Construction Challenges

The movement of the historic house, the interaction between the concrete and the steel structure, and the temporary supports for the assembly of the steel structure were the three relevant challenges in the construction of Torre Reforma.

The concrete walls and the steel structure were built by different contractors, which required a greater-than-normal level of coordination of work and storage spaces, crane and work schedules, progress rates, and topographical controls. As two of the five walls of the tube are steel, the stability of the overall structural tube would not be assured until the "hypotenuse" was closed. For this reason, the advance of the concrete walls and the progression of the steel structure had to be closely synchronized between two contractors.

Another challenge arose from the tensioning function of the diagonals in the front of the building. The tensioning cannot work until the top slab is cast, which forced constructors to build a series of temporary struts along the front edge to support the floors while the diagonals were constructed. Once the slabs that formed the tension connections with the diagonals were cast, they began to take loads, so it was necessary to build the steel structure with a slight "lift," on the order of 50 millimeters, so that, at the moment of removing the struts, the floor, and the steel structure would be level.

The construction of the concrete shear walls utilized an unconventional approach. Contractors poured the wall in 700-millimeter-tall horizontal strips, instead of the more conventional 4.2-meter-tall strips that contractors normally prefer (see Figure 16). By pouring one strip per day over six days a week, one-floor-per-week construction could be achieved, while producing a unique architectural appearance. The variations in the concrete mix from day to day resulted in a random pattern of darker and lighter concrete, separated by 19-millimeter-deep reveals in the formwork between pours, thus providing texture to the monolithic concrete walls on the two short faces of the building.

Less Glass, More Green

The success of the Torre Reforma has shown that skyscrapers can break from the mold of all-glass cladding. The prospect of climate change and the wasteful nature of glass façades has challenged architects to pursue a practical alternative, the fortunate byproduct of which is a new aesthetic. ■

Unless otherwise noted, all photography credits in this paper are to LBR&A Arquitectos.

Project Data

Completion Date: 2016
Height: 246 meters
Stories: 55
Total Area: 77,053 square meters
Use: office
Owner/Developer: Fondo Hexa, S. A. de C. V.
Architect: LBR&A Arquitectos
Structural Engineer: Arup (design); Diseño Integral y Tecnología Aplicada SA de CV (engineer of record)
MEP Engineer: Arup (design); DYPRO (engineer of record); Garza Maldonado y Asociados (engineer of record); Honeywell (engineer of record); Uribe Ingenieros (engineer of record)
Project Manager: Lend Lease
Main Contractor: Lomcci; COREY; Cimentaciones Mexicanas, S. A. de C. V.; HEG Diseño e instalacion S. A. de C. V.
Other CTBUH Member Consultants: Alan G. Davenport Wind Engineering Group (wind); Arup (acoustics, façade, fire, geotechnical, LEED, sustainability); Van Deusen & Associates (vertical transportation)
Other CTBUH Member Supplier: Schindler (elevator)