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CHUM— BUILDING A MEGA HOSPITAL

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MEGA-HOSPITAL in Montreal

The first phase of the Centre Hospitalier de l'Université de Montréal (CHUM) is almost complete. The structural and mechanical-electrical engineers describe the challenges of designing for this massive P3 construction project on a tight urban site.

Near the Ville-Marie Expressway in downtown Montreal, a gigantic construction project is transforming the landscape. The $1.9-billion Centre Hospitalier de l'Université de Montréal (CHUM) is one of the most ambitious urban integration projects in the city's history. And at 3 million square feet (276,000 m^2 in Phase 1, 66,000 m^2 in Phase 2), it will be the largest hospital in North America serving a French-language population.

In another first, it is to date by far Canada's largest healthcare project done as a public private partnership. CHUM is being delivered, financed and will be maintained for 30 years by the Collectif Santé Montréal, a joint venture formed by Innisfree, Laing O'Rourke, Obrascon Huarte Lain (OHL) of Spain,

Above, centre of photo: Phase 1 CHUM hospital complex under construction facing onto St. Denis Street in downtown Montreal. (The completed CHUM Research Centre on the left was by another consortium.)

and Dalkia Canada. Laing O'Rourke and OHL, as Construction Santé Montréal, are responsible for the design-build contract.

The hospital is the result of a 1996 merger between three existing hospitals: Saint-Luc, Hôtel-Dieu and Notre-Dame. The new complex is at Rue St. Denis and Blvd. René Levesque, immediately adjacent to the existing St-Luc hospital, which has remained operational throughout the first construction phase.

Phase 1 is nearing completion and due to open by the end of next year. It includes a hospital of 21 storeys and a 19-storey outpatient clinic fronting on St. Denis, both with four levels below grade. Plus there is a 9-storey specialized and logistics building behind. The three components are connected by two tunnels and a sky bridge. The hospital has 772 private rooms in 26 in-patient units, 39 operating rooms, seven MRIs and 12 cancer treatment bunkers.

The second phase, scheduled for 2016-2020, includes the demolition of St-Luc Hospital and the construction of additional outpatient clinics, clinical and administrative offices, and an amphitheatre and square along St. Denis. Across Viger Avenue is the CHUM Research Centre which was completed in 2013 by a different consortium.

CHUM was envisioned not only as a place of healing, but as a place of gathering. It is to act as a "spark" for the redevelopment of an underused part of downtown located between the historic cobbled streets of Old Montreal and the city's Latin Quarter.

Designing the mega hospital was especially challenging because of the tight urban site. Near the half-submerged expressway and a subway line, it is also within walking distance of a festival area that causes entire city blocks to be closed to traffic during a good part of the summer. Hydro-Québec has also been upgrading infrastructure under many streets around the site.

STRUCTURAL ENGINEERING

By PL Lanoue. ing,
Project Director
Pasquin St-Jean et associés

The three buildings in the first phase of CHUM are gravity structures made of reinforced concrete. They were designed according to the National Building Code of Canada and the Quebec Construction Code as a post-disaster use and Class A seismic design for Montreal.

One of the challenges was designing the seismic force resistance system for three buildings that were built in two phases, but which behave as one. Spectral and push-over analyses were performed using ETABS computer modelling to calculate the distribution of forces over the height of the buildings and the behaviour of plastic hinges in the structure.

The performance specifications imposed many loading variations depending on the function of the spaces, whether they were patient or operating rooms, laboratories, etc. As an example, the live loads for the hallways are 4.8 kPa, whereas for patient rooms the live loads are 2.4 kPa. Where protective shielding materials are necessary, these added to the loads.

The foundations of the buildings consist of reinforced concrete (30 MPa or 55 MPa at parking locations), spread footings to reduce the excavation depth necessary, and reinforced concrete (35 MPa) slabs under the shear walls.

Since the underground floor elevations differed according to the functions, reinforced concrete transfer walls had to be introduced in the structure as a discontinued system to resist earth pressures.

The 2-way structural concrete (30 MPa) slabs generally span 9 metres by 9 metres and are typically 260 mm thick with 100 mm drop panels over columns so that the localized shear resistance can be attained. The minimum amount of reinforcing steel bars in one direction for a centre strip of this type of slab is 0.35%.

Some zones have a greater slab thickness to increase the system stiffness and to respect special vibration criteria that are required for sensitive medical equipment or on floors that support heavy mechanical equipment.

The smallest concrete (25 MPa) columns are 500 mm by 500 mm and are located on the top floor of one building. They include nearly 1% of cross-sectional reinforcing steel bars. The largest concrete (80 MPa) columns are 1000 mm by 1000 mm and are located at the lower basement level of another phase 1 building. These columns

Above: street view.

Photos Helico/Construction Santé Montreal

CHUM FACTS (PHASES 1 & 2)

Surface area 3 million sq.ft.

Project start to final delivery: 9 years (April 2011 – March 2020)

66 elevators in Phase 1 and 11 in phase 2

12 mobile escalators

8 access points

12,000 different doors

12,500 individual rooms

1,400 parking spaces

47 air handling units

11,000 medical gas outlets

20,000 pieces of equipment

include 3.2% of cross-sectional reinforcing steel bars.

The truck loading area required concrete (45 MPa) post-tensioned transfer beams of 1.2 metres by 3 metres height, spanning 18.3 metres and supporting eight floors above. These transfer beams included up to 7 ducts containing 27 strands with a yield strength of 1860 MPa.

The engineering also involved two concrete tunnels, a steel and stainless steel pedestrian bridge linking two buildings, and various steel structures for roof tops, mezzanines and platforms.

Several temporary structures were designed in the early stages to maintain the existing St-Luc Hospital in service, including a three-storey steel structure for the power plant, and an ambulance shelter.


Construction Santé Montreal

Artist's drawing of hospital after Phase 2. A reconstructed church tower marks one of eight entrances, and an oval amphitheatre and courtyard is to the right off St. Denis.

During the site excavations, a bentonite slurry wall system with tie-backs was used to stabilize the walls and maintain water levels in the surrounding areas. The rock material was pre-shear drilled, controlled blasted and excavated to permit construction underground. The black shale rock needed protection at the spread footing locations in order to guarantee a 4 MPa service load capacity.

MECHANICAL AND ELECTRICAL DESIGN

By Nick Stark, P.Eng., Vice President HH Angus & Associates

The mechanical engineering design for CHUM had to meet many challenges, not the least of which was the sheer magnitude of the project on a congested urban site. There was also a strict energy target, along with request-for-proposal (RFP) requirements that drove alternative approaches.

In spite of the challenges presented by its sheer size, the project design was completed in Revit, enabling enhanced coordination of more than 2,500 building services drawings. Over 60 MEP models had to be maintained and data driven processes were developed to manage the information. Online collaboration sessions were essential for coordinating the work between HH Angus in Toronto, the project office in Montreal, and Cannon Design offices across the U.S.

Locating the plant. Locating the heating, cooling and emergency generator plants for an urban hospital complex presents a challenge. Traditionally a plant of this size would be located at grade in a separate building where it could be isolated from the clinical functions of the hospital. However such space did not exist on the CHUM site. The initial schemes positioned the plant below grade, but the real estate proved too valuable and was needed for clinical functions.

HH Angus developed a scheme to locate the plant 80 metres in the air above the ambulatory block. The boilers and chiller share one level, and the generators and cooling towers share another. These floors sit on top of an air handling plant room, forming a volume 30 metres high, fully enclosed with louvres. With this location, the design had to overcome challenges for the mitigation of noise and vibration.

The central plant consists of six dual fuel hot water heating boilers with a total output capacity of 30,900 kW, six dual fuel steam boilers and one electric boiler totalling 47,000 kg/hr. In addition to serving the needs of CHUM, the heating plant also supplies CRCHUM, the adjacent research centre, with steam and hot water. The cooling capacity is 9,000 tons in two multistage process chillers, two centrifugal heat recovery chillers and five conventional chillers.

Energy saving systems. The client mandated an energy consumption target of 40% less than the ASHRAE 90.1-1999 baseline — a very aggressive target for an urban acute care hospital. Every system that consumes energy was strategically assessed against possible alternative solutions.

The modelling target was achieved using a multi-pronged approach that incorporated:

- space by space control of air volumes (supply and exhaust)
- enthalpy heat recovery wheels on virtually all air handling systems
- reduced fan energy by reducing air velocity through air handling units and ductwork
- process cooling and chiller heat recovery systems as the primary source of low temperature reheat water
- a condensing boiler stack economiser

Stainless steel condenser water header located in the plant room on the 17th floor of the outpatient block.

- lighting power reductions coupled with occupancy and daylighting controls
- control strategies including supply air temperature reset.

In terms of environmental and energy design, the building is targeted for LEED Silver designation, with a potential for LEED Gold.

Ventilation systems and heat recovery. Ventilation in a hospital is the system that requires the most plant space, not only in terms of plant room floor area, but also for vertical shafts and ceiling space. The RFP imposed a number of requirements, including HEPA filters on all systems serving clinical areas, no air recirculation between departments, and a high level of redundancy — all with a limited air handling unit size. To meet these requirements would have required two full intermediate mechanical floors and at the same time would have severely compromised the system's future flexibility. HH Angus worked with CHUM to develop an alternative approach.

Where the RFP required a distinct air handling unit for each department, we proposed the use of 100% outdoor air units serving multiple floors where the occupancy was similar, and demonstrated to the hospital the merits of this approach from the perspective of infection control and future flexibility.

To mitigate the energy penalty of 100% fresh air systems, we proposed enthalpy heat recovery wheels. The RFP initially prohibited these wheels, but we used our 25+ years of successful experience with the technology to demonstrate to CHUM and their compliance team that their infection control concerns could be successfully mitigated with the right components and controls. The RFP was then modified accordingly.

The RFP also mandated a standby air handling unit for each unit serving a critical care space. This solution would have required much higher capital and operating costs over the life of the building, as well as more space. We developed an alternative approach by combining a number of air handling units together into one duct system to share the redundant capacity. This solution considerably increased the overall reliability of the systems while reducing operating costs.

The client mandated an energy consumption target of 40% less than the ASHRAE 90.1-1999 baseline — a very aggressive target.

Lastly we demonstrated that the restriction on air handling unit size could be raised to 33,000 l/s without any practical impact. Even so, 46 air handling units are required for a total supply volume of 1,300,000 l/s.

Combining these alternative approaches in the ventilation system design resulted in many benefits, including the ability to modify the occupancy of the spaces and enable future renovations. The net result was that additional clinical floors could be constructed under the zoning height restriction, which was a key factor in developing a successful bid.

CHUM TEAM

Design, build, finance, maintain P3 consortium:	Collectif Santé Montréal (Innisfree Canada, Obrascon Huarte Lain (OHL), Laing O'Rourke Corp., Dalkia Canada)
Design-build:	Construction Santé Montréal (Laing O'Rourke/OHL)
Architects:	Cannon Design and Neuf Architects
Structural engineers:	Pasquin St-Jean et associés (PL Lanoue, ing., Normand Leboeuf, ing., Krasimira Alexieva, ing., Marc-Yvan Jacques, ing., Christian Renault, ing.)
Mechanical and electrical engineers:	HH Angus & Associates (Nick Stark, P.Eng., Marianne Lee, ing., Anna Chan, ing., Bob Tibbs, ing., Phil Schuyler, ing., Mohamed Kamel, ing.)
Infrastructure and land-use planning:	SM International Group
Acoustics, Vibration and Microclimate:	RWDI (Sonia Beaulieu, ing.)
Building Code:	Technorm

Operating suites. The 39 operating rooms (ORs) had to be spread over two floors, even with a floor plate the size of two football fields. HH Angus located a main air handling plant room on the floor immediately above to enable direct servicing of the ORs. The supply and return terminal boxes as well as the terminal humidifier for each OR is located in the plant room, reducing the need for maintenance personnel to enter the ceiling space of the sterile area.

Plumbing and medical gas. The domestic water supply in a typical hospital may consist of one or possibly two pressure zones. For CHUM, with a difference in height of 120 metres from the lowest mechanical room five floors below grade to the roof, five separate pressure zones had to be created. The scale of the medical gas system is unprecedented: over 11,000 outlets.

Electrical distribution. The project required understanding the crucial demands placed on a hospital's electrical system and knowledge of the intent and intricacies of codes and standards. Our team designed an electrical system that is robust, reliable and resilient, and one that met the owner's RFP requirements in a cost-effective manner.

The high voltage distribution system includes 25kV and 4160V switchgear, with four incoming Hydro Québec lines totalling 36MVA. The emergency power generation system for the CHUM complex consists of four 2.5 MW diesel generators, generating at 600V, with four 2.5 MW back-up generators producing 4160V.

Lighting, fire protection and security systems. Lighting layouts were designed to balance the aggressive LEED requirements with CHUM's stringent requirements for light levels. To provide an atmosphere that is elder-friendly efforts were taken to ensure even illumination, with gradual changes between adjacent spaces. The lighting is controlled by a building-wide lighting control system.

The addressable two-stage fire alarm system is combined with the public address system. Two complete CACF (central alarm and control facility) rooms were provided.

The security systems include CCTV, card access, intercom, and a real-time locating system. The card access system and CCTV system are IP based using POE (power over ethernet), which minimizes the risk of down time by using a centralized UPS system. CCE