A Royal Addition

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A modern, angular addition to Toronto's Royal Ontario Museum uses steel to augment the existing historic structure.

IN 2001, THE ROYAL ONTARIO MUSEUM (ROM) IN TORONTO EMBARKED ON A MISSION TO REJUVENATE AND EXPAND ITS HISTORIC FACILITY. The first order of business was to establish an international design competition, one that would attract renowned architects from around the globe. Studio Daniel Libeskind (SDL) was eventually selected to design the project, and six years later, ROM's Michael Lee-Chin Crystal addition has come to fruition. The new angular structure is adjacent to, and also overlaps, ROM's classic façade.

From the onset, it was clear that structural steel was the right material for the job, as it was the only solution that could make the vision conceived on the famous "Libeskind napkin sketch" a reality. The engineering team recognized that the irregularity of the structure would amplify gravity forces and needed to be as light as possible. The site limitation also required minimum construction staging space and quick erection. Arup and SDL team members who had already experienced SDL's Denver Art Museum, a project with similar structural demands (April 2007, p.30), shared the lessons learned with the rest of our group, including the owner and construction manager.

Design Stage

Early in design, a process was implemented between the architects and the structural engineers that provided a virtual space where the steel members had to "live" and established "no-fly zones" for the rest of the building systems to work around. The architectural modeling work was carried out using Form-Z software, and then the plans were imported into AutoCAD where individual floor and diagrid elements were modeled by the structural engineers. The architects used this line work to review the structure and coordinate with their design.

Once the geometry was finalized, the line work was imported into finite element design and analysis programs. At the preliminary stages, GSA (a structural analysis software package developed by Arup) was used for its capability to provide a better graphic interface with other software being used. In the final production stage, SAP 2000 was used for its compatibility with X-steel (now Tekla Structures), which the team predicted would be implemented during detailing. After ironing out a few translation and communication issues between the different software products used, this process proved to be extremely valuable.

At the preliminary stages, custom-built skewed tube sections were specified at various locations, including the corners where the diagrid planes met. By collaborating with the fabricators, we learned that the fabrication of these custom sections was not going to be economical and timely. Although it was the correct response to provide box sections that were torsionally stiff and achieved concentric corner details, it was evident that the local market demanded the use of sections that were readily available. It was obvious that the custom-made box sections had to be redesigned to allow the use of readily available wide-flange sections.

Detailing Stage

The file transfer protocol that was adopted during the design stage was complementary to the protocol adopted during detailing and fabrication stages. The team added one more step to the file exchange process. Once the structural steel elements were designed in SAP, the geometry and the section properties were forwarded to the detailer. The detailer then imported the line work into Tekla Structures, where the single-line work was converted to actual extruded sections. The extrusions were rendered and then exported into Form-Z for compliance review. Once the geometry was coordinated, the changes were fed back into the structural design and analysis program in order to revise the design and load paths. The extra efforts made during the detailing stage eliminated almost all problems during fabrication.

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Fabrication

The fabrication process was, in a word, intriguing. The complex geometry required that many members be framed into a single node from many different directions. Shop personnel had to be equipped with laptops in order to visualize the 3D models of the nodes and execute their work. One of the more complex nodes required a shop drawing that was 5 ft wide by 8 ft long with more than forty views of the node. This process proved yet again that extra time spent in the shop pays off during erection.

Since the structure was irregular, a conventional grid system could not be established. A general grid system was in place that identified the diagrid and floor planes with their corresponding crystal form. However, an unconventional naming system was also adopted to identify the various connection locations that could not be referenced to the grids. Metaphoric names such as "Owl's head," "Thore's brother's broken leg," (named for an SDL team member), "Stair of wonder," and the "Pinnacle" were used to reference these locations.

Construction Engineering

The construction managers identified the proper construction sequence to enable other trades to move into the building and start their work while the steel structure was partially erected. But the team was concerned that the partially erected steel structure might not behave as modeled and designed, and hired Halsall to carry out the construction engineering and to provide the necessary staging sequence to reflect the schedule needs.

Halsall's job was to ensure that the partially erected structure did not experience overstressing due to locked-in forces, as well as to predict the behavior of the partially erected sections to avoid misalignments for later erection. Roughly fourteen different partially built analysis models were created that addressed the partially erected structure and the sequencing of shoring installation and removal. Additional steel elements had to be introduced to compensate for the missing floor diaphragms, and shoring had to be added to maintain the geometry of the partially erected sections. It was crucial to maintain the building's geometry due to the proximity of the new structure to the ROM's existing 1914 and 1933 buildings on three sides of the site, as well as to accommodate the cladding that had already started the detailing process.

This process worked flawlessly. A number of monitoring targets were added all around the structure and checked at various stages of erection and after each concrete floor was constructed. The building structure behaved as predicted at all different stages of construction. The erection


Royal Ontario Museum © 2007

Aerial view of the Royal Ontario Museum.

Fabrication Bidding

At the design development stage, the team visited several local steel fabricators to understand their capacities and capabilities. It was evident that close interaction was needed between the steel fabricators and the design team, so employing a fabricator that was geographically close to the team and the project was a very important consideration.

With this knowledge in hand, the team tendered the project to four pre-qualified steel fabricators. The bidders were tasked with providing a guaranteed maximum price, ideas on fabrication and erection, and a detailed schedule of deliverables to expedite the steel work.

All four bids demonstrated excellent understanding of the work and had various approaches to detailing and building this structure, but only one firm could be chosen. Immediately after awarding the steel contract, the A/E/C team and the fabricator began the design interaction and implementation process. The challenge was to detail and fabricate the steel in order to have it ready for erection as soon as the sub-grade work was complete.

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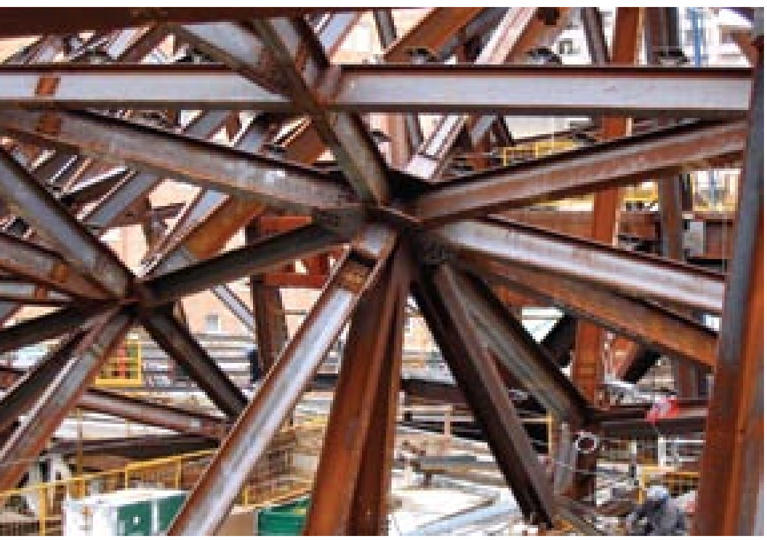

Halsall

Left, top: Interior spaces prominently feature the structure's unusual geometry.

Left, bottom: Due to the complexity of the structural nodes like this one, shop personnel had to be equipped with laptops in order to visualize their work in 3D.

was completed with minimum modification on-site, and few coordination issues arose.

At times, the challenges appeared overwhelming. Despite this, the building team was able to create the landmark architectural icon that the ROM envisioned. And given the effort that went into the steel work, some of the complex steel structures were left exposed, giving museum patrons a glimpse of the skeleton. MSC

Shahé Sagharian was Halsall's project principal for the ROM Michael Lee-Chin Crystal addition.

Owner
Royal Ontario Museum, Toronto

Architect
Studio Daniel Libeskind, New York/B+H Architects, Toronto – Joint Venture

Structural Engineer
Arup, London
Halsall Associates Ltd., Toronto

Construction Manager
Vanbots Construction, Markham, Ontario