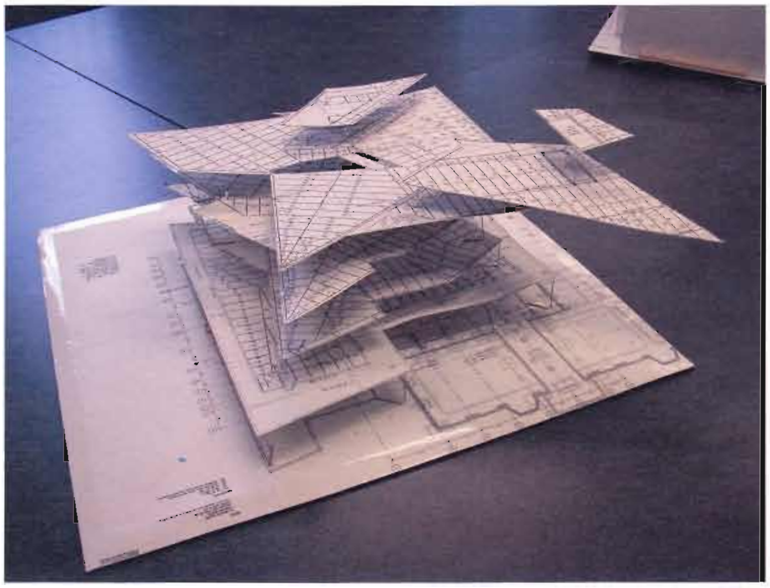
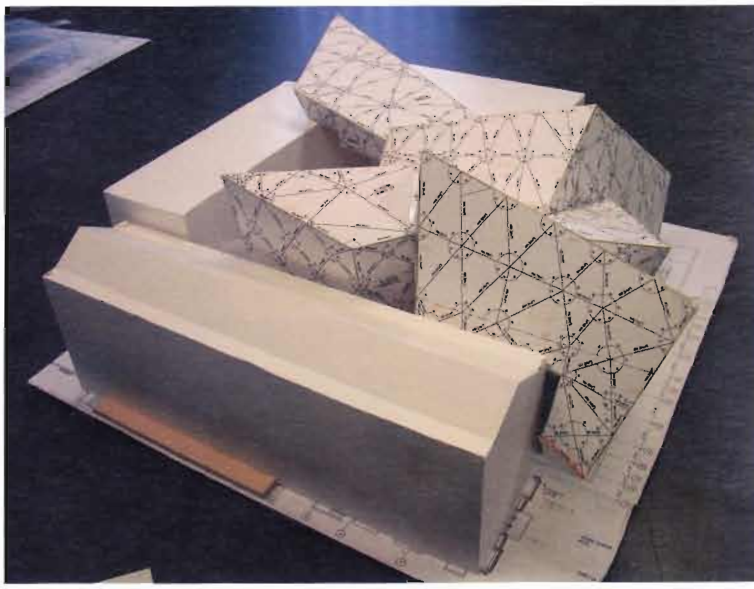
ORDERING CHAOS





THE LABORIOUS PROCESS OF STEEL CONSTRUCTION EMPLOYED IN THE ROYAL ONTARIO MUSEUM'S CRYSTALLINE ADDITION RELIES HEAVILY ON 3D COMPUTER MODELLING, CAREFUL STAGING ON THE SITE AND THE EXPERTISE OF STEEL FABRICATORS.

TEXT AND PHOTOS TERRI MEYER BOAKE

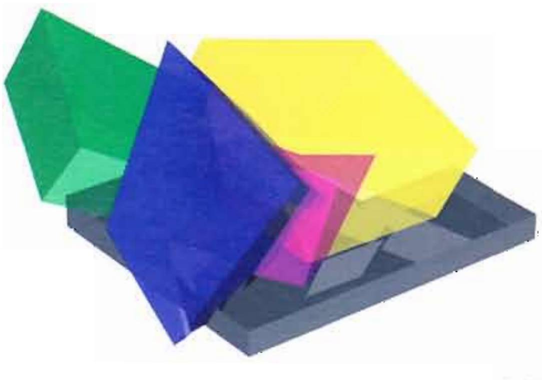
Inasmuch as the technical limitations of the 19th century deemed the visionary creations of Etienne Louis Boullée unconstructable, so too would be the fate of many current projects, were it not for the rapid advances in computing technologies.

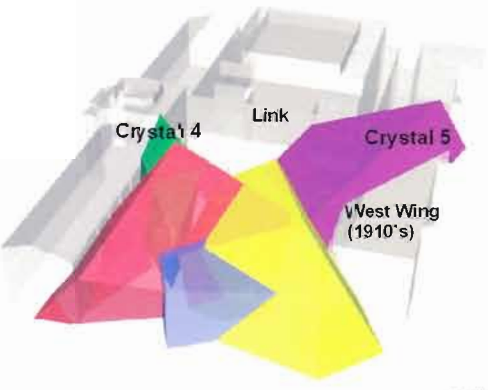
Watching the erection of Daniel Libeskind's Royal Ontario Museum (ROM) addition along Bloor Street in Toronto, the casual observer will likely see nothing more than a disorderly, dense mass of weirdly angled steel. Transforming this project from Libeskind's napkin sketch to what is one of the most controversial architectural projects to be built in Toronto has required those working on the team to use specialized tools and processes to distill an orderly and logically constructed building.

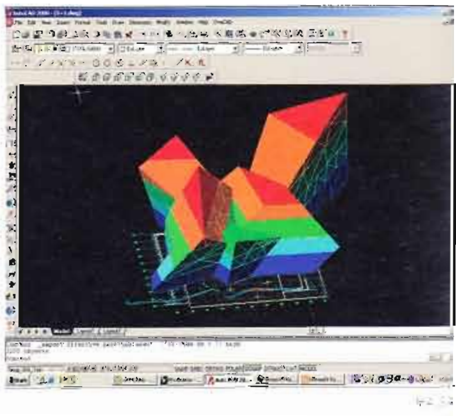
Simple orthographic drawing convention was not useful in defining the volumes of the project at virtually any stage of design, fabrication or construction. Within the architectural practice, a 3D computer model was the central reference piece. Standard architectural plans, sections and elevations were developed but these required significant supplementation to make them "useful." While the floors might be flat, most of the interior and exterior walls lie at an angle to the vertical and intersect at irregular points, making each piece of the project unique. Material take-offs and dimensioning needed to be done via drawings in the same plane as the angled surfaces. While methodologies for constructing and assembling the skin of the building may be in and of themselves straightforward or repetitive, each face, peak and valley required distinct detailing to account for the technical challenges presented by unceasing anomalies.

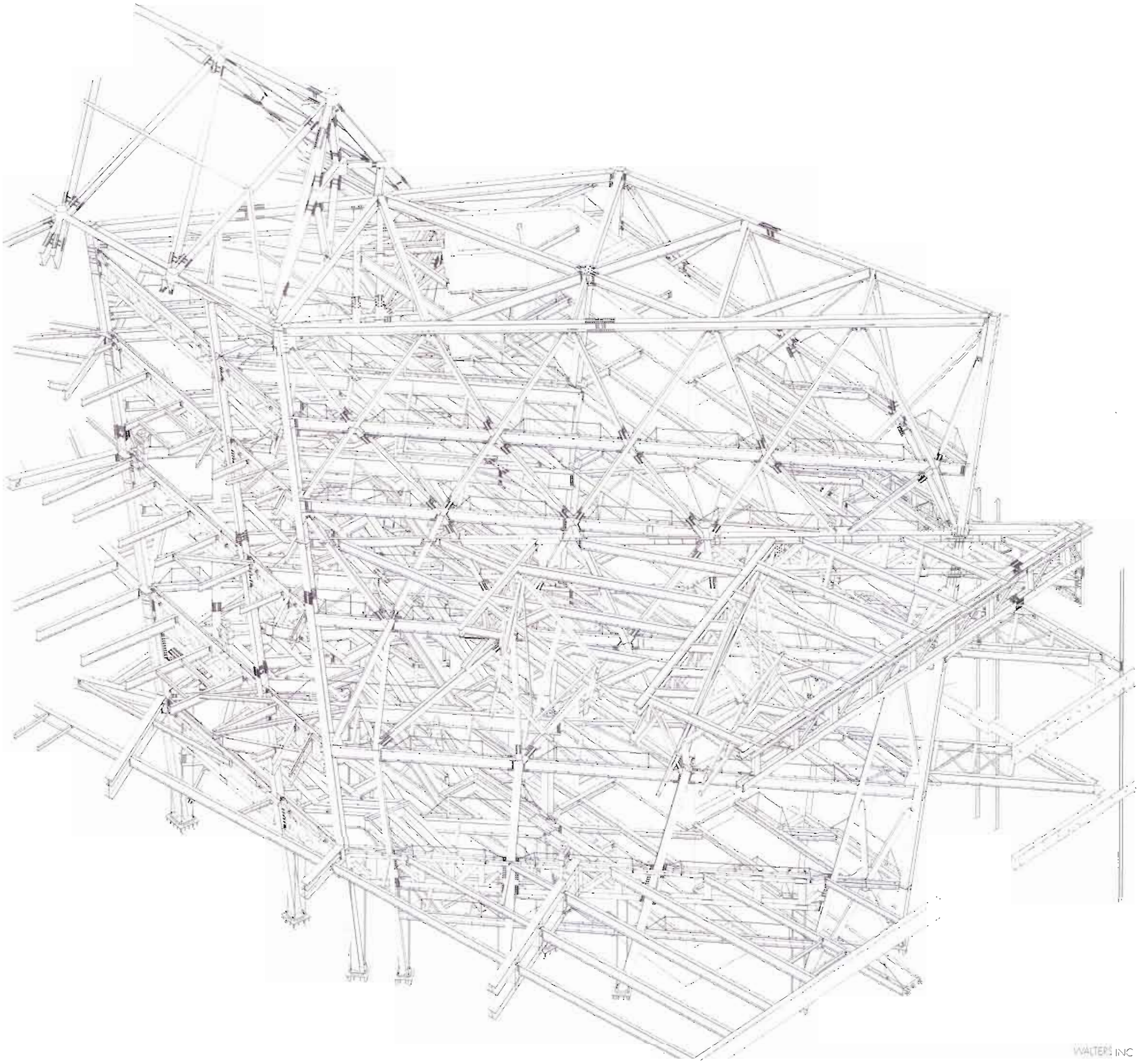
In most "standard" architectural projects, the architect and engineer define and prepare contract documents for bidding, often in concert

TOP, LEFT TO RIGHT FABRICATOR'S MASSING MODEL WITH FLOOR FRAMING ONLY; THE MASSING MODEL SHOWING THE DIAGRIDS ON THE FACES OF THE CRYSTALS. **BELOW, LEFT TO RIGHT** THE CRYSTALS ARE SHOWN BOTH ISOLATED FROM THE ROM, THEN INSERTED INTO THE EXISTING MUSEUM; A SCREEN CAPTURE ILLUSTRATES HOW THE CRYSTALS ARE SUBDIVIDED INTO FLOOR PLATES; USING 3D IMAGERY, THE FABRICATOR MODELLED THE CRYSTAL'S STEEL SKELETON; A DETAIL OF A COMPUTER MODEL MOCKS UP ONE OF MANY STEEL ASSEMBLIES WHICH ARE THEN INSTALLED ON SITE. **OPPOSITE TOP** AXONOMETRIC WORKING MODEL OF "CRYSTAL 4" COMING FULL CIRCLE. SOME HAVE SUGGESTED THAT THIS DRAWING IS REMINISCENT OF LIBESKIND'S EXPERIMENTAL WORK FROM THE CRANBROOK SCHOOL OF DESIGN IN THE EARLY 1980S.









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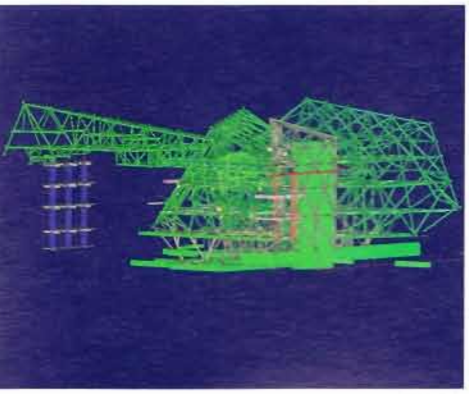
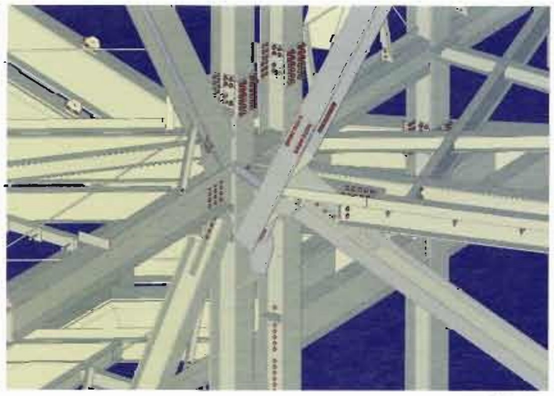
with the project management team. In this instance it was the steel fabricator, detailer and erector—Walters Inc. of Hamilton—who in concert with Halsall Engineering (working with Arup of London), had the facility and expertise to transform the three-dimensional crystalline aspirations into actual steel members and realizable connections. This seems to have become the norm for a steel fabricator such as Walters who has also been responsible for the steel fabrication and erection of other complex structures such as the addition to the Ontario College of Art and Design and the Regeneration Hall in the new Canadian War Museum in Ottawa.

In addition to the basic framing floor plans, the central reference model for the fabricators was a series of axonometric drawings that define the five "crystals" of the museum. Three-dimensional physical models were also used to visualize the structure—ones showing the floor framing layers and ones with the steel diagrids of the crystal faces overlaid on the volumes of the building. Such drawings were broken down to generate a series of fabrication drawings used in the





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ABOVE, LEFT TO RIGHT WALTERS SITE SUPERINTENDENT BRIAN PENNY REVIEWS HIS CREATION; STEEL COMPONENTS IN THE FABRICATOR'S YARD AWAIT SHIPMENT TO SITE. **BELOW, LEFT TO RIGHT** THE SMALL BUT IMPORTANT STAGING AREA AT THE CONSTRUCTION SITE; EACH STEEL MEMBER HAS VERY LITTLE TOLERANCE FOR ERROR AND MUST BE CAREFULLY ERECTED.

shop—one for each unique piece of the frame. Although the triangulation in the diagrid form itself gave stability to many of the planes, moment connection systems were also used throughout the structure to reinforce and increase lateral stability, particularly where large truss members or skylight enclosures are left hanging or cantilevering in the final design.

The steel erection began "crystal by crystal," with Crystal 4 in Summer 2004. The various erection sequences defined the ordered progress of the steel erection. Affection for the project was evidenced by the nicknames for the disparate pieces—the "palms" or the "owl's head"—as the steel's visual characteristics gave each piece a unique personality.

As in the case of Regeneration Hall, Walters used proprietary 3D technology to work out the myriad of connection details. Such programs allow the detailer to use a three-dimensional model of all of the steel components that incorporates loading, and much like an architectural 3D design model, rotate and pull it apart to look at the distinct sections, member sizes, plate thicknesses and bolting and welding requirements. As virtually none of the steel in this building was intended to be exposed, the choice of member shape and size was left to the detailer's discretion in response to issues of connectability, economy and architectural "sleeving boundary."

The steel members were fabricated in Walters shop in Hamilton and then transported to the Bloor and Avenue Road site, to be delivered in such a way as to avoid traffic congestion as much as possible. The staging area on the north edge of the site was extremely tight, so the steel was offloaded and laid very compactly on a "to be erected" basis. Trucking restrictions along the 403 and Gardiner Expressway limited the size of components, so many of the larger angled pieces of the diagrid were shipped as essentially straight members with their palm-like heads attached in the shop, and assembled into larger configurations in the staging area prior to erection. As th erection proceeded through the fall and non-st through the harsh winter of 2005, the staging area steadily shrank as the building displaced th free area of the site. This made sequencing and placement of deliveries even more critical.

For normal steel erection, gravity assists in pulling the pieces into their final position. Contrary to what may be thought, steel joints in project as complex as the ROM must have extremely tight tolerances—extra space to allow for members to connect more easily would only compound into error and lack of fit further dow the erection sequence. Gravity was the enemy o much of the erection at the ROM. Lifting points and chain lengths for the complex angled piece had to be carefully calculated by the erectors to reflect the gravitational centres of the oddly shaped assemblages. The ironworkers sometim made several attempts at obtaining the correct lifting angle or position so that the piece could slid into its receiving connection. This some-

times required that the staged pieces be turned over or rotated within the tight staging area prior to their final hoist. Sudden movements or slippages of members could not be tolerated during a lift, were the gravitational centre not found.

Ninety-nine percent of the erection was achieved with the use of a single tower crane located at the centre of the project. The positioning and reach of this crane was critically calculated. Again the restrictive site area and location played a role as the nearness of Bloor Street and tight staging area negated the use of larger boom cranes to routinely assist with the erection sequence.

Ironworkers Toronto Local 721 erected the steel, and on July 12, 2005 when the final piece was lifted into place with Daniel Libeskind looking proudly on, it was surmounted by an evergreen tree, symbolic of an accident-free workplace. This is a significant accomplishment in and of itself as the nature of the construction of this steel had to see the effective use of fall protection systems as ironworkers climbed up angled steel beams four or five floors above grade to disconnect the crane hook or complete connection bolting.

All of the steel on the project was sized as required. Although it may appear heavy and oversized, the large eccentric forces on all of the non-vertical members put enormous deflecting loads on the unbraced system. The angled members had to be sized much larger than standard vertical columns to prevent increasing sag in the structure. They had to be virtually self-supporting until permanent floor systems were in place, and they had to avoid the need for large numbers of temporary shoring members or systems. A system of diagonal tension cables was used to brace the structure during erection, and were left in place until the completion of the deep concrete floors whose diaphragm action was essential to locking in the shape of the frame. Once the concrete floors were complete in September 2005, all of the temporary cables and rare vertical steel support members were removed.

Steel experiences a significant amount of expansion and contraction due to temperature changes. Walters delivered the structural frame in mid-summer 2005. Subsequently, the frame experienced new loading due to the installation of the concrete floors, and with current winter temperatures, the frame is not the same size nor shape as it was mid-summer. At present, over 10,000 connectors are being attached that will permit the installation of the cladding system, designed and fabricated by Josef Gartner GmbH in Germany, in concert with Permasteelisa. Along with Arup, members of this team have been responsible for the detailed design and installation of the cladding on the Disney Concert Hall by Frank Gehry in Los Angeles, as well as Gehry's Experience Music Project in Seattle and his Guggenheim Museum in Bilbao. Accommodating the severity and temperature swings of the Canadian climate may prove to be the most interesting technological challenge of this element of the construction.

Of the building itself, many might ask, "You can do it, but should you?" The ROM's steel skeleton may be criticized as being excessive or inappropriate, but the process does start an interesting conversation, and might not be a bad thing considering the overall neutrality of most Toronto architecture. It is unfortunate that this intriguing ordered chaos of steel will be mostly concealed by either cladding or drywall. Intumescent coatings would have allowed this energetic structure to be exposed for countless generations to continue to experience and enjoy—like the giant dinosaur bones once hidden by flesh that will soon be housed inside the newly expanded museum. Perhaps the fault lies in the perceived typological difference between what is acceptable as a "museum" (backdrop) and "science centre" exhibit? CA

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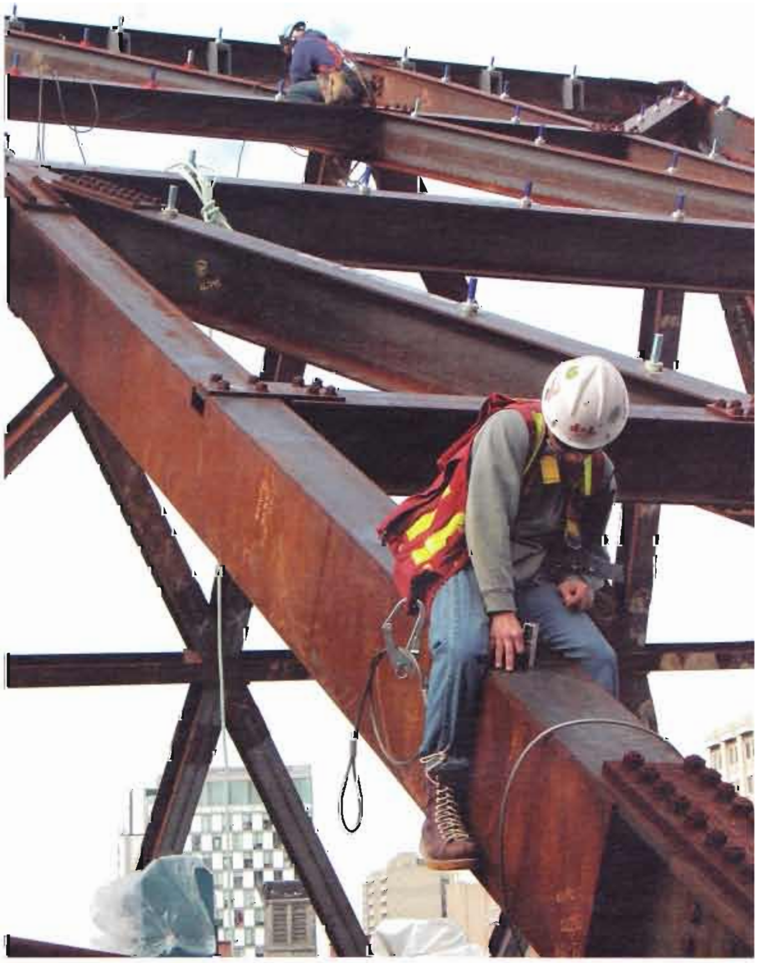

TOP A VIEW FROM INSIDE THE NEST OF CRYSTALS. **RIGHT** WORKERS INSTALLING SOME OF THE 10,000 CONNECTORS USED FOR THE EVENTUAL CLADDING SYSTEM.