



Art Gallery of Ontario

RENOVATION AND ADDITION

Canadian
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Project of the Canadian Wood Council



Photo: Sean Weaver, Images Resources, Art Gallery of Ontario
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Introduction – about the AGO

The Art Gallery of Ontario (AGO) was founded in 1900 as the Art Museum of Toronto. In 1919 it became the Art Gallery of Toronto and in 1966, took on its present name. The original gallery was a home (The Grange) built around 1817, located on the south side of the AGO facing Grange Park (Figure 1). In fall 2008, the Art Gallery of Ontario received wide acclaim when its recent renovation and addition, designed by Frank Gehry, was opened to the public. The work involved the renovation of existing spaces and the addition of 9,016 m² (92,000 ft.²) of new floor space.

The renovation and addition to the AGO is notable for several reasons. First, the design needed to unify and enhance previous constructions done in 1918, 1929, the 1970s and the 1980s. The design team made extraordinary use of structural and decorative wood elements to achieve this goal, as well as to lure, calm, entice and amaze visitors. In addition, the AGO needed to remain functional for prolonged periods during the construction process.

Finally, the wood design, fabrication and erection was very complex. In the words of Bill Downing of Structurlam Products Ltd., the glulam supplier, in reference to the Galleria Italia portion of the AGO, “This is the most complex wood structure in North America.”



Photo: J Burrows

“ The AGO is open at last and what a beautiful gallery it is. The new AGO, a culmination of light and wood, is a warm and cozy place that Torontonians are sure to enjoy. ”

toronto.com, Toronto Star Newspapers Limited

Wood Uses in the New AGO

Figure 1 is a section through the main entry of the building. It shows the main features of the building and also the major structural and decorative uses of wood elements.

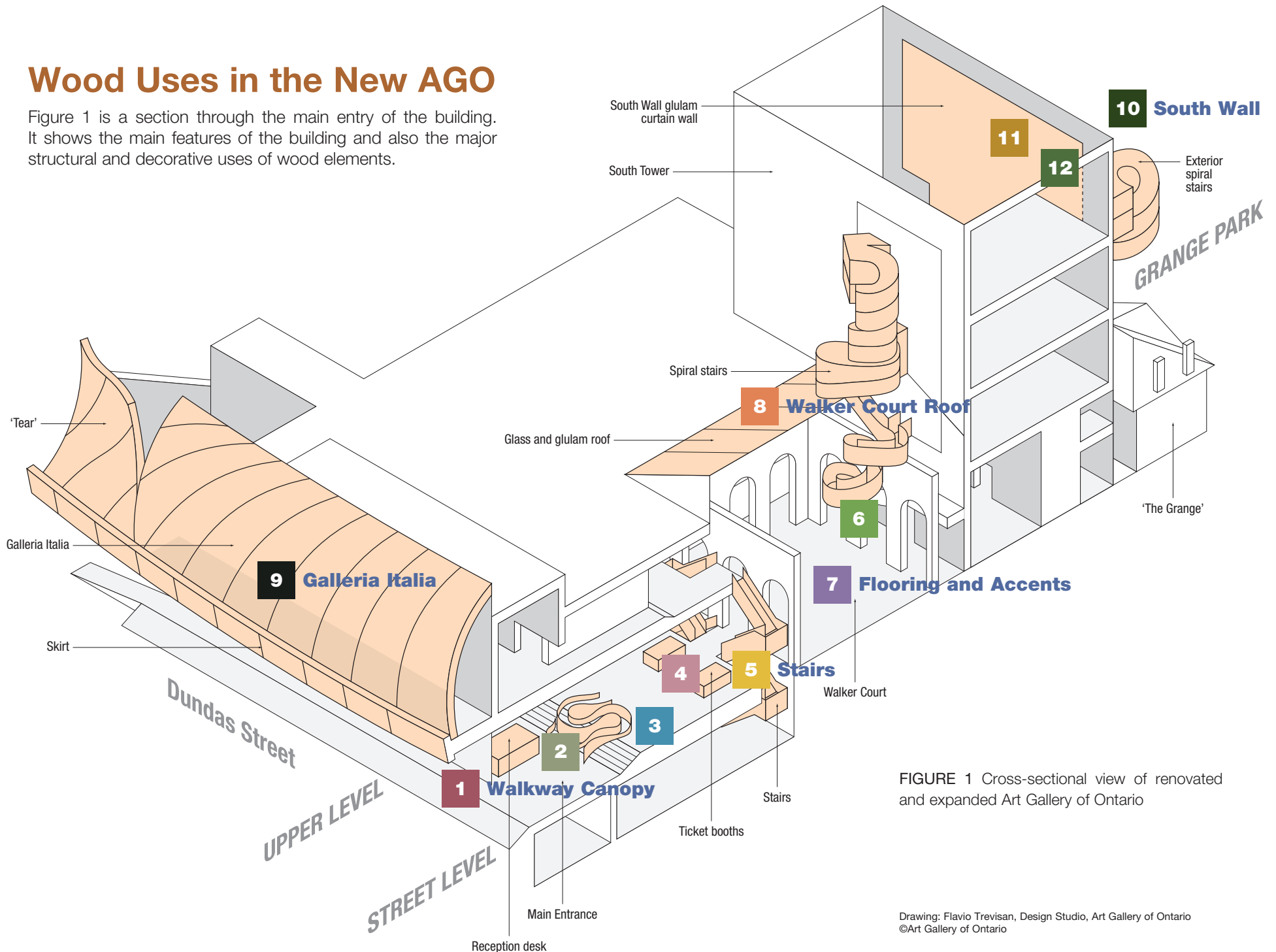


FIGURE 1 Cross-sectional view of renovated and expanded Art Gallery of Ontario

Drawing: Flavio Trevisan, Design Studio, Art Gallery of Ontario
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Walkway Canopy 1: The 200 m length of the AGO fronting on Dundas Street is covered by the projecting canopy of the Galleria Italia and the ‘tear’ end sections of the building above. The wood panels on the soffit provide a warm contrast to the concrete passageway and the glass façade.

Immediately upon entering the building, visitors are greeted by the warm wood colours of the **information desk** and the glulam-framed entrance wall **2**.

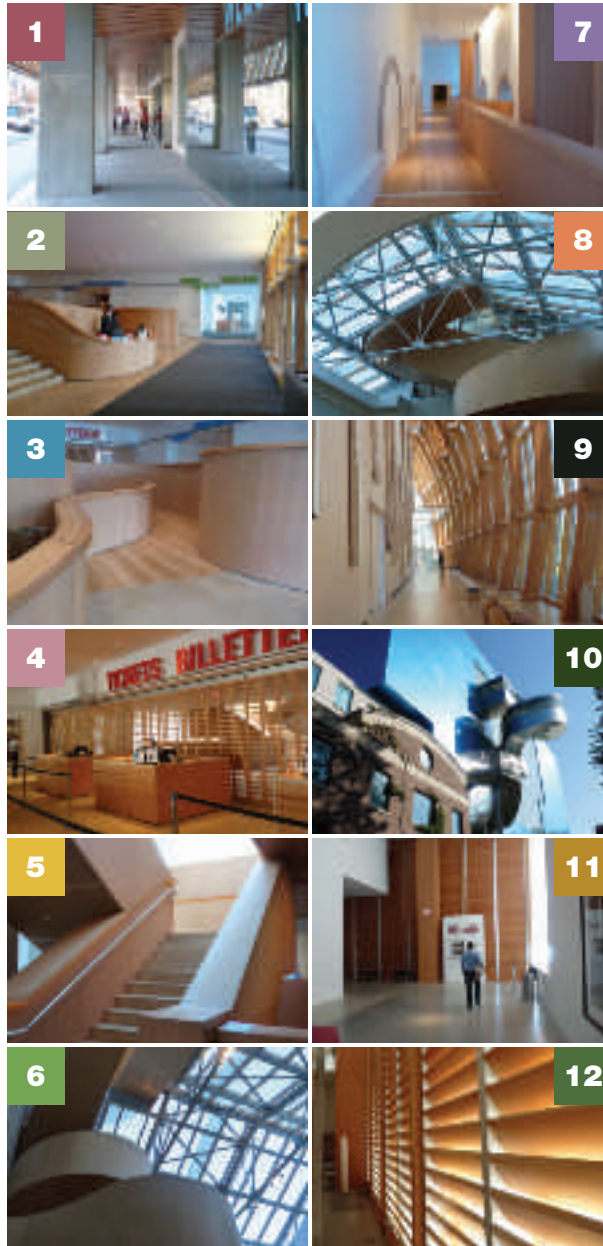
Entry **3** into the gallery is made directly via stairs or by means of a curved **ramp** draped in wood cladding.

The **ticket booths** and the folding **security grill 4** are wood clad.

Although the ceiling height in the entrance is low due to constraints of the previous renovations, the careful use of wood creates a warm space and a sense of anticipation for the art and architecture that lie beyond the entrance.

Stairs 5: Immediately inside the gallery, wood-clad stairs provide access to lower and upper levels.

Inside Walker Court, a wood-clad **spiral stair 6** weaves up through the roof to the floors of the new five-storey exhibit space.



Photos: J Burrows

Flooring and Accents 7: The AGO makes effective use of wood to contrast wall and ceiling surfaces.

Walker Court Roof 8: The steel girder trusses supporting the Walker Court Roof were retained and a glulam frame was added to support a new roof. The roof structure of glass panels provides a 325 m² (3,500 ft.²) skylight that makes the Court bright and welcoming.

Galleria Italia 9: The enclosed portion of the 200 m (600 ft) Dundas Street façade is the Galleria Italia, a glulam and glass gallery that provides a contemplative space with a view of the street below. At both ends of the gallery are exterior portions called ‘Tears’ because they give the appearance of the façade having been pulled away from the building.

South Wall 10 11 12: The five-storey South Gallery block is finished with custom-made titanium panels. An exterior, cantilevered spiral staircase with wood treads and risers provides access between the fourth and fifth levels.

The glazing in the window areas on the south wall and elsewhere is supported by glulam frames. Wood louvers on the interior control the amount of light admitted to the exhibit areas.

“ The Galleria Italia is the most complicated wood structure in North America. ”

Bill Downing, President, Structurlam Products Ltd.

Structural Wood Uses

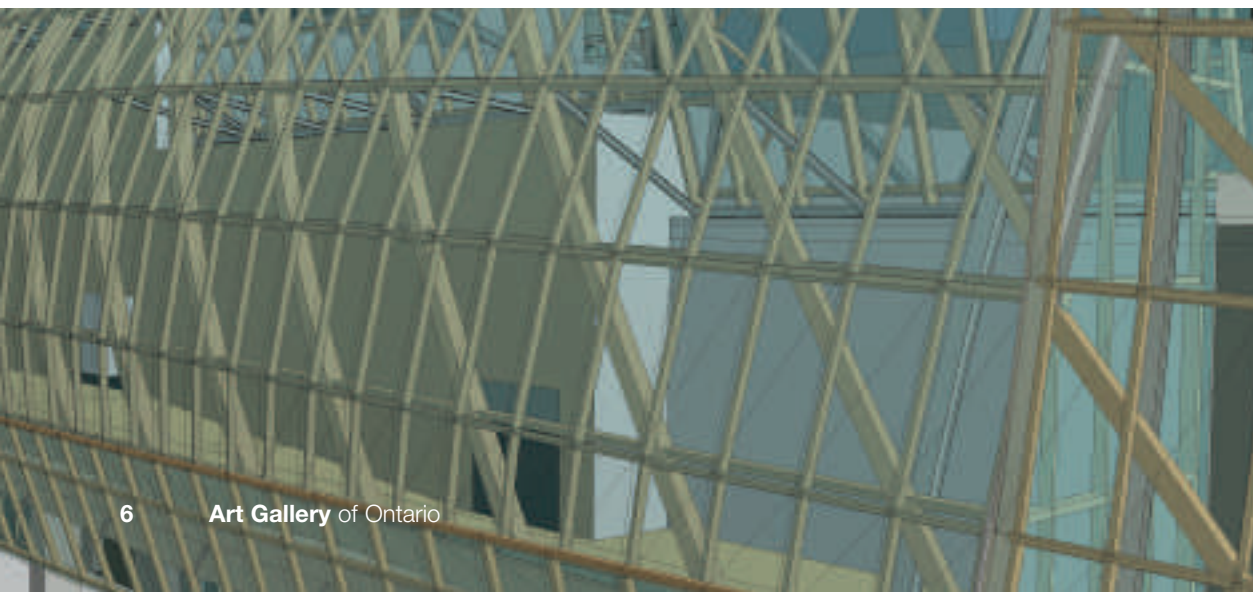
Glulam was used in three main areas of the AGO (Figure 1): the Dundas Street façade, the Walker Court roof, and the South Wall.

The Dundas Street façade is a complex wood structure. Project engineer Crispin Howes of Halcrow Yolles notes there are 1,800 glulam members in the façade and each member is unique, as are the connectors.

The Galleria Italia, the enclosed portion of the Dundas Street façade, is comprised of two specialized layers (Figure 2). The radial arches, of which there are 47, are the inner layer. The radial over the main entrance is vertical, and east and west of that member, each radial slopes at an angle that increases with distance from the entrance, changing both the dimensions and the degree of curvature. The radials provide lateral support for wind load on the second layer, the mullion grid. Also comprised of glulam members, the mullion grid supports the glazing and transfers its weight vertically down to the floor. Due to the differences in coefficients of expansion between the wood structure and the steel framework on which it sits, the mullion grid is supported on sliding bearings that allow the curtain wall to adjust to temperature change without compromising the triple-glazed glass envelope.

FIGURE 2 BMI rendering of Galleria Italia façade

Credit: Halcrow Yolles



There was an architectural requirement to maximize the transparency of the façade. This resulted in the need to make the members small in cross-section, but still large enough to meet the gravity, wind and seismic load requirements after the reductions in cross-sectional area required for the concealed connections. There are 2,500 glulam connectors in the Dundas Street façade and no two are identical. Each connector has unique geometry to accommodate the increasing angle of slope of the radial members. The design of the connectors was complicated by the architectural drive to have them concealed from view and by the fact that in some cases, several members converge at individual nodes.

There are 128 horizontal beams preventing the radials from twisting by means of a moment connection. It was not possible to completely conceal these connections. A repeatable steel connector was designed that involved milling unique connection pockets on both sides of the glulam radials and connecting them with internal through-bolts.

Building Information Modelling

Due to the complexity of adding to an existing building, the designers used modelling to identify conflicts. For example, structural support for the five-storey South Tower involved piling and foundation construction through the existing building.

The structural engineer used building information modelling (BIM) to conceptualize, analyze and design the complex shapes of the Galleria Italia and the spiral staircases, and integrate the designs with the rest of the building. The wireframe model was exported to SAP2000 (integrated software for analysis and structural design). Specialized spreadsheets were also used to aid design.

The designers developed three-dimensional solid models and wireframe models for each glulam application, complete with calculated loads and member sizing. A wireframe of the models was sent to Structurlam Products Ltd., the subcontractor responsible for the connection engineering, detail drafting, manufacturing, delivery, and installation of the glulam. Structurlam used the information to develop a working solid

model that included the glulam members, connections and hardware. The model was used to create shop drawings for approval and eventually for data input to the computer numerically controlled (CNC) equipment used to machine each glulam member to exacting tolerances and to shape the complex framing for each connector.

Glulam Manufacture

As indicated, the glulam and connection configuration is very complex due to the incrementally increasing slant and changing radius of curvature of the radial arches. For this reason, an explanation of how design and fabrication was handled may assist others contemplating complex wood architecture. It also demonstrates the degree of wood design complexity made possible by 3D modelling and computerized wood shaping equipment.

Shop drawings were created from the solid models, and then converted to PDF format and posted to the general contractor's FTP site along with the working 3D model, for review and approval. From the structural models, Structurlam exported the individual component parts to program its Créno Lamelle wood processing machine. The Créno Lamelle uses a gantry crane to travel over large wood members and perform precise machining. It uses a combination of saws, drills and milling cutters to execute computerized instructions. Structurlam acquired a special customized tool head for the Créno to mill out the deepest pockets in the bases of the radial arch members.

The Créno Lamelle was used to make a plywood template of each radial arch and the template was used to situate the glulam forming jig. The CNC machines were used to make fine adjustments to dimensions resulting from springback and to make the seats for the connectors. Another specialized piece of equipment, the Hundegger K2, was used to manufacture smaller members. The Créno 5-axis machine was used for the larger sections and for the most complex cuts. This project would not have been feasible without the CNC machinery capable of creating the geometry and precision required for this design.



Photo © Structurlam

Structurlam subcontracted the design of the connections to Equilibrium Consulting Inc. Due to the architectural directive for the glulam radials to be slender and elegant, the design of the connections was an iterative process with Structurlam and Equilibrium interacting with the architect to find solutions that met both structural and architectural needs. To minimize site fit-up problems, all connectors were test-fitted in the shop prior to delivery to site.

The interior glulam is made of Douglas fir and has a 'Quality' finish. All the glulam (interior and exterior) was sanded to an 80 grit finish. Two coats of Sikken's Cetol® finish were applied. Each member was individually wrapped in 6 mil polyethylene, as per Structurlam recommended practice. The wrap is meant to protect glulam from sunlight and wetting until a building is enclosed – some of the wrapped glulam members at the AGO were exposed for nearly a year before the glulam was protected by the building envelope.

All steel connectors were galvanized or made of stainless steel to provide protection against staining of the wood surfaces – another practice recommended by Structurlam. A paint coat finish was applied to the interior connectors once the building was enclosed.

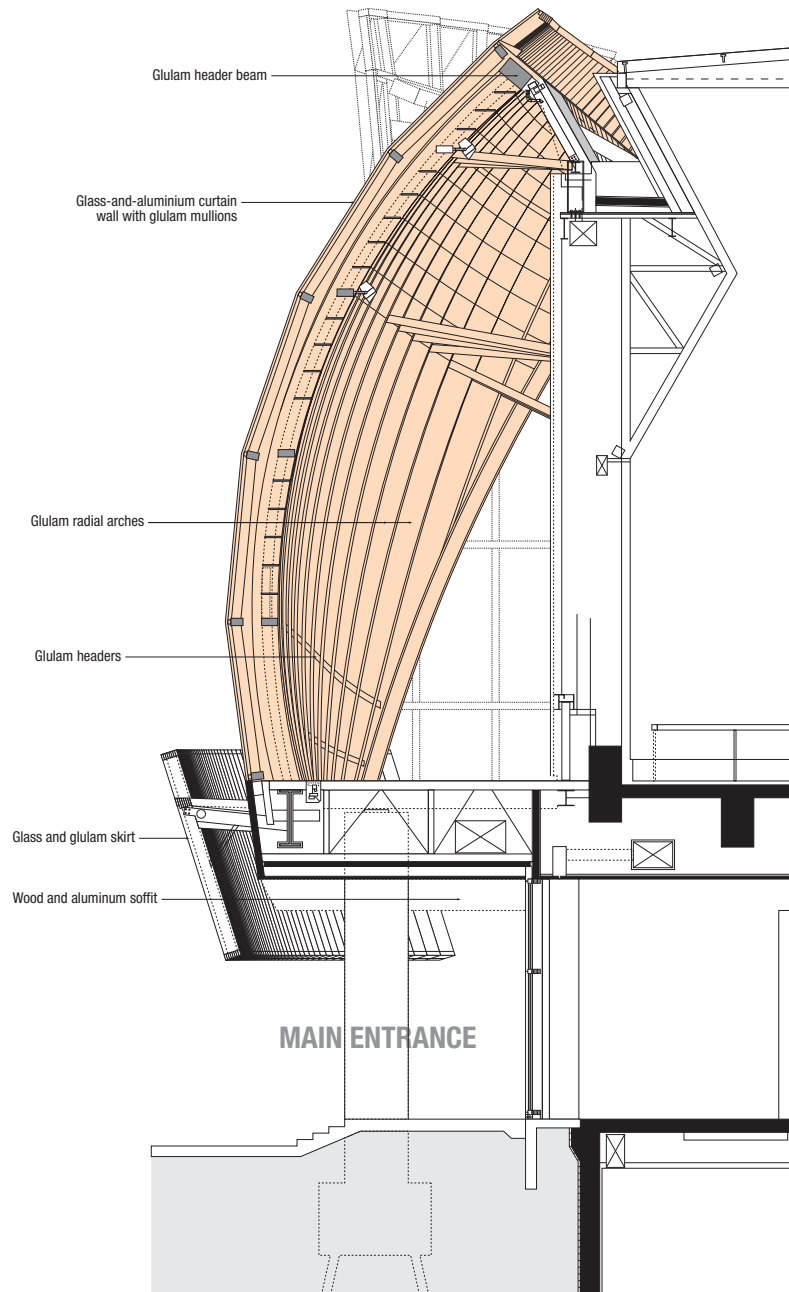


FIGURE 3 Section through Main Entrance and Galleria Italia

The glulam in the 'Tear' sections at the ends of the Dundas Street façade was pressure-treated to provide protection and maintain appearance. The treating was done by Permapost Products Company in Oregon with HI-CLEAR II,TM a petroleum solvent based, two-component wood preservative system for the pressure treatment of lumber, timbers, laminated beams, plywood and architectural wood products. This treatment is intended to protect wood in above-ground, exterior and interior applications. It contains a fungicide and insecticide to protect against both decay and insect attack. HI-CLEAR IITM can be used to pressure treat high-grade wood products used in applications where appearance is important.

Shipment and Installation

The glulam members were manufactured and shipped from Structurlam in Penticton, BC. The connectors were manufactured in Quebec and most were shipped to Penticton for test fitting and attachment to the members at the Structurlam factory. Each truck typically contained five radials and straight glulam sections to balance the loads.

The sloped radials were installed in groups of five and secured in place temporarily with cables in a procedure developed by Equilibrium. From a narrow staging area along Dundas Street, the radial members were lifted from trucks and rotated to allow the attachment of the steel connection elements. The crane operator, who could not see the placement locations, was directed by voice and hand signals. Custom rigging was required to select the unique lifting points on each member. Throughout the installation of the Dundas Street façade, total station site surveying technology was employed to gauge the installation tolerances and make adjustments to ensure small errors did not accumulate over the 200 m (600 ft) length of the façade. Once all the members were installed, the glulam structure was connected to the steel structures at both ends to provide permanent lateral stability.

Decorative Wood Uses

In addition to the impressive structural applications of wood in the new AGO, wood was used decoratively to provide visual highlights.

Stairs, entry ramp walls, ticket booths, folding security grill and interior Galleria walls

These areas are faced with vertical grain, Douglas fir veneer affixed to an MDF (medium density fibreboard) or plywood substrate. The veneer is finished with Sherwin Williams catalyzed lacquer, dead flat, 5 gloss units.

Hardwood flooring

The floors of the new areas are surfaced white oak engineered flooring (Kultur™: 14mm (5-¼ in.) width, minimum 1.3 m (4 ft.) lengths). The flooring is affixed directly to the concrete substrate with Fortane™ LD wood flooring adhesive.

Photo: Sean Weaver, Images Resources
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Fire Safety

Design for the Art Gallery of Ontario was based on the 1997 Ontario Building Code (OBC). The major occupancy is classified as Group A, Division 2, up to 6 stories, any area sprinklered (Sentence 3.2.2.24). According to David Galvao, Senior Associate and fire protection/life safety code consultant with Leber Rubes Inc. (LRI), due to the complexity of this building and the architectural goals, building code consultation meetings were held with the City of Toronto early in the design process to review requirements and to provide alternative solutions that would meet or exceed the intent of code provisions.

For example, previous modifications to the AGO resulted in the installation of sprinklers in new areas and the provision of one-hour fire separations between the new sprinklered areas and the older areas that were not required to be retrofitted with

sprinklers. The same methodology was applied for the recent renovation of major existing floor areas and the expansion. This means that most of the building is now sprinklered and those existing spaces that are not sprinklered are separated by one-hour fire separations. As a result of this recent renovation, an overall increase in the performance level of the building with respect to fire suppression and compartmentation has taken place.

The following sections review areas where wood was used and measures that were taken to meet building code requirements.

Walkway canopy soffit

The soffit of the walkway canopy that extends along the length of the AGO on Dundas Street is comprised of aluminium and wood panel claddings (Figures 1 and 3). The OBC permits



Photo: J Burrows

combustible canopies in noncombustible buildings. The second floor gallery space above the canopy is sprinklered in order to provide the required protection to openings in the exposed wall directly above the canopy. Although the second floor is not entirely sprinklered, immediate gallery spaces adjacent to the canopy are sprinklered, meeting the intent of the code.

Exterior wall assemblies

Heavy timber was used on the exterior walls in the Galleria Italia (Figure 2) and for the glazed areas on the south wall of South Tower (Grange Park). The exterior façades were not required to be constructed with a fire resistance rating and were permitted to be constructed with 100% unprotected openings. The use of heavy timber was considered acceptable on the basis of its inherent flame spread rating, fire resistance rating equivalency, and permissions in the code for the use of similar wood features such as combustible millwork and solid lumber partitions in non-combustible buildings.

Heavy timber elements supporting roofs can be used in buildings up to two storeys in building height. Although the AGO is more than two storeys, it was demonstrated that the areas where heavy timber was intended to be used met the intent of the provision. This equivalency was explained and accepted early in the design process and allowed the powerful use of wood structures in both the Galleria Italia along the Dundas Street façade and on the south façade.

Although not required, the building has a smoke detection system that provides early warning and initiates the first stage fire alarm signal, which allows a potential problem to be investigated before sprinklers are activated. This two-stage fire alarm system provides the best balance between security against theft, protection of the art against unnecessary activation of sprinklers, and protection of the building occupants.

The heavy timber wall assembly on the south elevation was not continuous from floor to floor. A specially approved fire stopping material was used between the floor slab and the curtain wall to achieve the floor to floor fire separations.

Walker Court roof assembly

The AGO is more than two stories high. The 1997 and the current 2006 OBC permit the use of heavy timber roofs (and supporting elements) in buildings up to two storeys in building height, regardless of building area, provided the building is sprinklered. The OBC requires that the flame spread rating of ceiling finishes not exceed 25, except that combustible ceiling finishes with a flame spread rating not exceeding 150 can be used over 10% of the ceiling area. Walker Court is a two-story portion of the building and is sprinklered. Based on sprinkler protection, no fire resistance rating was required for this roof assembly. The approach used took into account the inherent properties of heavy timber – its 45 minute fire resistance rating – and limited the use of heavy timber to the glulam purlins, which did not constitute more than 10% ceiling area, and were supported by the historic steel truss structure that was refurbished during the AGO addition and renovation.

A one-hour fire separation was required to address floor-to-floor fire separations between Walker Court and the South Tower. This was accomplished by providing a window sprinkler system consisting of two tiers of window sprinklers, one above the other. Each row of glazing is protected by a row of sprinklers. The glazed units are separated at each level by a horizontal mullion. This deep-set mullion provides a ‘rain-shield’ to protect the sprinklers in the lower tier from cold soldering. Cold soldering can result from the wetting and cooling of un-activated sprinklers by water sprays from adjacent sprinklers that have activated first. In this case, the activation of sprinklers in the top tier could potentially cold solder the sprinklers in the bottom tier and thus prevent their activation. In addition, the doorway openings between Walker Court and the South Tower were limited in size to 10 m² in order to meet the requirement for floor openings (in this case, applied in a vertical plane) within interconnected floor spaces.



Photo: Craig Boyko, Images Resources,
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Wood used for decorative applications

Decorative wood finishes were used liberally in areas of the AGO that are sprinklered. The 1997 and current 2006 OBC permits the use of wall finishes with flame spread ratings not exceeding 150 provided they are not more than 25 mm thick and are not foamed plastic materials. Flame spread ratings for lumber, Douglas fir plywood (with no cellulose resin overlay), and plywood with spruce face veneer meet this requirement, both unfinished or with a paint or varnish thickness not exceeding 1.3 mm in thickness.

The underside of the exterior soffit along Dundas Street is constructed of 32 mm (1¼ in.) thick marine grade veneered plywood with solid edges. The approach of using heavy timber construction at the north façade exterior canopy was accepted by the City of Toronto. The use of the plywood with solid edges was considered to meet the dimensional requirements for heavy timber floor and roof assemblies in accordance with OBC 3.1.4.6.

Based on OBC 3.1.13.2, the maximum flame-spread rating of interior wall and ceiling finishes cannot exceed 150. In addition, the flame-spread rating of materials used for interior finishes in a building required to be of noncombustible construction must comply with requirements of Subsection 3.1.5. In accordance with Subsection 3.1.5, the combustible ceiling finishes (other than foamed plastics) and wall finishes are permitted in a building required to be constructed of noncombustible construction provided they:

- are not more than 25 mm thick
- have a flame-spread rating not more than 25 on any exposed surface, except that up to 10% of ceiling finish may have a flame-spread rating up to 150.

The Douglas fir veneer cladding on the spiral staircase meets these requirements. Combustible finished flooring elements are permitted in accordance with Sentence 3.1.5.8.(4).

The wood shade fins on the north and south interior façades and the wood lattice in the entrance lobby were considered to be combustible millwork and permitted in a building required to be constructed of non-combustible construction in conformance with OBC Article 3.1.5.7.

Many Reasons for Using Wood

The United Nations' Intergovernmental Panel on Climate Change deems buildings to be the greatest opportunity for making considerable reductions in carbon dioxide emissions. Using sustainably harvested wood as a construction material is a simple and cost-effective step in this direction.

Carbon Dioxide

Carbon dioxide is a key factor of global warming and it is also a major ingredient of wood. As trees grow, they draw carbon dioxide from the atmosphere and, using solar energy, convert the carbon dioxide into wood fibre (50% of wood is carbon) while releasing oxygen back into the atmosphere. If trees are harvested before they burn or decay, the carbon is stored indefinitely in the wood products, and new trees are planted to begin the cycle again.

Wood products sequester more carbon dioxide than the amount emitted during harvesting, transportation and manufacturing, which means they actually have a negative greenhouse gas footprint.

“ Specifying wood in public procurement can help fulfil national and local climate change programmes. Encouraging the use of wood products can act as a greener alternative to more fossil-fuel intensive materials. Substituting a cubic metre of wood for other construction materials (concrete, blocks or bricks) results in the significant average of 0.75 to 1 t CO₂ savings. ”

International Institute for Environment and Development
<http://www.iied.org>



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Wood and Life Cycle Assessment

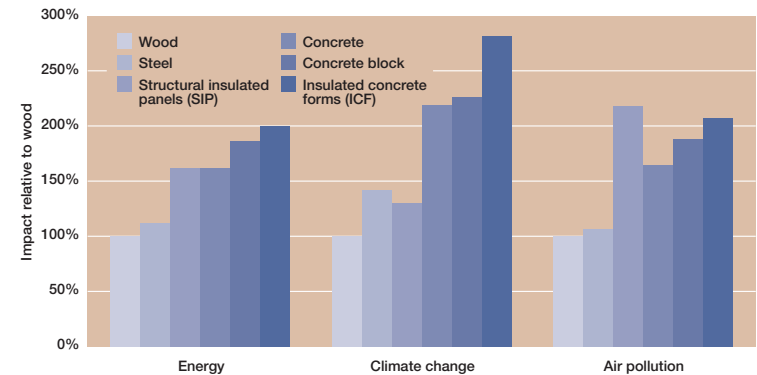
Life cycle assessment is a scientific measure of the environmental impact of a product throughout its entire life – from resource extraction through to product manufacturing, on-site building construction, occupancy, and eventual demolition, as well as disposal, reuse, or recycling. Numerous life cycle assessment studies worldwide have shown that wood products yield clear environmental advantages over other building materials at every stage.

Life cycle assessment takes away environmental performance guesswork by calculating actual outcomes based on quantifiable indicators of environmental impact, such as global warming potential, resource use, embodied energy, air pollution, water pollution and solid waste.

The ATHENA® EcoCalculator for Assemblies is a tool based on life cycle assessment that allows architects, engineers and others to quickly assess and compare environmental impacts of hundreds of building assemblies that are commonly used in construction. The ATHENA EcoCalculator is available free at www.athenasmi.ca

Scientific analysis of building materials shows that wood has the lowest environmental footprint of all major building materials (Figure 4).

FIGURE 4 Embodied environmental impacts of various exterior wall assemblies



As environmental awareness grows, building professionals are finding wood is an excellent choice for green construction designs that minimize the use of energy, water and materials, and reduce negative impacts on human health and the environment. Wood is a high-performance and versatile choice for any new construction or renovation. Wood is light in weight, yet strong. It has excellent load-bearing and thermal properties, is easy to work with, and is well suited for large or small projects. Wood adds warmth and beauty to any building, enhancing the well being of occupants.



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Project Team

Architect Team

Gehry International Architects Inc.
(architectural design)
12541 Beatrice Street
Los Angeles, CA 90066 USA
Tel: 310-482-3000
www.foga.com/contact.asp

Adamson Associates Architects
(on-site architects)
401 Wellington St. W., 3rd Floor
Toronto, Ontario M5V 1E7
Tel: 416-967-1500

Structural

Halcrow Yolles
Queen's Quay Terminal
Suite 550, 207 Queen's Quay West
Toronto, ON M5J 1A7
Tel: 416-363-8123
www.halcrowyolles.com

Fire Protection and Building Code Engineers

Leber Rubes Inc.
2300 Yonge Street, Suite 2100
Toronto, ON M4P 1E4
Tel: 416-515-9331
www.leber-rubes.com/

Glulam Supplier

Structurlam Products Ltd.
2176 Government St.
Penticton, BC V2A 8B5
Tel: 250-492-8912
www.structurlam.com

Glulam Connection Design

Equilibrium Consulting Inc.
405-19 Duncan Street
Toronto, ON M5H 3H1
Tel: 416-255-3337
www.eqcanada.com

Glulam Erector

Spring Valley Classic Custom Corp.
635 Trinity Road, RR 1
Jerseyville, ON L0R 1R0
Tel: 905-648-1881

Millwork

Provincial Store Fixtures Ltd.
895 Meyerside Drive
Mississauga, ON L5T1R8
Tel: 905-564-6700
www.psf ltd.com



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Alberta Wood WORKS!: 780-392-1952
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US Program: 1-866-966-3448

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