CONSTRUCTING A "GEHRY"

THE LATEST IN A RECENT FLURRY OF RENOVATIONS AND ADDITIONS TO CULTURAL INSTITUTIONS IN TORONTO, FRANK GEHRY'S VERSION OF THE ART GALLERY OF ONTARIO IS EXAMINED FROM A TECHNICAL PERSPECTIVE.

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LEFT, TOP TO BOTTOM A CRANE HOISTS ELEMENTS INTO PLACE ON THE NEW NORTH FAÇADE OF THE AGO; A COMPLEX NETWORK OF SCAFFOLDING IS REQUIRED TO SCULPT THE INTERIOR SPACES OF THE AGO, AND THE SIGNATURE CURVE OF THE STAIRCASE IS ALREADY BEGINNING TO DEFINE THE SPACE AT THIS RUDIMENTARY STAGE. **OPPOSITE** A PHOTOGRAPH OF ONE OF THE FIVE ORGANICALLY CURVING STAIRS CAPTURES IT AS A POETIC WORK IN PROGRESS.

The renovation and addition to the Art Gallery of Ontario (AGO) might be considered atypical of a Frank Gehry building in that the final design of the new north façade is one of the first high-profile projects to be designed by Gehry that does not use a highly contorted structural steel frame for its support system. Unlike the Guggenheim in Bilbao, the Experience Music Project in Seattle, and the Disney Concert Hall in Los Angeles, Transformation AGO is largely a renovation to an existing building which extends the floor area by approximately 20 percent. One significant challenge was that the building had to remain functional for a prolonged period during the construction process, and the project needed to accommodate and respond to the distinct needs of the existing segments that were constructed in 1918, 1929, the 1970s and the 1980s. The site itself also imposed severe constraints on the possible scope of the design of the addition, and on restricting the staging area for all aspects of the construction. One lane of both Dundas and Beverley Streets remain appropriated even into May 2008.

The major construction systems can be broken down into four distinct challenges: the steel-supported wood-and-glass gallery that stretches 180 metres along the Dundas Street façade; the structural-steel framing which envelops Walker Court and raises the number of floors of the centre block to five; the signature curved steel staircases; and the blue titanium skin. In speaking with the various firms involved in the construction of these systems, there is obvious interest, energy and pride attached to addressing the particular challenges associated with their complexity.

The South Gallery

Structural steel fabricated by Benson Steel of Bolton, Ontario, was the logical material choice for the framing of the five-storey centre block. In order to meet a demanding schedule, the drawings were fast-tracked to the point of proceeding ahead of approvals. Benson felt that using 3D modelling slowed the start of the project, but was essential in troubleshooting interferences between the new systems and existing structure. The steel was used to stitch together as well as shore the disparate existing and new elements. Steel columns had to be gently inserted around the historic masonry walls of Walker Court in order to support the deep long-span steel beams that produced a clear-span floor space for the upper levels of the new South Gallery. As these galleries can be programmed for events with a high occupant load, a tuned mass damping system has been incorporated into the service space between the upper floors.

The five-storey steel tower is supported on a new system of micropile foundations that had to be installed within the footprint of the existing building. The micropile system, designed by Isherwood Associates, had to respond to extremely restricted access as there was at best 2.75 metres of headroom for the drill rigs to install the high-strength piles that would reach from the subfloor and 20 metres into the shale

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bedrock below. The new foundation system and the steel structure were used to bring the building up to a Zone 2 seismic standard.

The North Gallery

The erection of the sculpture gallery along Dundas Street has been one of the most visible elements during the last year of construction. The fully glazed new north façade is formed by a series of glue-laminated timber arms, subtly supported by and connected with structural steel components. Steel arms act almost like marionette strings working from behind, giving the appearance that the glulam is acting on its own. What made this glulam gallery so challenging to construct is that every arm is unique—each aligned at a more severely reclining angle, resulting in highly eccentric loads and mandating steel connectors at the top and the base that are different for each member. The first arm to be erected set the vertical alignment datum, and required significant erection time to be sure of its precision—as all of the other arms would be relatively positioned. The surveyor overseeing this portion of the project had recent experience on Daniel Libeskind's addition to the Royal Ontario Museum, which likely served as excellent preparation for this project!

Experience is helpful when detailing and erecting any complex project. There were, however, no local precedents for the construction of such a complex composite wood-and-steel structure. The erection team married the expertise of Ironworkers Local 721 and the Carpenters Union as almost every aspect of the assembly of the north façade incorporated both materials and benefited from the combined expertise and problem-solving abilities of the two trades.

Steel and timber exhibit different characteristics that need to be accounted for during the design, detailing, erection and service life of a project. When used in combination, steel performs better in tension and wood in compression. The coefficient of expansion of steel greatly exceeds that of wood; however, wood will expand as a function of relative humidity. Steel corrodes and wood is subject to decay, so moisture must be controlled during construction as well as during the service life of the building. Once wood reaches its equilibrium moisture content in a fully enclosed structure, it will stabilize, but considering that the erection of the arms commenced in June 2007 and the gallery is only nearing full enclosure as of May 2008, both the steel and wood have been subjected to extreme changes in temperature and environment for close to a year. Movement in the structure must be accommodated in the design of the steel-to-wood connections.

The curves have been directly translated from Gehry's hand-drawn sketches via Catia to digital drawings, to the glulam manufacturer, and then to the jobsite. Where technology permits such translation in contemporary representation methods, it does not yet answer the ultimate challenge of ensuring that the members are properly aligned at a "live" 3D jobsite. The combined curve, rotation and slope of each of the elements has to fit perfectly or the subsequent couple of dozen will not align. Although the ironworkers and carpenters can perform some minor adjustments when placing the pieces, these are practically limited.

Translating steel erection practices to glulam has other challenges. During the erection process, steel and timber require different handling. Forceful practices that may be used in structural steel erection (use of chainfalls or come-alongs) would be too rough and could possibly result in visual or structural damage to the large glulam elements. Methods of "encouragement" for large glulam structures are more akin to those used on architecturally exposed structural steel. Lifting straps must be carefully padded to prevent surface damage, particularly to the crisp corners of the members. Excessive force absolutely cannot be used. The workers use the same cloth-based belts and straps that are employed for lifting the pieces to manually (with direct one-on-one force) pull the pieces into position.

The glue-laminated members were manufactured and shipped from Structurlam in Penticton, BC. Each truck would typically contain five curved arms and the large horizontal top-connecting member that tied them together. In the small staging area along Dundas Street, the arms would need to be lifted off of the truck and rotated to allow the attachment of the steel connection elements. The majority of these connectors have a galvanized finish to provide enduring corrosion resistance. Art galleries are typically kept at 50% RH (relative humidity), and this, along with large expanses of glazing, will result in conditions of higher humidity that could result in corrosion. Galvanizing is less expensive than using stainless steel connections, and is more durable than a painted finish.

Working on a geometrically challenging project also translates into working without the aid of the natural force of gravity to position the pieces. During a site interview with Mike Jackson, Toronto Ironworkers Local 721, he said that he has to assess each unique piece and select the lifting points—entirely by experience. He used two points along the curved arms to initially lift them off of the truck and flip them over so that they were "curve down" for the final lift. For this final lift, a single strap was placed (by his eye) about a quarter of the way from the top. Due to the tight staging space, the crane operator had limited visual access to the lift as he was located directly below the gallery

LEFT SEVERAL PHOTOS REVEAL THE DIFFICULT CHALLENGES OF CONSTRUCTING GEHRY'S COMPLEX DESIGN. FOR THE NORTH GALLERY, CURVED GLUE-LAMINATED TIMBER ARMS ARE SUBTLY SUPPORTED BY AND CONNECT TO STRUCTURAL STEEL COMPONENTS. EACH ARM IS ALIGNED AT A MORE SEVERELY RECLINING ANGLE, RESULTING IN HIGHLY ECCENTRIC LOADS THAT MANDATE STEEL CONNECTORS AT THE TOP AND BASE THAT ARE DIFFERENT FOR EACH MEMBER.

floor and was positioning pieces over a ledge and beyond his view. He had to rely on the verbal and hand signals of the lead ironworker to know how to move the piece. Similar to steel lifting, a rope was attached to the bottom end to guide the piece into place. The steel connections, in keeping with current AESS (architecturally exposed structural steel) practice, use half the standard tolerances for structural steel. Each base element had to resolve the unique geometry and orientation of the arm with the steel supporting beam.

For the long top-beam member, the steel connection made the 7,000-pound piece substantially heavier at one end than the other, so the two strap lifting points were adjusted accordingly. The horizontal beam had to connect to the five supporting arms as well as to the end of the adjacent beam, so the galvanized steel connectors were counting on the precise alignment of the previously erected arms.

Smaller glulam members were installed as each section was completed. These provided lateral bracing between the arms, and tied the top beam along its south face to the roof behind. Temporary X-cable bracing remained in place in every fifth bay until the façade framing was complete.

Although less apparent in the middle section of the gallery, the glulam system is reliant on some key AESS elements for its general stability. At either end of the gallery, where the reclining curved arms extend beyond the building, highly articulated arched steel ribs and struts provide support for the wood. This is true also of the twisted glulam framed planes that form the external termination to the gallery at its east and west ends.

In order to provide support for the façade glazing, a more rectilinear layer of smaller glulam members was erected. These provided a faceted surface to which the glazing panels could be attached. In situations where the curve of the façade could not be fitted into a simple curve, the glazing units were triangulated to accommodate multiple curves.

Signature Staircases

Where the glulam and steel elements will form a permanent visual part of the AGO, the intensity of the design, fabrication and erection of Gehry's signature staircases will be hidden beneath their final finishes. Mariani Metals of Toronto was charged with the fabrication of these complex sculptural steel structures. Transformation AGO is their third Gehry project, having already worked with Gehry Partners to assist in the design and fabrication of complex steel elements for the Peter B. Lewis Building in Cleveland and the Princeton Science Library. In all cases, work is based on the 3D models provided by Gehry. Mariani refined these to include member sizes (based on structural calculations from Halcrow Yolles) detailed the specifics of the connections, and resubmitted the model to Gehry. The 2D shop drawings were secondary to this process. All five stairs were preassembled in the shop before being transported to the site.


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TOP A VIEW OF THE UNDERSIDE OF ONE OF THE CURVING STAIRCASES REVEALS THE COMPLEX DESIGN OF ITS STEEL STRUCTURE. **MIDDLE LEFT** THE STAIRCASES WERE ALL FABRICATED AND PRE-ASSEMBLED OFF-SITE BY MARIANI METALS. **MIDDLE RIGHT** THE STAIRCASE AS A DRAMATICALLY EXPRESSED ELEMENT, THRUSTING THROUGH THE BUILDING'S ELEVATION. **BOTTOM** A VIEW DOWN THE ATRIUM SPACE OF THE NORTH GALLERY. CURVED GLULAM MEMBERS ARC GRACEFULLY OVERHEAD.

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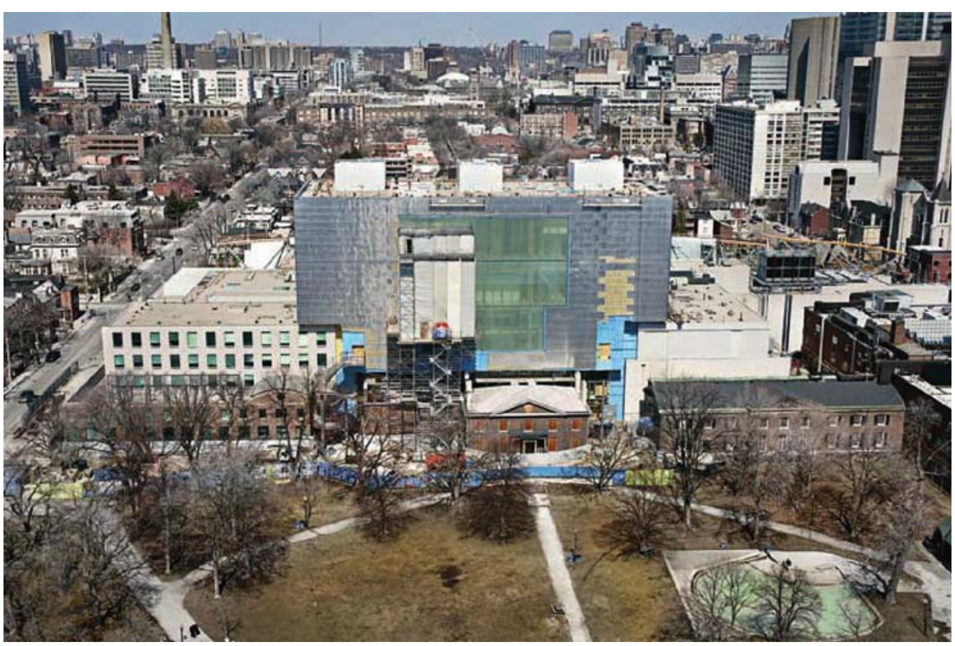

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Vince Mariani cites the key difference in Canadian projects as the limitation of his contract to the structural steel only. For the US projects, it was normal for his contract to also include the cladding, railings and glass components.

Steel was the only material capable of responding to the requirements of the complex curved geometry, deflection limitations, the cantilevered design, and in the case of the central stair, the necessity of winding through some existing building elements. A combination of bent HSS tubes and large gently curved plates was used to fabricate the stair structures. Special sleeved connections had to be designed and fabricated to permit the tube-to-tube stair section connections to be welded on site. This proved problematic as the heavy wall of the tubes (varying from 5/8" to 7/8") naturally tends to deform when bent, so ensuring proper fit and the integrity to meet with tough third-party welding standards was challenging. The stair sections were assembled in the fashion of a 3D jigsaw puzzle, essentially while suspended in mid-air.

The Shiny Blue Skin

The five-storey South Gallery block will be finished in blue custom-made S-lock titanium panels—a signature Gehry cladding material. The titanium skin is the outermost layer of the 3-1/2"-thick envelope. Vertical Z bars were installed at 24" on centre, over an air barrier layer. The depth of the Z bar layer holds the rigid insulation, over which was installed a 14-gauge aluminum backup panel. The 4mm-thick titanium is to be spaced an additional 1/2" out from the aluminum sheet to allow it to both breathe and drain. The installation of the titanium cladding requires "a white glove treatment" as the oil from the workers' skin will stain the material. Gehry has also called for a slightly staggered "earthquake" pattern in the cladding, which necessitates more careful co-ordination with the positioning of the Z bars hidden beneath the aluminum backing panel. Flynn Canada's contract also includes the stainless steel cladding on the sculptural stairs. The blue-clad box with its cantilevered spiral stainless steel-and glass-clad stairs will make a striking axial termination for the view north up John Street. **CA**

Transformation AGO is currently said to be reopening to the public in Fall 2008.

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TOP LEFT THE DUNDAS STREET FAÇADE APPEARS AS A SMOOTH CURVED GLAZED SURFACE, A TRANSPARENT INVITATION TO THE PUBLIC. **LEFT** A VIEW OF THE AGO'S SOUTH ELEVATION FACING GRANGE PARK. THE GRANGE, THE HISTORIC GEORGIAN MANOR DATING BACK TO 1817, WAS RETAINED IN THE SCHEME.