The University of Manitoba
Pembina Hall Residence

Submitted to: Canadian Consulting Engineering Awards 2012

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May, 2012

Crosier Kilgour & Partners Ltd.™

CONSULTING STRUCTURAL ENGINEERS

THE UNIVERSITY OF MANITOBA PEMBINA HALL RESIDENCE

The concept: a new 360 unit, 10 storey residence block at the University of Manitoba, high enough in and of itself, however lifted up 4 storeys and constructed above the existing Pembina Hall. The structural challenge: design a clear span structure, so that it can stretch 50 metres without penetrating the dining facility beneath, which will need to operate more or less continuously.

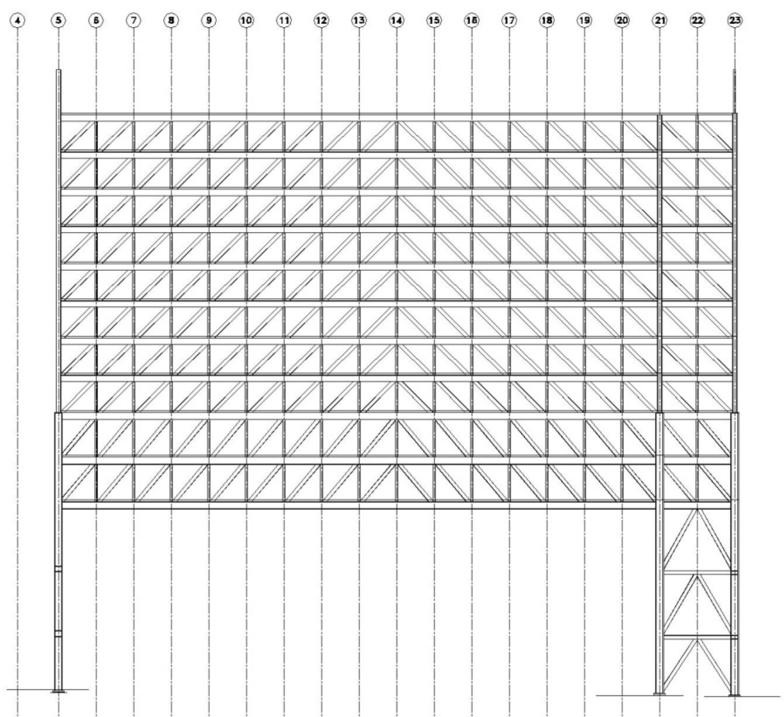
Certainly, there were numerous challenges. Execute the project within the constraints of the University's Project Domino budget. Complete the design, tendering, construction, and certification of a complex $40,000,000 facility in less than 30 months, in order for students to take residence in September of 2011. Have the design reflect that there would be very difficult access, and very little lay down area for the contractor to be able to work from. Construct the building to maintain safety to the occupied Pembina Hall beneath, as well as to the thousands of students and staff that pass by the site every day.

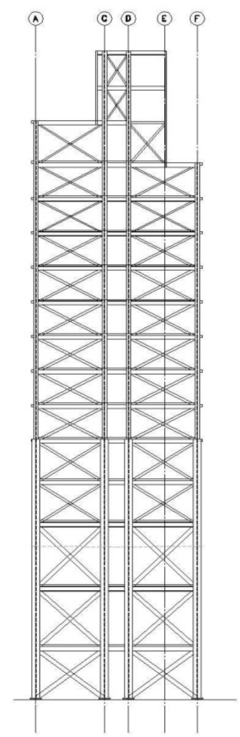
However, the real heart of the challenge was the structure. Could a 360 room residence be designed and constructed over an existing building without having any intermediate columns or supports, which would need to penetrate through the dining hall beneath, and trigger prolonged shutdowns. Most consultants that studied the University's Request for Proposals dismissed the possibility without a second thought, assuming that it could not be accomplished practically. However, during the process of preparing a response to the Request for Proposals, one, and only one client asked us a simple question, "Can it be done?" The answer is now obvious; it stands on the campus, at 30 McLean Crescent.

PROJECT ATTRIBUTES AS THEY RELATE TO THE JUDGING CRITERIA

Application of Technology/Originality/Innovation

The architectural concept for the Pembina Hall Residence was relatively simple; build two slender 14 storey towers with sufficient strength to support a 10 storey high residence block. Incorporate 36 rooms on each level and have the residence block span 50 metres over the existing Pembina Hall.

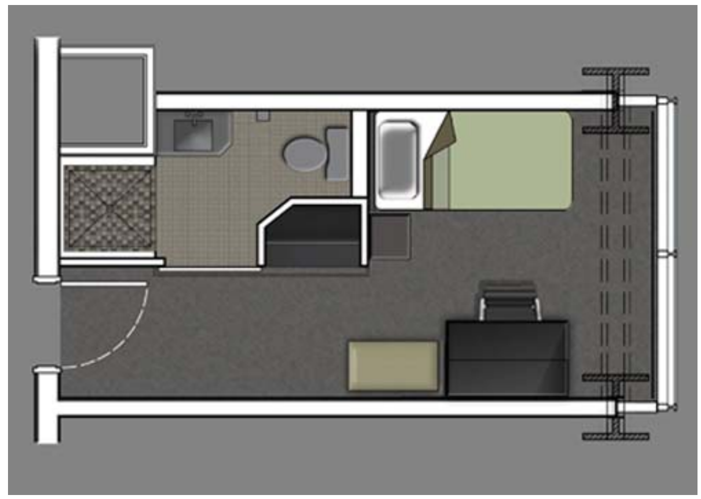




To be honest, the corresponding structural model was simple in concept as well, and immediately came to mind. The only practical way to design a 10 storey building able to clear-span 50 metres would be to mobilize the entire height of the residence block, creating a very large and rigid structural box. Two 10 storey-high interior trusses would need to be incorporated into the hallway walls; two 10 storey-high exterior trusses placed just inside the exterior glazing. Floors would be required by Code to be constructed with a two hour fire separation and a suitable separation to noise transfer, yet be as light as possible, to minimize the cumulative load that the trusses would need to support. Yes, simple in concept, yet highly complex in design and construction.

In the end, it is clear that the resulting structural system is innovative and unique. Here’s why.

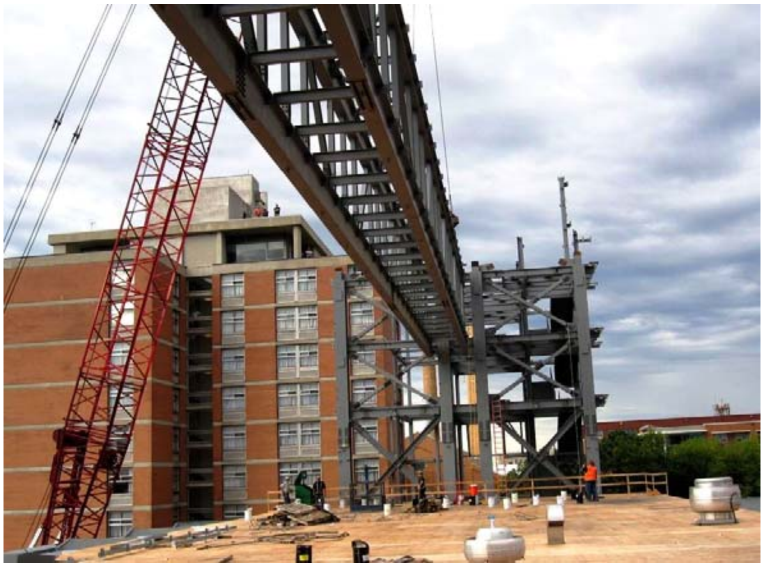
- The exterior trusses are fully exposed. Their diagonals are wide flange shapes, which measure 308 mm by 305 mm. The truss verticals are typically welded wide flange shapes, measuring up to 660 mm by 660 mm. These structural elements are exposed and visible in the rooms, creating what the University has described as *"a blend of contemporary and innovative design. This state-of-the-art facility will be comparable to other urban living centres found across the globe."*



- These members must by Code be afforded a two hour fire resistance rating, which would normally be provided by multiple layers of gypsum board drywall or spray-applied fireproofing. Either of these approaches would however create significantly larger assemblies, reducing the aesthetic within the rooms, and increasing the potential of damage. An alternate approach was therefore developed utilizing intumescent coatings, which allowed the steel to be exposed, as slender as possible, resistant to vandalism, and in the view of many residents, a big part of why the rooms are so captivating.

- Use of an intumescent coating rather than encapsulation with fireproofing, triggered the need to detail these "naked" structural members and connections with an absolute eye for appearance. Exposed structural elements are recognized as being very much the exception rather than the norm for multi-tenant residential construction. While highly unusual, exposing the robust exterior truss members within the modestly-sized residence rooms created a dramatic design, which accentuated the need to incorporate artful structural design details.

- The exterior trusses incorporated building-high diagonals, consistent with the most economical truss configuration, however the interior trusses could not, due to the presence of the residence room doors within the hallway walls. A hybrid truss design was developed, incorporating Vierendeel and diagonal truss concepts, which required substantial amounts of analyses in order to minimize the size and weight of the members, and maximize the economy of the structure.
- The underside of the floor structures are also exposed, again creating a more vandal-resistant finish, and a space that the residents view as ultramodern. Rather than using the normal spray-applied fireproofing, which could easily be damaged, supplemental reinforcing steel was embedded within the concrete topping above the metal floor deck, to provide the required 2 hour fire separation.
- Rather than employ a separate floor finish, the concrete itself was coloured and patterned, in order to provide a suitable appearance, and enhance durability significantly.
- In August 2010, 13 months before the first resident was to move in, with the structure consisting only of two eight storey-high towers 50 metres apart, the contractor connected the towers together by erecting one of the largest steel trusses ever installed in Manitoba. Two 300-ton cranes simultaneously navigated over one building and aside another to put the truss into place. The truss measured 50 metres long, 5.2 metres high and 2.4 metres wide and was assembled on the ground. Crews took eight days to assemble the 55-tonne truss, which is comprised of six individual pieces.
- All lifts conducted throughout the entire construction process were completed above an occupied space, creating the need for comprehensive safety measures, which we were mindful of throughout the design



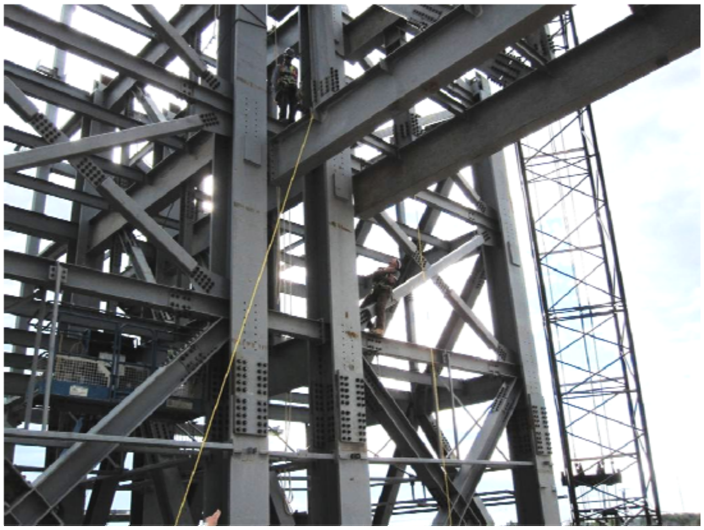
process. The contractor summed up the situation best, *"We built a protective platform over the existing structure to protect the roof and its occupants, and we covered the walkways into the building to keep people safe. The construction area went beyond the existing structure's footprint and above. We started with the east and west towers and built up to the eighth floors, and then we began erecting the trusses for each floor.*

- Given the length of the truss members, thermal expansion and contraction played a pivotal role in the constructability of the building frame. Precise calculations were completed at the time of design in order to understand how temperature effects would affect the ability to construct the frame. Just as importantly, detailed calculations were required to determine the stresses introduced into the structure as a result of temperature changes. One example can be cited that clearly illustrates the sensitivity of the structure to thermal effects. When the truss discussed above was measured the night before the first and heaviest lift, it was too long, and would not have been able to be erected. In the morning, after the truss had been exposed to the cool night air, it fit perfectly.
- The structure is frankly more akin to a sail or a billboard than a typical building form. The structure rises 57.2 metres above grade, and extends almost 80 metres in an east/west direction, however it is typically only 13.3 metres wide in a north/south direction. The slenderness of the building, which is evident to all that pass by, created complexities with the building foundation. It is not normal in a building of this size to need to be tied down by the foundation; usually the dead weight of the structure is more than ample to overcome the overturning loads that wind introduces on the building. That is, the foundation is usually only required to hold the building up; however, with the Pembina Hall Residence being the significant size that it is in the east/west direction, and so slender in the north/south direction, the foundations are required to hold the building down during strong winds. Foundation caissons were therefore cored into and embedded within the bedrock, to resist uplift.

Complexity

As noted previously, the initial truss assembly that was set in place between the two building towers was one of the largest trusses ever installed in Manitoba. The design, fabrication, and erection of the initial truss, while highly unusual, were just three of a large number of complexities inherent in the project.

Many of these have been discussed or alluded to already. As an example, we noted that the evening before the initial truss assembly was to be installed, it was confirmed that it would simply not fit between the two rigidly-braced towers. The steel fabricator/erector worried through the night, however needn't have. After being cooled by the night air, the truss fit perfectly. By our calculations, a 10ºC drop in temperature resulted in a 6 mm shortening of all of the principal building truss assemblies, including the initial trusses. The universal bolt hole tolerance used by steel fabricator/erectors to facilitate erection of steel structures is 1.5 mm, which is obviously too small to accommodate the possible degree of temperature movement for this structure. While the use of relatively standard slotted connections addressed this issue, careful design was nevertheless required to direct when final bolt tightening was appropriate. It was determined that final tightening was to be completed only after a minimum of four floors above had been constructed; these processes were conceived in collaboration with the contractor, to allow erection to continue without temperature delays and overall schedule extensions.



Interestingly, all of the structural steel members for the building were fabricated in Quebec. This obviously necessitated the fabrication of assemblies that could be shipped long distances economically, the implication being that smaller assemblies with a greater number of connections were required. Taking into account the very large sizes of many of the truss members, and the fact that they are exposed in all of the residence rooms, this complicated the design process and again accentuated the need for close collaboration between the steel fabricator/erector, the project architect, and ourselves. Absolute attention was paid to the need for “build-ability” in the fabrication shop, “transport-ability”, “lift-ability”, and “connect-ability”, all in the context of minimized cost, maximized aesthetics, minimal lay down area, compromised site accessibility, compressed schedule, and a heightened need for safety.

Not only were building movements due to temperature effects problematic; the overall vertical deflection of the 50 metre span was a concern. Building codes will typically stipulate a maximum allowable deflection of the span of the member in question, divided by 360. Considering the trusses as a whole, this equates to almost 1.4 metres, certainly not appropriate for any type of building structure. The client’s desire was of course to achieve flat, level floors throughout all levels, which at first glance appeared to be easily achievable. However, the calculations required in order to determine how much camber, or upward arching of each floor, was going to be required in order to achieve the desired final flatness were lengthy and complex. These were made even more convoluted by the fact that as the concrete was cast and cured at each level, it in essence locked that floor into a relatively rigid configuration or shape, due to the composite design principles employed for the metal floor deck and structural steel beams found throughout each floor. Designing each concrete floor to “relax” under the weight of additional floors above, while at the same time ensuring that this easing of the floor did not cause unsightly cracks in the exposed and coloured concrete floors within the residence rooms was an elusive process for certain. In the end, the amount of specified camber decreased as you moved upward in the building, and the casting process followed a predetermined schedule based on the number of floors erected above.

As noted previously, the sail-like shape of the building created significant complexities in the wind-resisting elements within the building structure. Very substantial rigid steel frames, incorporating diagonal braces and vertical members ranging up to 660 mm by 660 mm and weighing 864 kilograms per metre, were employed to resist lateral wind loads. Some of the members employed are the largest stock steel members available from North American steel fabricators; there are no larger standard mill members fabricated. Steel members of this size and weight were not only necessary to adequately resist the forces imposed, they were also required in order to limit the amount of drift or lateral deflection of the building. Again, due to the unusual configuration of the building frame, a large amount of time was spent in modeling the structure, in order to determine the amount of lateral movement or drift expected at the top of the building due to wind loads. Our final analysis confirmed that the calculated drift was 61 mm, not an insignificant amount however well within code limitations.

During maximum wind forces as stipulated by the applicable codes, the uplift created in the principal bracing columns significantly surpassed the entire combined dead and live loads of the tower. If the foundation system could not in fact hold the structure down, it would literally fall over. Intuitively, it is hard to imagine that under high wind loads, the foundation must hold what is in essence a 14 storey building down, rather than hold it up.

Multiple analyses were conducted to establish the exact amount of net uplift, which ultimately would be resisted by the limestone bedrock 18 metres below the building. This included independent analysis conducted by geotechnical specialists, to confirm that our in-house analyses were accurate and sound from a geotechnical perspective. In the end, the uplift forces were dealt with through the use of rock-socketted caissons, which were cored out of the bedrock. The uplift forces were resisted by the friction between the poured concrete, and the bedrock surrounding the perimeter of the sockets. The sockets were in the order of 1.5 metres in diameter, and extended more than 5 metres into the bedrock.

Given the proximity of the facility to the Red River (the bottom of the rock sockets are significantly below the adjacent river level) a high flow of water into every caisson was experienced. The amount of flow was such that the water could not be pumped quickly enough to create a clear hole into which the concrete could be cast from grade, as would be normal. In response, the concrete was placed by tremie method, where it was deposited at the base of the socket via large diameter hoses, in the process displacing the water from within the socket and shaft, and cutting off additional water ingress. The concrete mix was adjusted to accommodate the tremie placement method, and resist the inflow of water under pressure. A second complication arose with the foundation. Resisting the lateral wind loads was highly problematic, due again to the sail-like form of the building, and the fact that it was in essence supported on two small tower footprints and not a broad base. The absence of any measureable basement that would “key” the building frame into the ground and resist the sliding forces, heightened the situation. After significant study and collaboration with the geotechnical consultant, we arrived at a hybrid foundation system that augmented the rock-socketted caissons discussed above, with driven precast concrete piles that were battered, or installed at an angle, to provide increased resistance to lateral loads.

The use of battered piles is not unique; what is unique, and to our knowledge has never been incorporated in a Manitoba structure before, is the placement of piles within pile groups that are battered in two directions. As can be imagined, the concept of installing precast piles that arrive from the casting plant at approximately 18 metres long, which need to crisscross each other and are then tied into the same pile cap at a horizontal spacing of no more than 1.8 metres, was complex in design and correspondingly difficult in execution.

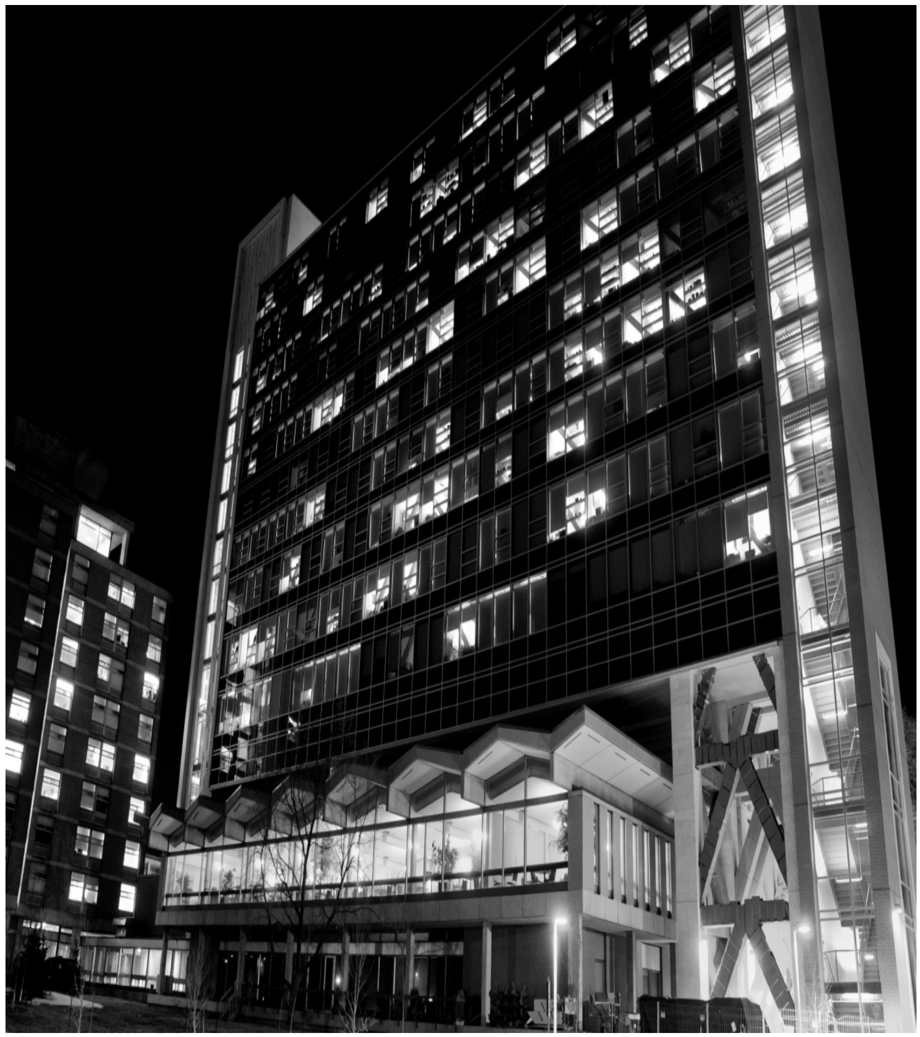
Social/Economic/Environmental Impact

Within the context of the University society, the Pembina Hall Residence has created a significant impact; 360 single rooms made available to rural students, in a setting and environment that will nurture their development and studies. There is a good deal to be said for new students to live on campus, in close proximity to the University’s facilities and to their own faculties and studies, in comparison to the scenario of having to travel off site daily, of having the responsibility of meal preparation, of having to maintain living quarters, likely with other students to share costs. Students are enamored with the residence rooms and their associated services, for good reason.

There has also been a very positive impact created by the residence on the community's perception of the University, as well as an elevated sense of pride within the University itself. An excitement has been created; a tangible consequence of the construction of this showpiece. Students, faculty, and administration alike have expressed their enthusiasm for the purity and boldness of the design, and their recognition that the residence is an example of the future-thinking that the University must continue to foster. University of Manitoba President David Barnard has said, "*Pembina Hall (Residence) will greatly enhance the already excellent student experience we offer and is a cornerstone of the positive physical transformation of our campuses that will make the University of Manitoba an even better place to live, to work and to study.*" The fact that the residence stands high above the surrounding campus and can be seen from a significant distance no doubt has had an effect on the aura that the building radiates.

The amenities provided by the residence; individual washrooms, abundance of natural light, spectacular views of the campus to the north or over the river to the south, cutting edge space surrounded by sustainable finishes; these combined have allowed the University to derive an economic benefit from the residence. Room rates are between 22% and 59% greater than other campus residences, notwithstanding the fact that the durable and damage-resistant finishes allow a reduction in building maintenance costs.

Germane to this matter is the elevated energy efficiency of the building; LEED (Leadership in Energy and Environmental Design) concepts were followed in the design of the facility, resulting in a highly efficient building with reduced energy consumption. Expressing the structure and maintaining a minimalist design approach to the room fitup, rather than employing numerous finishes, significantly reduced the amount of end-product materials incorporated into the building. This in turn reduced the associated cost, energy consumed, and environmental drain. That is not to say that the design approach left the rooms less than desirable; there is a significant demand for the Pembina Hall Residence rooms, based on the factor citied above.



Owner's/Client's Needs

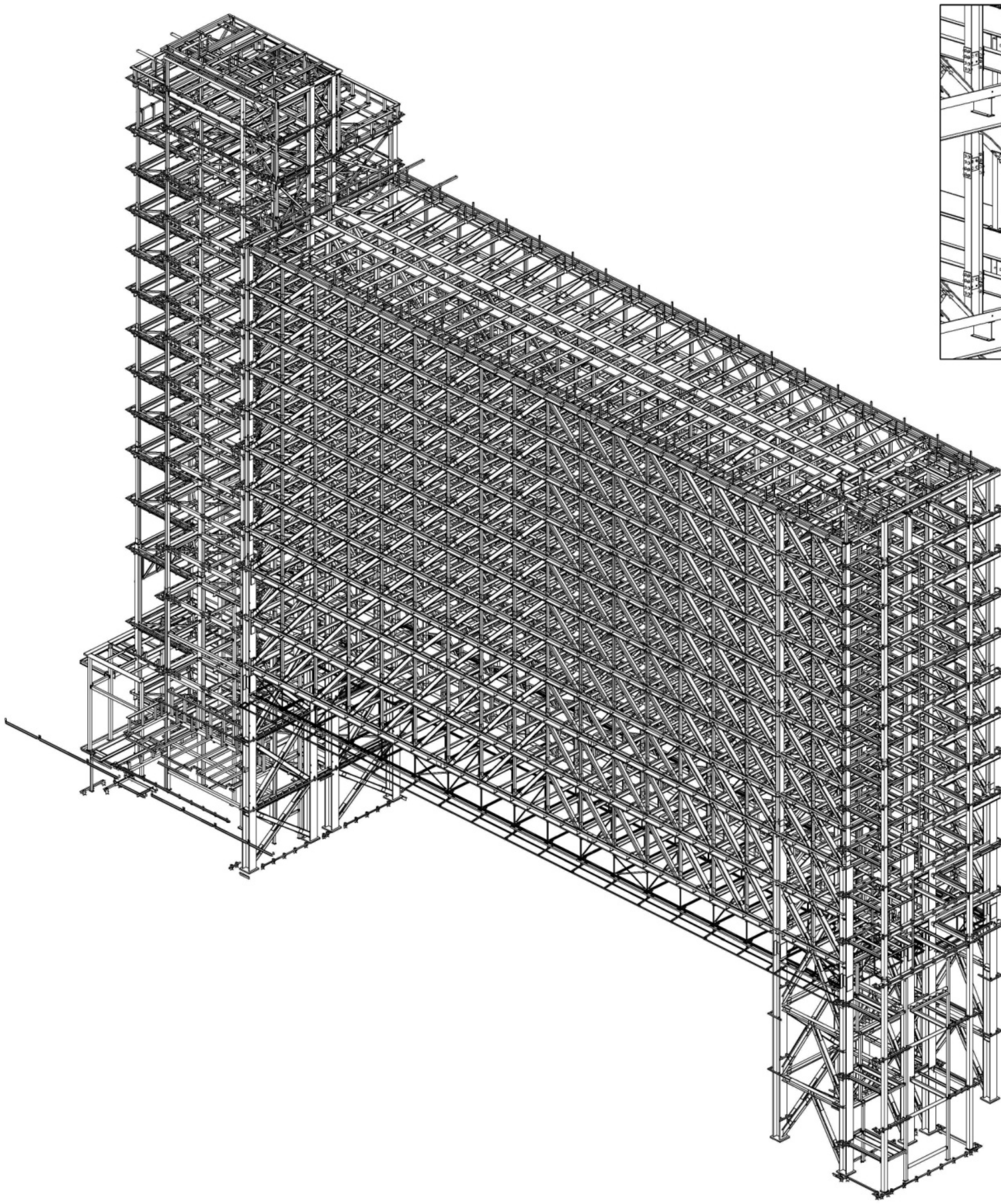
Mr. Alan Simms, Associate Vice-President (Administration) of the University of Manitoba, well understood the difficulties faced by the design team, and the structural subconsultant in particular, in putting forward his project goals. After experiencing the process, which was by everyone's admission, trying at times, Mr. Simms said this, *"The University of Manitoba worked with Crosier Kilgour & Partners on the new Pembina Hall Residence that opened in September of 2011. With very limited space, the structure was designed to clear span the existing dining hall by 50 metres, starting at four stories high. It is a very narrow building that is structurally complex; built on a very restricted and small site footprint. This construction project also had a critical timeline – 360 students required housing by September 1st, 2011. The construction and consultant team delivered on budget and on time.*

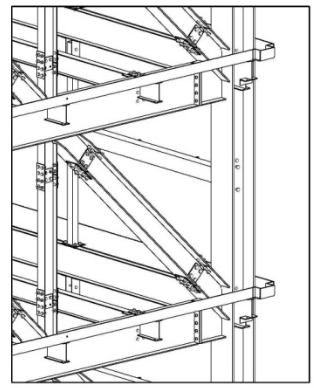
Due to the amount of steel required, the project required complex coordination skills both on site and with the structural supplier and structural engineer. Crosier Kilgour & Partners showed dedication, attention to detail and schedule, and ensured the coordination of steel production and delivery was on time and on budget with professionalism and quality control.

It was gratifying to be recognized as meeting the following client goals and needs, particularly given the project complexities and demands.

- The residence was constructed in the exact location desired by the client, and provided the required room count.
- Despite an extremely compressed schedule, which saw the initial structural site inspection for the very first pile installation occur on March 4th, 2010, residents moved into the facility on September 3rd, 2011. This was the firm and final date required by the client to allow students beginning their fall term to occupy the residence; it was only 16 hours or so after final certification for occupany was granted by the City of Winnipeg.
- Along the way, the client had completed risk analyses on the potential of the building not being completed by the required date and had considered contingency plans. The project team was committed however to the completion within the required timeframe and fulfilled that commitment, literally within hours of the first student arriving.
- The ability to open the facility within the allotted timeframe relied heavily on collaboration between client, consultant, and contractor, brought together by an intense project management process.
- The desirability of the rooms exceeded the client's expectations.
- The residents are enamored with their accommodations.
- The construction affected the surrounding buildings and their day-to-day functions in a very minimal way; the Pembina Hall dining facility operated in essence without interruption.
- The client's budget was met. At the end of the construction, the final project cost was 1% over the budget amount; content was however added to the scope of the work during the construction phase.

In the end, one measure of a project's success is the sense of fulfillment experienced by those involved. It is evident that the sense of fulfillment and pride created by Pembina Hall Residence project extends well beyond the project partners, to the student, staff, and administration of the University, as well as to the community itself.





THE UNIVERSITY OF MANITOBA PEMBINA HALL RESIDENCE

SUBMITTED BY: CROSIER KILGOUR & PARTNERS LTD.: 300 – 275 Carlton Street; Winnipeg, MB R3C 5R6

PROJECT HIGHLIGHTS

The University of Manitoba required a new 360 room student residence, however did not have an appropriate greenfield site available in a location consistent with the campus master plan. In concert with the University, and the Project Architect, Raymond S.C. Wan Architect, Crosier Kilgour & Partners Ltd. devised an innovative and complex, yet cost-effective structural solution, which allowed the residence to clearspan 50 metres without supports, over an operating dining hall. The result, which has exceeded all University expectations, is a beacon and a showpiece that has created a sense of fulfillment and pride among residents, staff, and University administration.

Application of Technology

While the structural model for the Pembina Hall Residence was relatively simple in concept, it was highly complex in design and execution. The residence is a rigid structural block, built above an existing dining hall facility that remained in use more or less continuously, with a form that was more sail-like than any sort of typical building mass; it demanded particularly advanced and innovative engineering skills. The absence of any interior supports necessitated that the 10 floors of 36 rooms each, would need to span approximately 50 metres, stretching the bounds of structural building compositions that are typically employed. Additionally, given that the principal structural elements were to be exposed in order to create a cutting edge environment and an exciting home for the residents, the structure had to be artful and aesthetic in its design. Finally, given the compressed project schedule, coupled with the unique construction methods that the clear span composition of the building demanded, a highly collaborative design and construction process was necessitated, far and above what would have routinely been employed for more typical buildings.

Social/Economic/Environmental Impact

The fabric of the University is obviously altered whenever a new building is constructed on campus. The addition of the Pembina Hall Residence goes far beyond that; there has been a significant impact to the University's society, created by the residence. An admiration has been created amongst the students, staff, and administration, who have expressed their excitement for the boldness of the design. It has been recognized as an example of the future-thinking that the University must continue to foster.

The design of the facility followed LEED (Leadership in Energy and Environmental Design) concepts, to maximize energy efficiency. At the same time, allowing the structural elements to be exposed, reduced the amount of end-product finishing materials required; use of sustainable materials and exposed structural assemblies reduced maintenance requirements, and mitigated the potential for defacement. The rooms are awash with an abundance of natural light, reducing the consumption of energy. Conversely, during summer conditions, the glazing was designed to significantly reduce the solar heat load on the building's physical plant. Finally, the residence rooms offer extraordinary views of the campus to the north, and the Red River and community beyond to the south; it is not an overstatement to say that these elevate the emotional state of the residents, contribute to their well-being, and are a factor in the demand being experienced for the rooms.

THE UNIVERSITY OF MANITOBA PEMBINA HALL RESIDENCE

Complexity

From the initial stages of the design, through the construction phase, to the final certification of the facility, mere hours before the first resident moved in, a myriad of structural complexities inherent in the project challenged our design team. Notable among these was the design of the 10 storey-high trusses required to allow the residence rooms to span 50 metres over the dining hall beneath. Issues of truss deflection triggered the need for differential cambers to be specified for each floor. In addition, the casting of the concrete floors within each level had to follow specific guidelines; floors could not be cast until four levels of the major trusses had been erected above. Some of the members making up the principal trusses are the largest stock steel sizes that are available from North American steel mills; by way of copious amounts of structural analyses, we were confident in employing these largest-available members, even at the limit of their capacities.

Temperature effects were vastly more critical for this structure than typical, in that a 10°C change in ambient temperature caused a 6 mm change in the length of the principal trusses. The first truss installation, which was the heaviest truss installation in Manitoba, was a case in point. The 50 metre span truss assembly, weighing 55 tonnes, was measured the evening before erection was to take place. It was too long and was not going to be able to be placed between the twin support towers. After weather predictions were reviewed and calculations completed, the truss was left exposed to the cool night air; in the morning, two 300 tonne cranes lifted the truss into position where it fit perfectly. Specific details were subsequently designed to allow erection to continue notwithstanding temperature fluctuations. Interestingly, only after a number of floors had been erected above, could the final connections be made within each floor level. That is, it was necessary for the sequential erection procedures to loop back constantly, in order to complete the required erection protocol.

The sail-like form of the structure caused complications with the wind-resisting elements of the building. Under full wind load, the resulting overturning required that the principal foundation points hold the building *down,* rather than up. Rock-socketted caissons, embedded in some instances more than 5 metres into the limestone bedrock, were employed to create the required tie-down. To resist the lateral or sliding loads created by wind forces, a hybrid foundation system was devised which included groups of battered driven precast piles, with piles battered in two different directions incorporated into individual pile caps. We are not aware that this innovation has been employed in a Manitoba building in the past.

Owner's/Client's Needs

The facility was constructed in the owner's desired location overtop an existing dining hall, without significantly affecting its occupancy. Even the concept of this approach was dismissed by most. At the end of construction, the project budget was exceeded by 1%. The facility has exceeded the owner's requirements, including their initial vision for the facility, and provided a dramatic showpiece that has fostered a sense of fulfillment and pride. While extremely aggressive, the project schedule was met; residents moved in to the facility on the appointed day, at the appointed hour. The high number of complexities and demands of the project necessitated an advanced project management process, incorporating a highly collaborative process between owner, consultants, and contractors, from concept to completion. The result speaks for itself.