



Canadian Consulting Engineering Awards 2014

Project: The Canadian Museum for Human Rights

Category: A. Buildings

Submitted by: CH2M HILL

A black and white photograph of a construction site, showing a large concrete structure under construction. The structure is heavily reinforced with a complex network of steel beams and scaffolding. In the background, a cable-stayed bridge is visible. A blue horizontal band is overlaid across the middle of the image, containing the text.

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Entry Forms



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Project Outline



Summary

The building for the Canadian Museum for Human Rights (CMHR) was envisioned to be an iconic symbol of Canada – to showcase a world class experience which is a true testament to the importance of the nation, and to inspire the human rights debate relating to the diversity of human experience. The building was designed by renowned US architect Antoine Predock, who won the international design competition in 2004. CH2M HILL was selected to provide structural engineering consulting services.

The museum is the first large project of extreme complexity in Canada where interdisciplinary collaboration and construction were successfully achieved utilizing virtual models. In addition to the spatial unique building design, the CMHR also strives for LEED Certified Silver designation. When the building opens in September 2014, it is expected to bring positive energy, new economic development, and recognition to the local community in Winnipeg and to the province.

Innovation

The CMHR has been recognized as the first large project of the extreme complexity in Canada where interdisciplinary collaboration and construction were successfully achieved utilizing virtual models for the real-time collaboration and interaction between various groups often participating from different geographic locations (40 companies located in eight cities from North America and Europe). The high tech collaboration tools combined with computer generated models were unconventional in the beginning, but quickly recognized as the essential elements in design and construction processes for this unique building and related precise details associated with various components and materials. Commencing with the basic 3D visualization of the building, continuing through the preconstruction planning, quantity take-offs, procurement and construction, virtual models proved to offer a complete package that helped clearing unknowns, improving efficiencies and mitigating potential risks; a new process implemented into a traditional industry proved to be a great success while traditional 2D documents proved to be inadequate.

By now the advantages and disadvantages of Building Information Modelling (BIM) are well documented in the building construction industry but at the time of CMHR design initiation it was a relatively new technology that forced a cultural change to the design consultant teams. For the complex three dimensionally curved and sloping geometric forms of this building CH2M HILL developed a sophisticated workflow to capitalize on the best aspects of several software programs more common to the industrial, automotive and aircraft industries. Starting with CATIA in 2004 and moving to a full REVIT model in 2008, these building models were utilized as contract documents along with conventional 2D drawings. Various components of the building such as the Roots, Mountain, Cloud, and Tower of Hope were broken out and individually translated from design concept into structural components using Rhino, Grasshopper and proprietary computer programs, and later manipulated back into the master BIM geometric model.

Ultimately the benefits of BIM were realized in excellent 3D visualization, sharing of information for coordination, and clear contract documentation. BIM was clearly the best tool to manage the structural complexity of this building. This project exemplifies many other firsts and innovation **introduced into** the structural design with the structural steel, glass and concrete designs advanced with modern technologies and tools to overcome design, collaboration and construction challenges for some aspects of this unique building, possibly most ambitious national museum.

Complexity

The iconic architectural forms used by Predock's team within CMHR resulted in exceptional structural complexity including large column free spaces, unconventional load paths, long spans and extreme cantilevers, delicate detailing of glass façade, and highly stressed connection points between steel forms and at concrete walls. Building components are reminiscent of natural forms incorporating icebergs, tree roots, dove wings and mountains; all with a task in symbolising hope for a better world. This project exemplifies the best of design excellence and marriage of classic materials to create a unique building structure.

Translation of complex geometry into structural solutions; the only way to advance the structural design forward was to break the structure into separate components that could be modelled independently and sequentially integrated into the overall scheme. Design and construction of the Mountain Galleries proved to be the most challenging aspect of the project. The Mountain consists of a randomly stacked array of stone clad diagrid forms of irregular shape suspended above ground floor and cantilevering 16m over the atrium. A disproportionately small back span required the floor diaphragms at the top and bottom levels to act as a horizontal couple to supplemental resistance to overturning. The connection to the concrete core proved to be challenging, requiring complex tie-in connections. Maintaining the vertical and lateral locations of key structural elements combined with construction in the region of extreme climate necessitated temporary shores, controlling the method steel erection and the sequence of concreting, and global cambering of the structural steel frame.

Social & Economic Benefits

Initiated in 2003 by CanWest founder Dr. Israel Asper to be the largest human rights institution and education centre in the world, the CMHR construction was made possible by a partnership that includes the Government of Canada. Located in the geographical centre of Canada at The Forks of the historic native lands Red and Assiniboine Rivers in Winnipeg, Manitoba, the architectural design was selected in one of the largest international competitions that included 62 submissions from 12 countries; in one of the largest judicial reviews that stretched over period of 18 months and included three levels of detailed submissions. This project brings positive energy, new economic development and recognition to the local

community in Winnipeg and the province, a home of native people and many settlers from across the Globe.

Museums Act: *“To explore the subject of human rights, with special but not exclusive reference to Canada, in order to enhance the public’s understanding of human rights, to promote respect for others, and to encourage reflection and dialogue.”*

Architect’s Quote: *“The Canadian Museum for Human Rights is rooted in humanity, making visible in the architecture the fundamental commonality of humankind—a symbolic apparition of ice, clouds and stone set in a field of sweet grass. Carved into the earth and dissolving into the sky on the Winnipeg horizon, the abstract ephemeral wings of a white dove embrace a mythic stone mountain of 450 million year old Tyndall limestone in the creation of a unifying and timeless landmark for all nations and cultures of the world.”*

Environmental

Sustainability is an all-encompassing issue that was considered and principles applied across all design disciplines in consideration of given budget constraints. In order to achieve the greatest benefits the principles of sustainable design were applied throughout the construction process and plan to extend into the building operation. With the main objective of sustainability to achieve social, economic and environmental benefits whilst minimizing the negative impacts of the development, the CMHR project is presently pursuing LEED Silver certification.

Client Needs

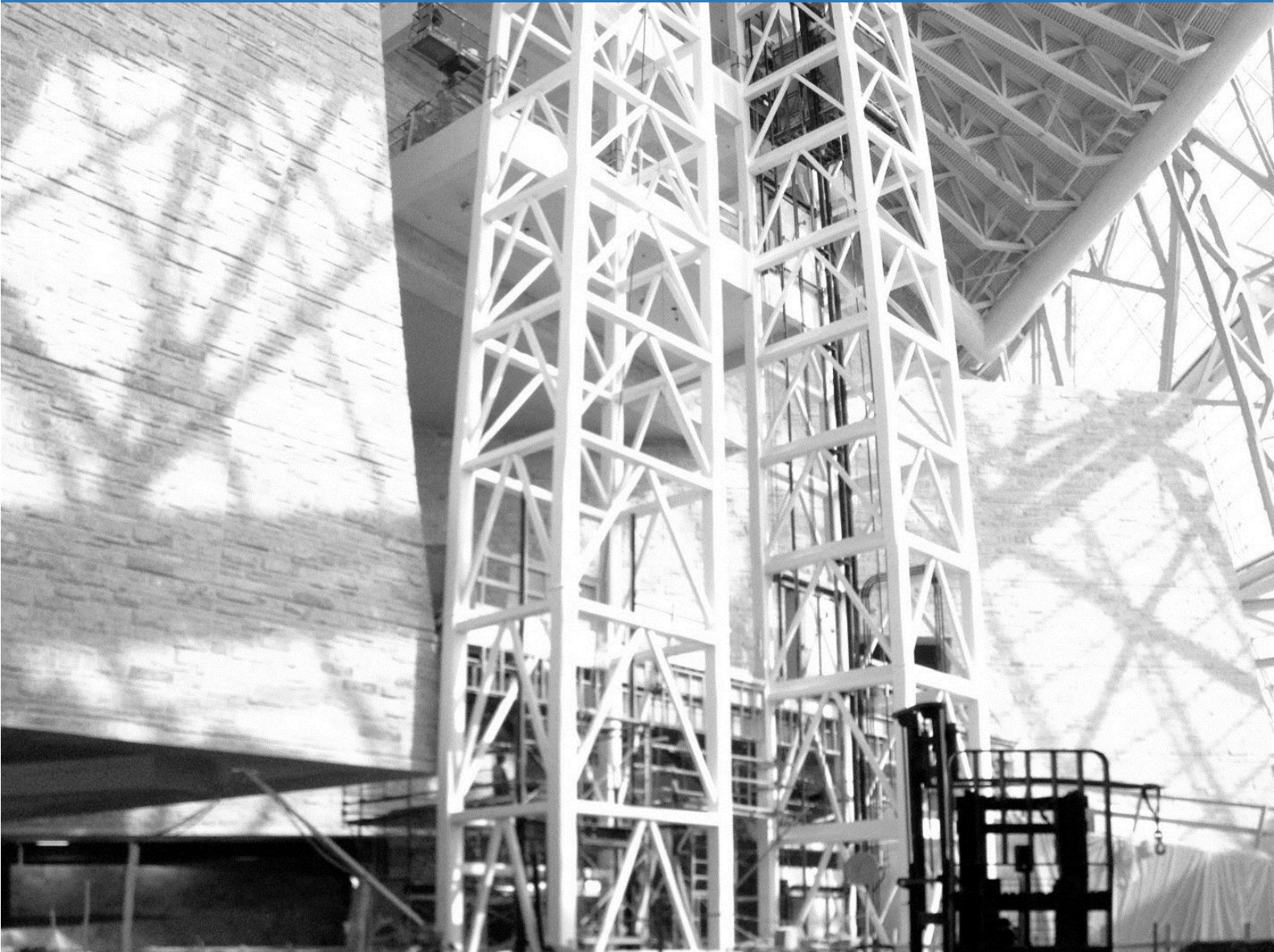
The museum is envisioned to be an iconic symbol of Canada – a magnificent and unique structure, showcasing a world class experience that will be a true testament to the importance of Canada, as a nation, and an inspiring place for the human rights debate relating to the diversity of human experience. Modern technologies and tools, including BIM, were successfully used to model, design, document and construct the building structure with various software tools used in analysis and design, visualisation and collaboration throughout all phases of the project.

A true team effort combined with latest advanced technologies were the only feasible options to satisfy the challenges posed by this architectural vision and the resulting magnificent building will be a true testament to the importance that Canada, as a nation, places on human rights. Structural steel in combination with reinforced concrete and glass were used to overcome numerous design and construction challenges for the architecturally complex CMHR superstructure including the conical forms of the Roots, stacked prisms of the Mountain, rationalized geometry of the Cloud and Tower of Hope, Garden of Reflection and the long span Hall of Hope ramps.



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Detailed Project Information



Project Team

Owner:	Government of Canada
Design Architect:	Antoine Predock Architect
Executive Architect:	Smith Carter
Structural Engineer:	CH2M HILL
Mechanical Engineer:	The Mitchell Partnership Inc.
Electrical Engineer:	Mulvey+Banani International Inc.
Exhibit Designer:	Ralph Applebaum Associates
Construction Manager:	PCL Constructors Canada Inc
Steel Fabricator:	Walters Inc.
Glazing Supplier:	Josef Gartner GmbH



Photo courtesy of PCL Constructors Canada Inc.

Canadian Museum for Human Rights

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Photos © Patrick Coullie Photography

Design excellence and structural innovation at the Forks

By Neb Erakovic, P.Eng., Crispin Howes, P.Eng., and Terry Dawson, M.Eng., P.Eng.

Located in the geographical centre of Canada at the Forks of the historic Red and Assiniboine Rivers in Winnipeg, the architectural design for the Canadian Museum for Human Rights (CMHR) was selected from an international competition that included 62 submissions from 12 countries. One of the largest judicial reviews in the country's history, it stretched over 18 months and included three levels of detailed submissions.

Antoine Predock's winning design draws inspiration from Canada's natural scenery and open spaces. The museum is envisioned to be an iconic symbol—a magnificent and unique structure, showcasing a world-class experience that will be a true testament to the importance of Canada not only as a nation, but also as an inspiring place for the wider human rights debate relating to the planet's diversity.

Initiated in 2003 by CanWest founder, Israel Asper, to be the largest human rights institution and education centre in the world, the CMHR construction was made possible by a partnership that includes the Government of Canada. The *Museums Act* reads:

To explore the subject of human rights, with special but not exclusive reference to Canada, in order to enhance the public's understanding of human rights, to promote respect for others, and to encourage reflection and dialogue.

Yolles, A CH2M HILL Company, was selected to provide structural engineering consulting services for the building. It completed this challenging task by collaborating with the architects to translate their vision of organic forms into rational structural component solutions tied together to create a building that is stable and constructible.



Above is the central atrium of the new Canadian Museum for Human Rights (CMHR) in Winnipeg. In achieving the nature-inspired forms, the project involved copious structural steel, modelling technology, and close collaboration.

Laticrete

1/2 Pg Horizontal

“ In combination with reinforced concrete and glass, structural steel was used to overcome numerous design and construction challenges. ”

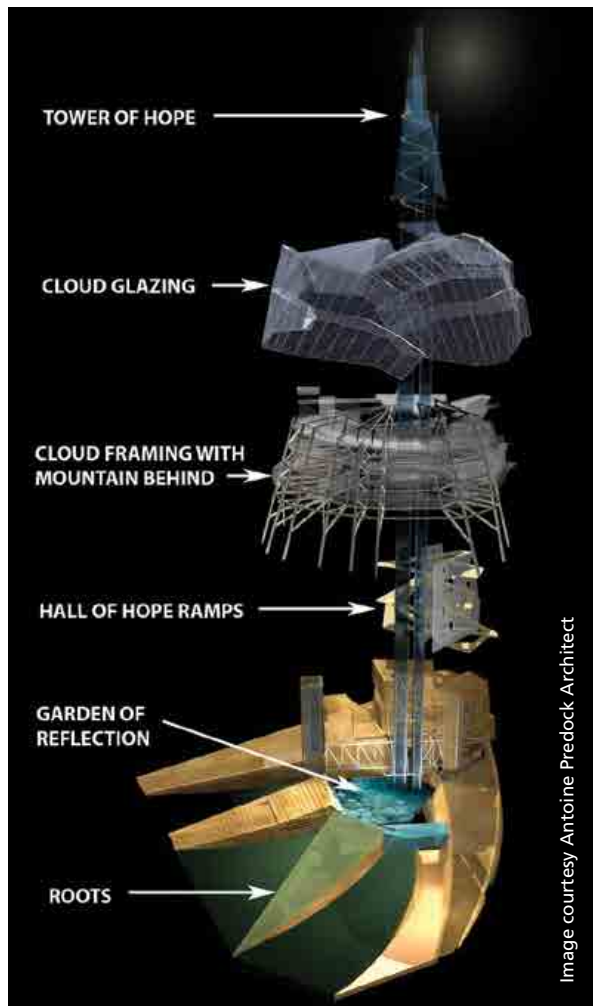


Image courtesy Antoine Predock Architect

The assembly of primary programmatic zones.

Project Team for the Canadian Museum for Human Rights

Design architect: Antoine Predock Architect
Executive architect: Smith Carter
Structural engineer: Yolles, A CH2M HILL Company
Mechanical engineer: The Mitchell Partnership Inc.
Electrical engineer: Mulvey+Banani International Inc.
Exhibit designer: Ralph Applebaum Associates
Construction manager: PCL Constructors Canada Inc.
Steel fabricator: Walters Inc.
Glazing supplier: Josef Gartner GmbH

From the structural perspective, this project highlights the benefits and importance of modern tools and the technology associated with three-dimensional modelling of complex geometric forms and development of interfacing details for building interwoven components; constructed using practically all common building materials, including steel, concrete, glass, and stone.

Complexity in form

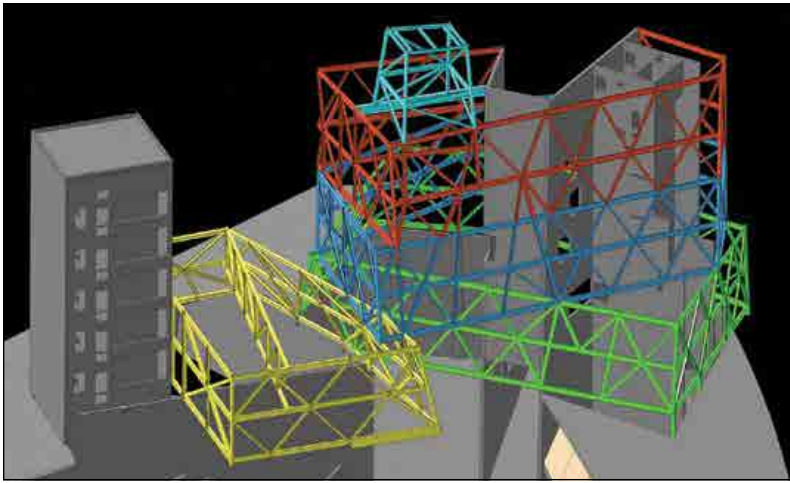
The CMHR is one of the country's first large projects of extreme complexity relying on interdisciplinary co-operation and construction to successfully achieve use of virtual models for real-time collaboration and interaction between various groups in different locations—as many as 40 companies located in eight cities in North America and Europe. The high-tech tools, combined with computer-generated models, were unconventional in the beginning, but quickly recognized as the essential elements in design and construction processes for this unique building and related precise details associated with various components and materials.

Commencing with a basic 3D visualization of the building, continuing through the preconstruction planning, quantity take-offs, procurement, and construction, virtual models proved to offer a complete package that helped clear unknowns, improve efficiencies, and mitigate potential risks. This new process implemented into a traditional industry proved to be a great success where, in many cases, traditional 2D documents would have proved to be inadequate.

The iconic architectural forms used by Predock's team within CMHR resulted in significant structural complexity, including:

- large column free spaces;
- unconventional load paths;
- long cantilevers;
- delicate detailing of glass façades; and
- highly stressed connection points between steel forms and at concrete walls.

When it came to the translation of the complex architectural geometry into structural solutions, the



Schematics of diagrid Mountain trusses.

only way to advance the structural design was to break the structure into separate components. This allowed them to be modelled independently and to be sequentially integrated into the building's overall structural scheme.

As a result of this process, the building structure can generally be considered as separate structural components tied to create the unique form. In many areas, the complex and unconventional geometry led to convoluted load paths between structural elements.

The basic design

The CMHR structure is generally composed of four base 'Roots,' radiating out from a central 'Great Hall' and 'Garden of Reflection' beneath a suspended 'Mountain,' 'Cloud,' and 'Tower of Hope'. The 50-m (164-ft) tall

'Hall of Hope' atrium at the back of the building cuts into the Mountain and Roots like a canyon and houses circulation ramps between galleries.

The Roots contain the functional spaces of the museum and are constructed of sloping, segmented, reinforced concrete walls. The Mountain contains the bulk of the exhibition spaces, and the Cloud encapsulates office spaces and a large atrium. Projecting above the Cloud roof, the Tower of Hope houses an observation gallery to provide visitors with a stunning view of the Forks, downtown Winnipeg, and the surrounding prairies. (All building components are reminiscent of various natural forms, also incorporating icebergs and dove wings.)

The unique Mountain exhibition galleries, curved Cloud façade, Tower of Hope spire, Garden of Reflection, and Hall of Hope ramps posed significant design challenges through use of structural steel frame interconnected with spatial concrete shells and multi-faceted curved glass façade. When an idea and design philosophy are transformed into a practical and constructible building, it takes the talents of all aspects of the industry and team collaboration to come together to deliver the finished product representing the original vision.

CMHR: By the Numbers

- 9:** years from architectural inception to project completion (2004 to 2013—contract documents began in December 2008)
- 44:** months for structural construction (April 2009 to December 2012)
- 20:** months between the start of caissons construction and concrete topping off (April 2009 to November 2010)
- 16:** months for structural steel erection (July 2010 to November 2011)
- 350,000,000:** approximate construction cost in dollars
- 50:** height, in metres, to the top of the Cloud Roof
- 100:** height, in metres, to the top of Tower of Hope
- 24,500:** area, in square metres, of total floor space
- 4500:** area, in square metres, of exhibition space
- 5100:** metric tonnes of structural steel
- 165,000:** bolts
- 18,000:** cubic metres of concrete
- 800:** metres of pedestrian ramps
- 4000:** metres of masonry shelf angles
- 6000:** concrete fasteners
- 2500:** embedded plates
- 2300:** concrete insert tie-ins 🔗

Form challenges and structural steel solutions

The Mountain consists of a seemingly randomly stacked array of five stone-clad closed steel forms of irregular shape suspended 18 m (59 ft) above ground floor. Initially conceived in reinforced concrete, use of structural steel framing was necessitated by the various design challenges, which included:

- highly stressed contact points between forms;
- large column-free spaces;
- significant form cantilevers;
- large openings in walls;
- sloping walls;
- eccentricity of stone cladding; and
- unconventional vertical and horizontal load paths.

Mountains

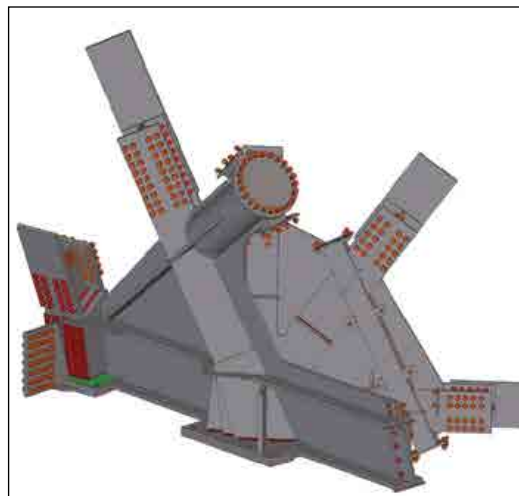
Each of the two-storey Mountain wall consists of structural steel W-sections and corner circular hollow sections to form the primary diagrid wall trusses spanning significant unsupported distances



Shared super nodes with diagrid members between Mountain forms.

between concrete walls and steel columns. The diagonal and vertical elements within the diagrid wall trusses are positioned around wall openings to provide direct load paths down to supports, but also transfer lateral loads down the building with composite floor diaphragms distributing those loads across to supporting walls.

Parametric sensitivity analyses were conducted to assess the effects of changes in temperature, slab and wall cracking, construction sequencing and staging, and connection fixities. Optimizing the stacked diagrid wall truss member locations,



designs, and connections with consideration to these parameters is complicated by their redistributive nature.

Another significant design challenge was the lower Mountain form cantilevers 16 m (52 ½ ft) over part of the Garden of Reflection. A disproportionately small 20-m (66-ft) back span required the floor diaphragms at the top and bottom levels of this form to act as a horizontal force couple. This provided supplemental resistance to the cantilever's overturning.

The connection of cantilever to the concrete core walls also proved to be challenging, requiring complex tie-in connections at this material interface. The massive supported weight of stone cladding, heavily loaded exhibition and plant floors, upper Mountain, Cloud roof, and the Tower of Hope meant this form needed to be super-elevated at erection to ensure flat floors in the final condition. Extreme loads also require six 500 x 100-mm (20 x 4-in.) solid steel plates to be built up to form a solid 500 x 600-mm (20 x 23 ⅜-in.) steel diagrid member. The design and construction of this cantilever form proved to be the project's most challenging aspect.

Rooted in Humanity

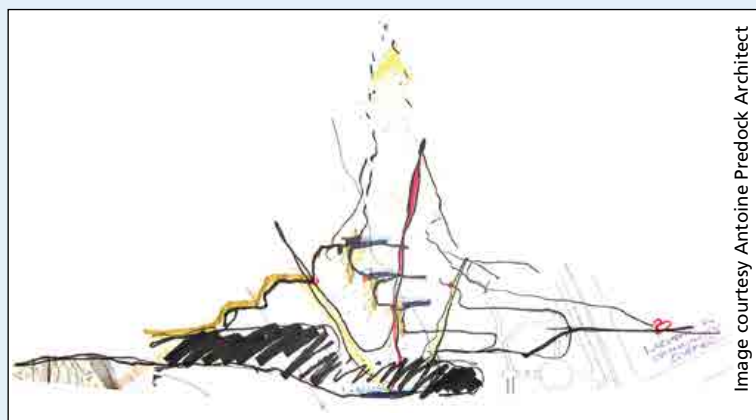


Image courtesy Antoine Predock Architect

The Canadian Museum for Human Rights is rooted in humanity, making visible in the architecture the fundamental commonality of humankind—a symbolic apparition of ice, clouds, and stone set in a field of sweet grass. Carved into the earth and dissolving into the sky on the Winnipeg horizon, the abstract ephemeral wings of a white dove embrace a mythic stone mountain of 450-million-year-old Tyndall limestone in the creation of a unifying and timeless landmark for all nations and cultures of the world.—Antoine Predock 🇨🇦

The Cloud

The glazed Cloud encapsulates the large central atrium, museum offices, and Garden of Reflection. The Cloud curvature is framed with a series of curved 610-mm (24-in.) diameter hollow circular steel pipes supported by raking built-up hollow steel columns that span more than 30 m (100 ft) from the Roots up to the Cloud roof.

Balcony-like partial perimeter office floors encircle the atrium at three levels, acting as diaphragms to provide lateral stability to the

Long-span trusses below the Garden of Reflection.



Photo courtesy Smith Carter Architects



Photo courtesy Antoine Predock Architect

The zone of overlap between Cloud wings.

raking columns. Steel framing allows light into the Tower of Hope and practically unobscured panoramic views out. The underlying geometry consists of two overlapping cones discretized into faceted shards of layered glazed panels.

The Garden of Reflection

Located at the base of the Cloud atrium and Tower of Hope, the Garden of Reflection provided its own structural complexity. To provide a column-free space for the dark void of the Great Hall below and to support the Tower of Hope elevator hoistway and spiral stair above, a two-directional, long-spanning, steel truss support system was used.

The Garden of Reflection's framing, which supports still water pools and Basalt stone seating, floats between surrounding

structural components (Hall of Hope walls and adjacent Roots) and sits on sliding bearings to prevent the attraction of significant compatibility forces. Behind the Garden of Reflection, circulation ramps, clad in backlit alabaster stone, link the museum exhibition spaces and fly through the Hall of Hope atrium—a 50-m (164-ft) high black concrete canyon.

These ramps, which are steel pony trusses up to 25 m (82 ft) in length, are highly irregular and susceptible to significant human-induced vibrations. Steel was the only viable solution for this complex series of pathways. As each ramp is unique in span and supports, a repetitive structural framing system was used to rationalize the fabrication and construction.

Temporary bracing

Owing to the prairie climate, it was anticipated the structure could experience temperature differentials of at least 30 C (54 F) before the building needed to be enclosed. Expansion joints were not possible within the interior due to the requirement for continuous diaphragms to resist wind loads and to hold sloping, cantilevered, and unbalanced parts of the building together. This meant locking the various steel components of the structure into the supporting concrete walls during construction would result in unacceptably high thermal restraint forces and potential damage.

Temporary steel slip connections and slab separation strips were used to disconnect selected structural components during construction with temporary bracing introduced to maintain stability until the building was enclosed.

Advances in reinforced concrete design and construction

Four projecting roots at the building's base were formed from vertical and inclined concrete walls that support sloping roofs. While the original design anticipated spatial forms to be double-curved surfaces, design evolved into segmented trapezoidal planes to rationalize truncated cones and to facilitate engineered formwork design. Some root walls are sloped up to 23 degrees from vertical, and are featured with faces finished in architecturally exposed, coloured, 'shaggy' concrete.



The Hall of Hope's ramps are clad in alabaster and lit by light-emitting diodes (LEDs).



Hall of Hope and root wall construction.

Shaggy concrete generally consists of pre-meditated poor concrete that emulates natural earthen surfaces such as exposed walls of sedimentary rock. The creation was closely developed with architects and the contractor to include methods to form, colour, pour, and finish concrete to create the desired appearance.

Floor diaphragms are important links between gravity- and lateral-resisting elements of any complex building structure, as they tie various elements to form a stable overall structural system. Floor diaphragms consist of reinforced concrete topping on steel deck and additional steel bracing beams where forces proved excessively high for thin slabs. A lack of detailed building code provisions for diaphragm analysis and design required Yolles to develop its own rational analysis and design process appropriate to the design of this essential component in an extremely complicated application with load paths difficult to visualize without the use finite element method (FEM).

Undesirable structural building deformation effects can result from various impacts, such as foundation settlement, temperature variations, and history of load application (including the placement of concrete for floor slabs, cladding, and finishes). Maintaining the vertical and lateral locations of key structural elements necessitated:

- additional temporary shores;
- controlling the method steel erection;
- cambering of the structural steel frame;
- controlling the sequence and timing of concreting and the installation of the building cladding components; and
- controlling the sequencing of construction for sections of the project.

Buildings built in the regions of extreme temperature variance, such as Winnipeg, require the designer to consider both the methods and schedule of construction since the distribution of forces and movements of the structure are affected by the sequencing and temperatures during. Regular buildings constructed about a central core experience reduced temperature effects as the building perimeter freely moves, the three cores of CMHR generate significant restraint forces as the structure is not free to move between the points of resistance.

Expansion joints were not possible for the building in its final configuration due to required continuity of floors and the building enclosure to hold sloping, unbalanced, and separated components, and to link them to the supporting concrete walls.

A temperature differential in uncontrolled environment for the building in construction meant unlocking the steel frame into the supporting concrete elements to control connection forces. Steel connection slip joint details, slab separation strips, three mega shores, and secondary temporary bracing was introduced to partially relieve the potentially significant thermal restraint.

3D visualization and information-sharing

By now, the advantages and disadvantages of building information modelling (BIM) are well-documented in the building construction industry. However, at the time of CMHR's design initiation, it was a relatively new technology that forced a cultural change for the design consultant teams.

For the complex, three-dimensionally curved and sloping geometric forms of this building Yolles developed a sophisticated workflow to capitalize on the best aspects of several software programs more common to the industrial, automotive, and



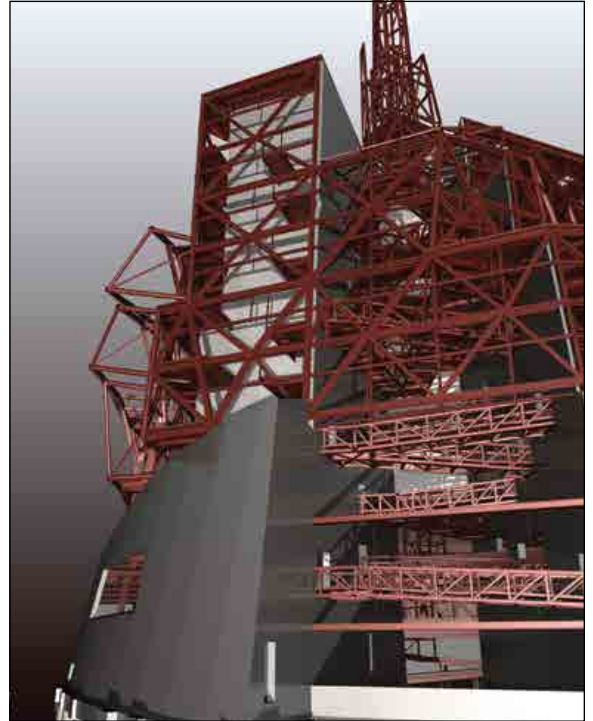
The CMHR is one of Canada's first large projects of extreme complexity relying on interdisciplinary co-operation and construction to successfully achieve use of virtual models for real-time collaboration and interaction. There were as many as 40 companies, located in eight cities in North America and Europe, working together to ensure success.

aircraft industries. Starting with CATIA (*i.e.* Computer Aided Three-dimensional Interactive Application, by French company Dassault Systèmes) in 2004, and moving to a full Autodesk Revit model four years later, these building models were employed as contract documents, along with conventional 2D drawings.

Various components of the building such as the Roots, Mountain, Cloud, and Tower of Hope were broken out and individually translated from design concept into structural components that were manipulated back into the master BIM geometric model. Ultimately, the benefits of BIM were realized in 3D visualization, sharing of information for co-ordination, and clear contract documentation. BIM was clearly the best tool to manage the building's structural complexity.

Lasting impression

In combination with reinforced concrete and glass, structural steel was used to overcome numerous design and construction challenges for the architecturally complex Canadian Museum of Human Rights superstructure. BIM was successfully used to model, document, and construct the building structure with various software tools used in analysis and design, visualization, and collaboration throughout all phases of the project.



Early structural building information model (BIM).

Image courtesy Yolles, A CH2M HILL Company

A true team effort and the latest advanced technologies were the only feasible options to satisfy the challenges posed by this architectural vision. The resulting magnificent building will be a true testament to the importance Canada, as a nation, places on human rights. 🇨🇦



Neb Erakovic, P.Eng. is a principal at the Toronto office of Yolles, A CH2M HILL Company. He specializes in design and management of structures with architectural complexity. Erakovic can be reached at neb.erakovic@ch2m.com.

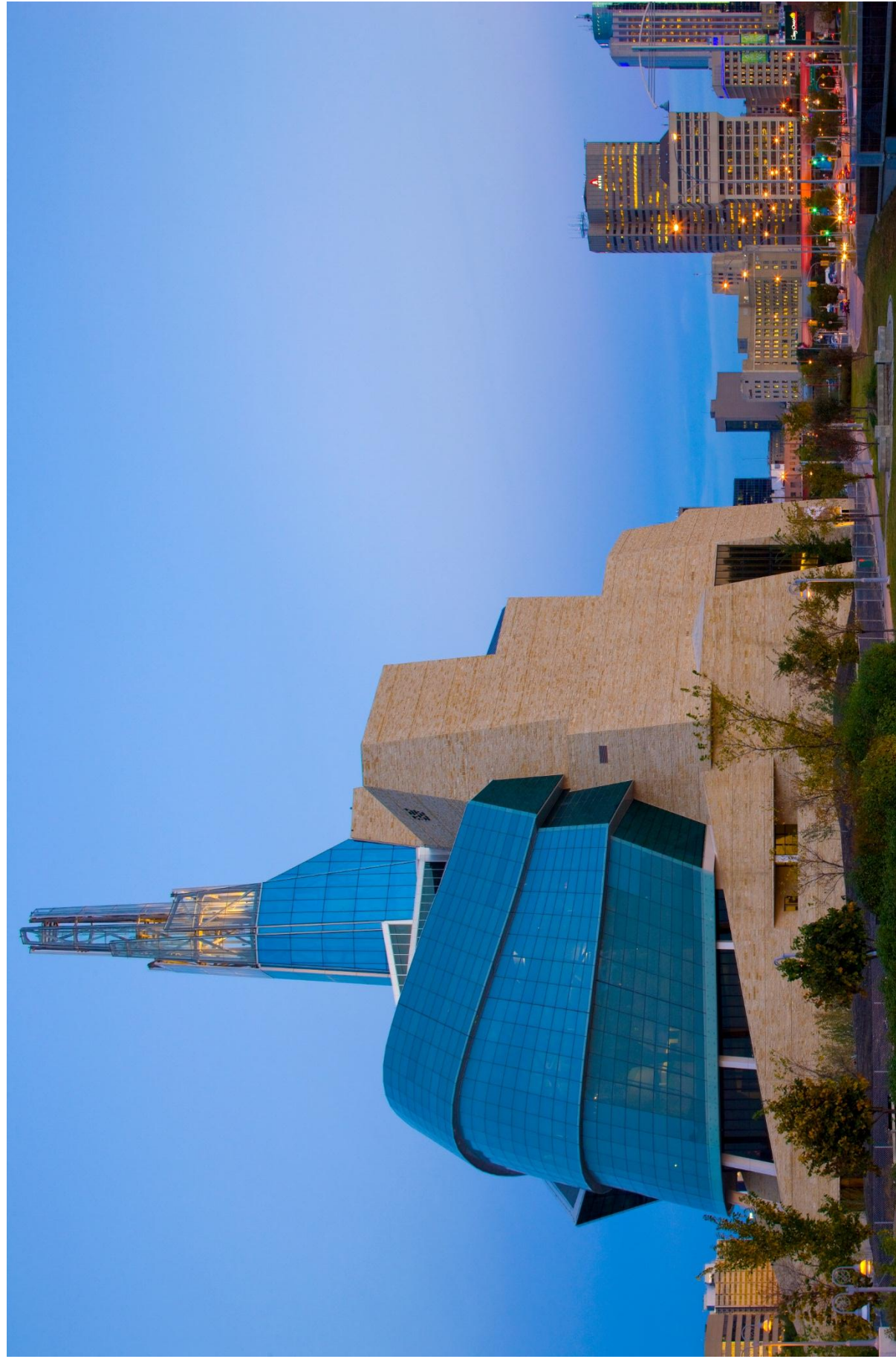
Crispin Howes, P.Eng., is a senior associate in Yolles' Toronto office. He specializes in advanced geometric structural engineering and heads the firm's Studio for Progressive Modelling. Howes can be contacted via e-mail at crispin.howes@ch2m.com.

Terry Dawson, M.Eng., P.Eng., was formerly an associate in Yolles' Toronto office. He has experience in structural engineering in Canada, the United Kingdom, and New Zealand. Dawson can be e-mailed at terry.dawson@ch2m.com.



Completed Museum at Dusk

Photo courtesy of Patrick Coullie Photography



East Elevation of Museum with the Downtown core beyond

Photo courtesy of Patrick Coullie Photography