Title: Overcoming the Challenges of a Complex Mega-Scale Project

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Overcoming the Challenges of a Complex Mega-Scale Project

Abstract
An architect’s best work flows directly out of how the challenges of a project—whether they are urbanistic, architectural, artistic, or technical in nature—are faced and overcome. This applies equally to the engineers and contractors who ultimately build the development. Undertaking a project on the scale of Raffles City Chongqing required a level of coordination and collaboration that went well beyond the requirements of a “normal” project. The developer understood this and put in place the framework and team infrastructure that allowed this intense level of collaboration to take place on-site. All the major design team consultants maintained a very strong on-site presence throughout the construction phase, which was paramount to achieving the response and turnaround times required to meet the aggressive schedule. It was the melding of all these necessary players into a cohesive, functional team, and navigating the challenges together, that made Raffles City Chongqing the success that it is.

Keywords: Chongqing, Construction, Project Management, Skybridge

Overview
Opening its doors a little over four years after the start of construction on the substructure, the 1.1 million square-meter Raffles City Chongqing (RCCQ) project moved at a very aggressive pace right from the start. In addition to the complexity and sheer scale of the undertaking, the project team had to deal with a site that was situated at the end of a narrow, very densely populated urban peninsula, abutting two active riverfronts—located at the convergence of the Yangtze and Jialing rivers—and with the historic Chaotianmen Square—Chongqing’s historic Emperor’s Landing—to the north (see Figure 1). Beneath the surface of the existing soil lay the archeological ruins of the ancient city wall. Meanwhile, the two adjoining flowing rivers brought annual flooding. Even from above, there were constraints that had to be addressed, such as height restrictions imposed on the location below the flight path of the international airport, forcing alterations to the two tallest tower cranes. Any project with world-class aspirations requires close and efficient collaboration between the ownership, the design team and the contractors to address the challenges that are presented, and at RCCQ, this was even more critical.

Segmented by Parts, Undivided in a Sense of Purpose
It was clear right from the start that the project had to be constructed and read as a single, cohesive whole, given the very tight timeline, a very congested site bounded by the two rivers, hilly site topography and operational inter-dependency of the different building elements and asset classes (see Figure 2). The need to ensure the structural and visual integrity of the sail-shaped design also had to be
considered. A delay in completing any one building element would have serious structural, visual and operational impacts on the entire development as a whole. Imagine a delayed middle tower affecting the construction of the 300-meter-long horizontal sky conservatory, or a delayed tower façade rendering the “fleet of sailing ships” incomplete, or the major safety concerns of a 350-meter tower still under construction on the operations of the retail podium just below.

The design team began to grasp the true complexity of how the construction of the mammoth project was being planned and the contracts packaged. With a primary demarcation line cut down the center of the development, utilizing two different main contractors for the structural works, each supported by many other contractors covering the other trades of mechanical, electrical, and plumbing, façade, architectural, landscape and specialist works, a number of well-founded concerns were raised. Starting with the first of the many tender interviews, the strategy for turning these concerns into a strength began to take shape. At each interview, the team opened by stressing the importance that the whole of the podium and the eight individual towers all read as parts of a much greater whole. The tendering contractors were all asked the same question—“Will you be willing to work collaboratively with the design team and the other contractors, sharing your ideas and adjusting your detailing and methodology if necessary, to help us achieve a consistency of detailing across the project?” Their reaction to this question carried a lot of weight in the evaluations of the tenderers. In the end, the results of these efforts exceeded the highest expectations. While each contractor remained responsible for developing their own shop drawings, when someone found an eloquent solution to a tricky problem or a more efficient way to construct or install common elements, the architects shared the ideas and details with all of the construction teams, and the other contractors took up the challenge of further refining the details. They all ultimately worked to incorporate the agreed approach into their own work. In essence, the construction details were crowd-sourced, enabling the think-tank of the design and construction teams to work together and collaborate to a degree that was never experienced before.

The Complexity of the Project

Thinking back, it is still mind-boggling—the tremendous collaborative effort required to manage such a project, with a team comprising more than 50 design consultants, two main contractors, more than 100 specialist contractors, and several hundred more direct suppliers. This meant having to administer close to 1,000 contract packages. The team also had to work with many levels of government and authorities on all aspects of design and construction for approvals, especially since there were many “firsts, no-precedent and never-done-before” designs and work practices that required specialist panel reviews before the authorities could approve.

The complex design for this mixed development proved a major challenge to meet firefighting design requirements, especially important to a city built on a hilly terrain, with long winding roads.

Figure 1. Raffles City Chongqing is located at the confluence of the Yangtze and Jialing rivers. © Junyi Lou (cc by-sa)

Figure 2. The visual and structural interdependency of the multiple buildings in the project required parallel construction programs to take place simultaneously on a congested site.
“Such was the concern of the authorities that a dedicated mini-fire station manned by the district fire bureau was eventually built within the project.”

Coupled with a huge population contributing to traffic conditions, firefighting requirements became of paramount importance. Members of the expert fire review committee regarded RCCQ as one of the most complex and demanding projects they had ever encountered. Such was the concern of the authorities that a dedicated mini-fire station manned by the district fire bureau was eventually built within the project.

Site Logistics and Resources

Managing the logistics of the labor force, which at peak was in excess of 5,000 workers, from their lodging to transport, to food and waste management, was a project in itself. Ensuring the safety of so many workers in a congested work environment was a major concern, which was addressed with strict safety enforcement from the start. The implementation of color-coded safety vests for each worker and site management staff allowed ease of identification, which helped prevent potential conflicts between the many different trade workers (see Figure 3). This practice is now a standard requirement for the developer’s projects.
Material deliveries to the site was also a major logistical challenge, given the external road traffic congestion, space constraints within the site, and with the development being constructed from the edge of one river to the other. The undulating terrain, with a ground-level difference within the site in excess of 40 meters, effectively limited transportation access to just one entrance for each main contractor, about 500 meters apart, which had to be shared by all other specialist contractors and suppliers (see Figure 4). With the site abutting the two rivers, material transport from the river was also initially considered. However, very high fluctuations in river water levels during the seasonal flooding months effectively ruled out this option, which would also have required clearance by the River Commission Authorities. With materials being handled by so many different contractors working on all areas of the site through these two access points, it was a logistical challenge. Major deliveries were often scheduled through the night, to minimize disruption to daytime construction activities.

**Land Handover**

While working in parallel on the design submissions, one of the first site activities included working with the authorities on temporary measures to divert existing traffic off the site to facilitate land handover, which could only be progressively carried out due to many other site encumbrance issues, which the government had to resolve with other third parties.

Diversion of existing underground utilities off the site, formerly a busy, densely built urban area, was another major undertaking during the initial post-handover period. This involved hunting down every existing utility buried underground within the site, with very limited and mostly outdated as-built drawings available, then establishing ownership and negotiating compensation costs, before physical diversion could proceed and the land could be cleared for construction.

During the early planning stages, the team realized that the existing utility networks could not cater to the massive demands of a fully operational RCCQ, especially electrical power. Through numerous negotiations with the district power bureau, a joint effort to build a 110kV sub-station within RCCQ was established, including constructing a 1.6-kilometer-long, 30-meter-deep underground cable tunnel, which was concurrently carried out over a period of two years. This model of collaboration for the sub-station is now a paradigm for the local power bureau. To upgrade the existing networks in order to meet the considerable demands of RCCQ, extensive negotiations to upgrade existing networks were also initiated with the gas and water companies early in the process.

**Unique Challenges: Flooding and the Ancient City Wall**

Every year, between August and November, the project is subjected to a major rise in the surrounding river levels, from 10 to more than 20 meters above the normal water level. During construction, temporary flood-control measures were enacted to ensure safe construction work, and then progressively replaced by permanent floodwalls, built around the entire perimeter to serve as the external basement walls, and for flood protection. A great deal of planning was necessary to ensure works in flood-prone areas were commenced and completed before the next flood. The temporary flood measures are replaced with a 15-meter-high reinforced-concrete basement/flood wall all around the development boundary, which was structurally designed to withstand a once-in-100 years flood. This massive floodwall was put to a real stress test on 20 August 2020, when the city battled a major flood that inundated most, if not all basements of developments along the two rivers (see Figure 5). RCCQ’s floodwall endured well, and the development continued its business operations as usual. It was a tense experience for the project team, who remained on standby as the flood levels quickly rose beyond 20 meters, finally stopping just short of the completed floodwall cap. This would surely count as a most unforgettable experience for those involved.

Another challenge deserving of mention was the discovery of the old city wall, which, although causing a stir initially, was eventually embraced as a symbol of the important cultural heritage and gift that history brings.
After extensive expert review, moderating between conservation and new development, the old city wall was preserved in part for display in its current condition, requiring the setting back of the basement wall and acceleration of works to catch back up to schedule, after more than a year of archaeological excavation. On the whole, the team did not regret the additional time nor effort that it necessitated, and deemed the discovery worthwhile and propitious.

Constructing the Crystal

The construction of the 300-meter-long skybridge, dubbed "The Crystal," sitting on top of the four 250-meter-tall middle towers and connected to the two 350-meter-tall north towers by perpendicular link-bridges, must count as a monumental engineering feat. To enhance quality and safety control, the main support bridge truss structures between the towers were assembled on the podium roof, and then hoisted into position some 250 meters above, to connect to the truss sections on the tower rooftop, which were constructed in-situ and supported on numerous movement bearings. The three hoists, each weighing about 1,000 metric tons, were achieved by hydraulic jacks mounted on the tower roof, each taking one week, inching steadily from the podium roof to its final position.

Similarly, the façade underbelly was also assembled on the podium roof and lifted by hydraulic jacks, to finally attach to the main structure already in position. Due to concerns with wind effects, particularly for such lightweight lifting, help was sought from the meteorological station to provide weather forecasts accurate to within 30 minutes throughout each lifting (see Figure 6).

The "sky conservatory" within The Crystal boasts some 100+ mature trees, mostly planted in an enclosed environment through its entire length. The selection, procurement and acclimatization of these trees, which are not typically found locally, required early planning, given the peculiar seasonal effects of a short spring transitioning through a very hot summer into autumn/winter weather. These trees were first acclimatized in the city suburbs before being individually lifted by tower cranes to the two ends, and then horizontally distributed through the entire length into pre-constructed concrete planter pits. Ensuring the survival of these trees while under various pressures of structural, façade and interior construction proved very challenging. Spare "soldier" trees were planted to prepare for some inevitable casualties. A mechanism to allow for future tree replacement, albeit with trees that would be small enough to be lifted by winch through a hatch in the conservatory underbelly and moved through finished spaces, was also installed. This, however, has not been utilized, as the trees planted have survived very well (see Figure 7).
Transportation and Connectivity

Over the past 20 years, Chongqing has experienced exponential growth, radiating outward and away from its historic center, where the RCCQ site sits. The project provided an unparalleled opportunity for the developer and the city to work together to upgrade the transportation infrastructure at Chaotianmen and improve the connections between this historic site and the new, modern Chongqing (see Figure 8).

Highlights of the Structural Design

The articulation of the extraordinary Crystal, the project’s crowning glory, posed a major challenge to the structural design team, which compared different design alternatives, examining the potential for the Crystal to either be fixed to, or isolated from the towers, as well as the impact of either option on the building costs, to determine the best option. The chosen solution uses a combination of friction pendulum bearings (FPBs) and dampers. The FPB provides resistance, such that the conservatory is fixed to the towers under various serviceability loadings (design wind/thermal load) and designed to withstand Level 1 earthquakes. When the seismic activity reaches Level 2 or Level 3, the bearings will allow movements and the Crystal will “float,” moving separately.

Figure 7. Mature trees have grown beautifully in The Crystal since construction was completed.

Figure 8. Overall planning diagram of RCCQ transportation and connectivity hub.
from the towers, thus dissipating the energy and helping to mitigate the effects of the earthquake.

Another major challenge was the high slenderness ratio of the north towers (9.4:1), which required a very strong structural frame for lateral stability. The project team compared different options and finally adopted a structural system comprising a reinforced concrete core, four corner megacolumns, belt trusses, a perimeter moment frame and four levels of hybrid outriggers (see figures 9 and 10).

By adopting the structural fuse component, this innovative design optimized the traditional system and improved mechanical performance in the following aspects:

• Dissipated the seismic energy in the case of intense seismic shaking, thereby protecting other components of the outrigger system and ensuring the safety of the whole tower.
• Simplified the design and construction of connection joints, especially the connection joint at the corner of the core tube.
• Saved about 10 percent of steel consumption as compared with traditional outrigger systems, without compromising the original mechanical performance, resulting in significant cost and time savings.

The new hybrid outrigger system was patented in China in 2014.

It is anticipated that this hybrid outrigger system will continue to spark enthusiasm and be implemented in many other high-rise building projects in China and elsewhere. This innovative design has also simplified construction of the steel connection joints, which are often very complex and bulky in traditional systems. It has achieved a higher rigidity and structural performance as compared to the conventional steel outrigger based on the same outrigger size/volume. The design is the first to combine the steel and concrete structures and introduce the concept of a "structural fuse"
The hybrid outrigger system developed for the project saved about 10 percent of steel consumption as compared with traditional outrigger systems, without compromising the required mechanical performance.

An Innovative Fire Safety Solution

The connectivity of the towers, both via the skybridges and at podium level, also posed complex fire engineering challenges. The design team introduced several fire engineering firsts for China on this project to resolve these issues. They included:

- Emergency vehicle access provision for a podium roof, along with a discharge and evacuation procedure onto this roof.
- Use of a refuge floor for evacuation transfer.
- Applying a performance-based design to such a large group of connected buildings.

With a high occupancy in The Crystal, the evacuation design includes 15 egress stairs that merge into 10 stairways in the towers beneath. A connecting refuge area was designed below the skybridge to provide sufficient space for people to use each connecting stairway and to reduce the amount of congestion.

Evacuation lifts in the towers, which are also used for normal circulation, were included to improve evacuation efficiency and facilitate inclusive evacuation procedures for those with physical disabilities. This method allowed a reduction in the overall number of stair cores, increasing the usable floor area in the towers.

To assess the evacuation strategy, a benchmark was created by conducting a comparative evacuation analysis, using a hypothetical design for separated towers with no skybridge. The design was based on a number of conservative assumptions, including a full maximum occupancy of people on all levels and a fire blocking the widest exit from the skybridge. The evacuation and fire modeling analysis demonstrated that, under each fire scenario, the building occupants would have sufficient time to evacuate before conditions became untenable, with an evacuation time shorter than that of the benchmark design (see Figure 11).

The fire consultant’s team modeled the conservatory using finite element analysis to optimize the fire protection of the structural steel under possible fire scenarios. The analysis identified that a majority of structural roof elements did not require additional fire protection, resulting in a significant cost saving. The smoke ventilation design took into account the impact of the wind due to the building’s location and the height of the skybridge.

At the podium level, the fire and structural engineering teams worked together on a design that could structurally accommodate the large loads created by firefighting vehicles on the podium roof, liaising with the local fire department on the loading, ensuring that there was sufficient space for the vehicles to safely maneuver on the roof. The analysis for evacuation, fire and structural modeling was reviewed and finally approved by the fire engineering expert panel.

Conclusion

It took an extraordinary team to build this extraordinary project. The level of collaboration, coordination and communication effort required by so many parties to piece this project together went well beyond the requirements of a normal project. Technical abilities aside, it was a place where social skills were also put greatly to the test, where people had to learn to work together, to manage differences, and to see the big picture, for the project to succeed as a whole. The hard work and sleepless nights have paid off. To those who were privileged to be involved in this engineering marvel, RCCQ must surely be a once-in-a-lifetime experience, a project that pushed them to their limits, a great training school where many have learned much, and a special project to forever remember. Raffles City Chongqing has now morphed into an icon, the pride of the city, and a must-visit destination throughout the day, attracting visitors from all over the world and within China.

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