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Eight residential towers and one hotel structure interconnected by elevated, public bridges constitute the Linked Hybrid mixed-use project in Beijing. This open city within a city also features a cinemateque, a kindergarten, parks, and other attractions. The structural and architectural features of this 220,000 m² pedestrian-oriented development range from the practical to the whimsical and in many ways exemplify the various challenges and rewards that face designers working on major projects in China. 

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WORKING IN CHINA CAN BE A CHALLENGE FOR engineers and architects, in part because of the contradictions intrinsic in modern Chinese culture—contradictions that were clearly apparent during the emergence of progressive architecture there in the 1990s and the first decade of this century. There has always been a strong design and craft culture in China because of the country's historical ambivalence toward fine art in the Western sense and because of the dominant role of engineers in Communist society. Indeed, many of China's current leaders are engineers who often embody the values of frugality, resourcefulness, ingenuity, and daring in the tradition of engineering.

For the older generation of Chinese engineers, many of whom lived and suffered through the upheavals of the Cultural Revolution and were at the vanguard of Deng Xiaoping's transformation of the Chinese economy, the inherent contradictions of any absolute rationalism are quite clear. Yet they have embraced a progressive disposition toward contemporary engineering and architecture, although tempered by a continuing feeling for frugality. Their progressive attitude is influential because of the control that many of them—particularly the university professors—have over the building permit approval process. This opens the way for many radical projects.

Facilitated by the call first made in the 1960s by Zhou Enlai (Chou En-lai) for modernization in the four areas of agriculture, industry, national defense, and science and technology and stressed again in the late 1970s by Deng Xiaoping, this progressivism was coupled with market liberalism. As was the case with the neoliberalism that took root in many parts of the world beginning in the early 1980s, the opportunities for profit and wealth often went to cronies as well as to entrepreneurs. In China, as in other developing economies, valuable land or industries sometimes went to those with connections rather than to those possessing merit. As a result, there was a very uneven sense of the value of capital and natural resources. While many engineers, physicians, and other professionals may have concern for the management of land, resources, and public welfare, those to whom opportunities are simply given are often willing to spend freely and without much regard.

This particular combination of factors—professional progressivism together with every capitalism—can create a unique challenge for both Western and Chinese designers. In China, it has been possible to design and construct buildings that would be inconceivable elsewhere, except perhaps in the Persian Gulf. Moreover, the expense of these spectacular projects, especially with respect to such resources as steel, concrete, aluminum, glass, and other materials, has been extravagant by any measure. These material costs are offset by the very low wages of the migrant workers who mostly originate from the countryside of China and often live in temporary dormitories at or near the construction site until the project's completion. Indeed the most disturbing and challenging factor, despite the nominal Communism in China, is the economic exploitation of low-wage migrant workers to the benefit of those given the business opportunities.

Many Chinese engineers and architects recognize the complexities of this situation and confront the difficult social and moral dilemmas at stake. For the most part this is reflected in debates and critical writings, but these misgivings have been unable to slow the rapid pace of development. Because many designers express their reservations with courage and honesty, it remains interesting to work in China, as opposed to other regions of excess and extreme development.
The Linked
Hybrid project, in Beijing, features eight 60 m tall towers and a 35 m tall hotel connected at their upper levels by a series of bridges. Designed as public spaces, the bridges feature a swimming pool, a café, a fitness room, art galleries, and other amenities and services.
HE LINKED HYBRID COMPLEX, in Beijing, is the largest of four structural engineering projects that Guy Nordenson and Associates has undertaken in China. It is also a project on which our firm worked on the design from its inception, in 2003, collaborating closely with Steven Holl Architects, which has offices in New York City and Beijing, and with our collaborators in Beijing at the China Academy of Building Research (CABR). The Linked Hybrid is a great example of the progressive, imaginative, and daring architecture that has emerged in China recently. The complex consists of 20 unique structures, including 8 residential towers (containing 644 apartments), a hotel, a cinematheque, a kindergarten, and an underground parking garage.

The 35 m tall hotel and the eight approximately 60 m tall towers are connected at their upper levels by a series of eight bridges. These bridges are public spaces in which residents and visitors can walk and enjoy various pastimes and activities, and they accommodate a café, a fitness room, a gallery, an auditorium, and other functional spaces. One of the largest bridges even contains a swimming pool. All of the residential towers and the other buildings can be accessed via the two-level underground garage that occupies the entire footprint of the site. The roof of the parking garage supports both the cinematheque and a large reflecting pond in the center courtyard of the complex.

Steven Holl has described the project as follows: "The 220,000 m² Linked Hybrid complex, in Beijing, creates a porous urban space, inviting and open to the public from every side. As a 'city within a city' the new place has a filmic urban experience of space—around, over, and through multifaceted spatial layers. A three-dimensional public urban space, the project has programs that vary from commercial, residential, and educational to recreational."

The key to this concept is the relationship between the "courtyard" formed by the buildings—an allusion to that of the siheyuan, or quadrangle house type, common in Beijing—and the openness of the building complex to the city around it. Unlike many gated communities that have been developed in Beijing, the Linked Hybrid complex is generally open to the public. The bridges create both a landmark and an inextricable visual connection between the complex and the surrounding city. This balance of
community and citizenship is what makes this project unique among the many characterless developments occurring in China. The shape of the space between the buildings and the circulation loops provided by the bridges were conceived before the buildings and the bridges evolved as objects. The cinema-theque, the hotel, and the kindergarten were included in the design after the central space, the towers, and the bridges had been developed as a composition. The positioning of the eight main towers and the circuit of bridges that link them was skillfully calibrated to shape the central shared space as well as the views to the city beyond. The walk along the complete bridge circuit provides an exhilarating and unique promenade in the air.

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The pedestrian-oriented complex is located adjacent to a former city wall of Beijing, a choice site at the northeast corner of the city's Second Ring Road where the highway to the airport enters the city. Similar to other parts of Beijing, this is a dense urban area with buildings that range in height from 2 stories to 20. The developer, Beijing-based Modern Green Development Company, Ltd. (formerly Modern Group), has built several housing complexes in the immediate area. It is among the major developers and patrons of modern architectural development in Beijing.

The tower structures, which feature large cantilevered sections at their upper levels, were designed to be as simple and robust as possible. Each building measures 30 by 30 m in plan and is typically divided into four residential units. These typical plans change at the upper levels at the points where the bridges link to the towers. The bridges are located between the 12th and 18th floors of the towers. The cores, which house the elevators, the stairs, and the mechanical services, are all compact and enclosed in cast-in-place concrete shear walls. Four shear walls, cruciform in plan, radiate from the central core to form the "party" shear walls for each unit, breaking the total plan into four quadrants. The floor systems feature cast-in-place beamless slabs.
with one large distinctive column in each unit to cut the span from the core wall to the perimeter. The 900 mm deep perimeter moment-resisting frame consists of beams and columns of cast-in-place concrete. The corners are open and free of columns, but the grid frame wraps continuously around to form a complete tube frame.

The structural diagram is clear and easily adapted to numerous apartment layouts. The lateral-force-resisting system comprises concrete shear walls, concrete moment-resisting frames, and concrete-encased diagonal steel bracing on the perimeter. This approach formed a redundant and very stiff lateral system that proved to be of paramount importance in designing the bridges. It was also essential in winning the approval of the local building authorities for the radical concept of floating bridges and cantilevered towers that in elevation form inverted L shapes.

The lateral-force-resisting system was designed to accommodate China’s national standards and codes. Following these provisions, the wind load was calculated in a way similar to the procedure given in ASCE-7 (Minimum Design Loads for Buildings and Other Structures), although wind pressure, rather than wind speed, was mapped. The Chinese codes were formulated on the basis of a pressure from a 100-year event amplified by the appropriate shape factor, terrain roughness, and height. In addition to static amplification, dynamic analysis was required to calculate the wind vibration amplifier (which is a function of the fundamental period). As a result, the final wind pressures varied from 1.8 kN/m² at the bases of the towers to 4.1 kN/m² at their tops.

For seismic designs, the Chinese code refers to two phases of analysis. The first phase involves designing within the elastic deformation range for frequent minor earthquakes. The goal of the first phase is to design the structure so that there is no damage to the structural members during a minor seismic event and so that the non-structural members also will avoid major damage. During this phase, the design team assumed that any deformation would occur elastically and that the seismic action would be set equivalent to a ground acceleration of 0.072g.

During the second phase, the design team considered elastoplastic deformations under a particular design "intensity"—in this case 0.2g—as well as under extreme earthquakes. The goal was to meet the code’s criteria so that the structure would be repairable if subjected to earthquakes of this greater intensity. During this phase, the design team assumed that elastoplastic deformation would occur but that the key structural members would continue to function elastically within the limit state. This would ensure that the structure would be repairable after a moderate earthquake. The seismic action would be equivalent to the ground acceleration of the design intensity. Furthermore, during this phase our collaborators at the CABS checked for plastic deformation in an extreme earthquake event to ensure that the structure would not collapse and that human casualties could be avoided. The seismic action was assumed to be 0.4g for this check and served to define the maximum displacements the building might experience.

The requirements of the seismic code considered, among other factors, the purpose of the buildings and their importance. In this case, the towers were designed to remain elastic under a moderate earthquake of 0.2g. This goal was used for the detailing requirements for certain key members, including the perimeter diagonals and the elements that link the shear walls.

For a typical 20-story tower, we found fundamental periods in the range of 0.7 to 1.1 seconds. The base shear coefficients were determined to be 0.07g to 0.10g for the design. Because the Chinese codes require that 50 percent of a building’s live load be considered in the seismic mass, the base shear, expressed as a percentage of the building mass, was on the order of 20,000 kN, depending on the tower. Moreover, because the buildings had vertical and horizontal seismic irregularities and included the unusual linkage features of the sky bridges, our design had to be approved by a special structural engineering committee.

On the basis of static and dynamic seismic analyses, which included both equivalent static and response spectrum analyses, we were able to determine the deflections of the towers at the support points of the bridges. The Chinese code limits the maximum story deflection to L/800, which is approximately 4 mm when the floor heights are 3.05 m. Fortunately, our design was well within this limit, averaging L/1,400. Under linear elastic analysis, the tower deflections were generally very small—less than 4 cm at the location of the bridge supports, which are roughly 50 to 55 m above grade. The deflections were still well within the code limits even when the design included amplification arising from the
nonlinear and ductile behavior of the tower structure. The CABR completed a time history analysis under the extreme earthquake scenario of 0.4g to better determine the minimum allowances for the bridge movements.

A major concern in designing the lateral-force-resisting system was the mass eccentricity caused by both the tower cantilevers and the bridges. The design team had difficulty, however, in meeting the code requirement that the maximum deflection on a particular floor not exceed the average deflection by 40 percent or more. In order to meet this deflection criterion, which is intended solely to minimize seismically induced torsion, we had to strategically place bracing members on the perimeters of the towers. In addition to the resistance provided by the concrete moment-resisting frames on the tower exteriors, the diagonal steel bracing provides stiffness to resist the large torsional demands of the cantilevered upper levels.

As described below, the effects of the bridges were eliminated by placing both ends of the bridges on isolators, which reduced to manageable levels the loads that the bridges impose on the structure. But the cantilevers of the towers could not be isolated. Thus, their effects were mitigated by using a combination of steel framing with metal decks and concrete fill to reduce the weight of the cantilevered sections and by adding steel braces to the perimeter grid frame to carry the cantilever shear forces.

Steel braces were also installed in locations with large openings or where the particular seismic forces necessitated their use. These diagonal braces feature wide-flange steel members encased in concrete and clad in aluminum. Vertical steel members also were embedded in some of the grid columns to resist the large tension caused by the cantilevers and the seismic effects.

Much like the overall project, the structural design of the Linked Hybrid complex contrasts the regularity of the basic system with the uniqueness of the exception. The balance of redundancy—core plus walls plus perimeter grid—and adaptability, that is, the use of lighter steel cantilevers and the occasional steel diagonal and vertical members, enabled us to receive official approval from the Chinese authorities for both the concept and the detailed design quickly and smoothly. This contrasted with the difficulties that the designers of many other challenging projects encountered in obtaining their approvals during the same period, which was just prior to the 2008 Summer Olympics.

The eight bridges of the Linked Hybrid project, which were never part of the client's original program, constitute its most radical aspect. Their presence in the final design attests to the tenacity of Steven Holl's vision and to the client's openness during the design process. The bridges not only link the towers but also incorporate spaces that can be shared by the residents, reinforcing the sense of community, and they provide visual links to the city at large. The bridges' functions are public and alternate between the practical and the whimsical, the spaces including a lap pool, a tea seating area, and a group exercise space.

The glazed, transparent bridges span between 20 and 60 m, creating floating hallways of light that contrast sharply with the heavy concrete of the towers. Designed as irregular and angular forms, the bridges are composed of steel units that were designed as pairs of parallel trusses—a hybrid of Vierendeel and Pratt trusses—in order to achieve the maximum transparency. The decision to use parallel truss chords was not easily made given the architect's original intent to install large steel truss members within the bridges. But the parallel truss chords resulted in an elegant design solution.

The top and bottom chords of the trusses are composed of wide-flange steel shapes. Infill wide-flange beams support the metal deck and concrete floor system. The vertical
Design store

Commercial structures. As a result of this isolation, a person swimming in the suspended pool will begin to feel the earthquake motion only well after the ground motion has ceased.

Although the cinemathéque is overshadowed by the towers that loom above it, this irregularly shaped structure at the center of the Linked Hybrid complex is a daring building in its own right, and its design proved to be just as challenging as that of the towers. The approximately 446 m² public building's faceted design features a cinema and a vegetated roof above the third floor. Especially critical was determining how to fit the cinemathéque, which has no vertical columns, on top of the underground parking garage, which features a regularly spaced column grid. Li Hu, the Steven Holl Architects partner in charge of the project, and his team considered many iterations of the design before finding a solution whereby the structure of the cinemathéque could be joined to the regular column grid below without the use of transfer girders. The structure comprises a series of diagonals composed of round hollow steel members.

To increase the transparency of the trusses, the geometry was refined by varying the spacing of the vertical members so that the greatest number of them—as well as the largest of the diagonals—would be concentrated near the supports. Thus, we were able to "tune" the bridge so that the tension in the diagonal profile was fixed. That is, the size of the tension rod bracing members could remain the same throughout and remain as efficient as an equally spaced—and more typical—Pratt truss. Finally the hybrid trusses were all designed with a so-called Vierendeel backbone that moment connected the vertical and horizontal members to one another, leaving the center one or two panels without diagonals. This backbone is also useful as an added measure of redundancy. In effect, the backbone can support the bridges in extremis, even though the diagonal members are necessary for stiffness.

Although the orientation of the diagonal tension members in the Pratt trusses minimizes the size of these elements, large connections were required between the gusset plates and the nodes of the columns or beams.

The bridges are light and delicate. To protect them from the effects of tower deflections at the upper floors under an extreme seismic event, Xiao Congzhen, our brilliant collaborator and a CABR structural engineer, suggested that we isolate them entirely. Initially we had imagined adding rollers, elastomeric bearings, or friction pendulum bearings to one side, leaving the other side fixed. But this fixity at one end of the bridge would have translated into large torsional forces in the towers because of the eccentricity of the bridge mass. When Xiao suggested that we simply isolate the bridges on both sides so they would be entirely free, we were delighted and astonished by the practical but poetic suggestion. Isolating the bridges from the towers not only reduces the forces on the towers but also protects the light bridges from the movement of the towers.

Together with the CABR’s engineers, we decided to use friction pendulum isolators, which were provided by Earthquake Protection Systems, Inc., of Vallejo, California. The isolators are shaped with a radius that can be customized to meet the requirements of the project. Friction pendulum isolators are unique in that they can be designed to a particular period by simply altering the radius of the isolator, independent of the mass and the stiffness of the bridge.

The bridges are perhaps the highest base-isolated structures in a seismic region anywhere in the world, an achievement made possible by the stiffness of the tower structures. As a result of this isolation system, a person swimming in
In the center of the complex's open courtyard are various attractions, including parks, ponds, an irregularly shaped cinema-theque with a vegetated roof, and a hotel that is linked to the network of bridges.

TheLinked Hybrid project has proven to be significant from a number of perspectives. While considered a landmark by virtue of its location and the uniqueness of its bridges, the Linked Hybrid complex is organized more as a public space than as an iconic building, which has made it popular with the city's inhabitants.