VERMONT TECHNICAL COLLEGE

Bachelor of Science in Architectural Engineering Technology

Capstone Senior Design Projects

(2021)

Cafeteria/Kitchen/Office Facility

Prince George, British Columbia

(1) Integrated Sustainable Building Design
(2) Structural Engineering Design

The following summaries describe two team engineering design projects undertaken by students this semester.

INTEGRATED SUSTAINABLE BUILDING DESIGN

Green Mountain Sustainable Design

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ARE 4720 Senior Project

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Background

We are all Seniors at Vermont Technical College studying architectural engineering. For our senior project, we were entered into the 2021 ASHRAE Integrated Sustainable Building Design competition. The project was a 50,000 square foot, two-story cafeteria, associated office, and commercial kitchen and storage space in Prince George, British Columbia, Canada.

UNBC Campus

The site we chose was located on the University of Northern British Columbia. Not only did it make sense logistically because the design is a cafeteria, but UNBC is already dedicated to reducing their carbon footprint. There is already a wood pellet heating system, and a bioenergy plant on site. We designed something that not only fit in with the look of the campus, but its culture as well.

The group's goal was to build a net zero energy building where any carbon produced in one area, was offset by a reduction in another. The Province of British Columbia has an incentive program for improving the energy performance of buildings called the Step Energy Program. Started in 2017, this program requires that the energy efficiency of buildings improves in 5-year increments. By 2032, all new buildings are required to be net zero. We decided to be ambitious and skip to the final step of this process and design a net zero building. With the combination of sustainable materials, energy efficient equipment, and onsite renewable energy , we didn't quite make our goal, but we came close.

HVAC

Equipment

To model and select an energy efficient and effective HVAC system that supports our zero-net goal, the design conditions listed in ASHRAE's Principles of HVAC, 8th edition, as well as guidelines and constraints provided within the Owner's Project Requirements were used to start. Prince George, BC has 9244 heating degree days and only 40 cooling degree days, so the emphasis was to select a system that can meet the increased heating demand. Additionally, the building's thermal envelope, high-efficiency fenestrations, and solar geometry further influenced and shaped the system selection. The last influence on the system selection was based on available energy sources that could decrease or eliminate negative climate effects and reduce costs:

- Direct use (non-electric use) of geothermal resources in the region (based on research completed by Geoscience BC)
- UNBC's on-campus biomass plant which provides hot water to heat surrounding campus buildings
- A low-sloped, roof mounted PV system to power pumps and fans (installed on the proposed project building), as well as lights
- Natural gas which is readily available in the area

Potential HVAC System Selections:

With the above design considerations in mind the following HVAC systems were considered:

1) Variable Refrigerant Flow (air or water) with heat recovery (HR) and a Dedicated Outdoor Air System (DOAS) with energy recovery

- VRF systems allows for zoning and individual temperature control
- Heat energy can be transferred for space heating, domestic hot water, or leisure activities
- Performs well at part-load operation due to variable speed compressors
- Less ductwork is required
- DOAS delivers 100% outdoor air ventilation, partial sensible load and provides latent heat management

2) VRF cooling only (air source) and hydronic heating only (ground source), with a DOAS system

- Capitalizes on the geothermal capacity and temperature projections of the region
- Heat rejection into the ground for cooling be may ineffective if ground temperatures are too high
- VRF air source system is being considered for cooling if ground temperatures are too high
- Thermal capacities of hydronics are higher than refrigerant-based systems and leaks are less hazardous
- DOAS system will be for 100% ventilation.

VRF System

3) Hydronic/Geothermal system: water-to-water geothermal heat pump for heating (sensible) and DOAS for 100% cooling (sensible & latent)

- Lower temperature water-based systems lower energy use & pair well with renewables
- Water has a higher thermal capacity (vs refrigerant) and is safer to use
- Research shows the geothermal capacity of the region has the potential for meeting sensible heating requirements through direct use
- Renewable ground source heat will aid in lower carbon emissions and decrease the use of fossil fuels.
- With 40 cooling degree days (CDD), the use of a DOAS unit is being considered for 100% ventilation air (latent load control) and sensible cooling.

After selecting options 1 (UNBC biomass plant) and 3 (local geothermal potential) as the best choices to proceed with, the systems were modeled in Carrier's Hourly Analysis Program (HAP) following ASHRAE's 90.1 Energy Standards for Buildings - 2019.

After analysis of the two HAP reports the biomass-based system demonstrated a better performance in responding to the sensible and latent load demands, reduced energy use & greater operating efficiencies, and lower annual operating costs. The overall biomass-based system employed a DOAS unit to supply 100% outdoor treated air and was able to handle all the latent demand and approximately half of the sensible heating load. The remaining sensible heating load was achieved by the VRF unit. Both units would receive hot water from the biomass plant to either transfer the heat energy onto the VRF's refrigerant and subsequently the system's terminal units. In the case of the DOAS unit, the heat energy would be transfer to the outdoor air as it passes over the heating coils.

Electrical

Goal

Production of electricity accounts for over 40 percent of global CO2 emissions. We cannot address the issue of climate change properly without having a meaningful discussion about where we get our energy. Our goal was to produce all electricity on campus through Zero Net energy standards and ASHRAE standards. When there was not an opportunity to provide electricity to our buildings with onsite renewable energy sources, we looked for renewable options that the city could provide.

Lighting

LEDs were our primary lighting source with the use of occupancy sensors to allow the buildings lighting to remain in the on position, and still turn off sections of the building that are not occupied. LED lighting provided us with low electrical demand for lighting.

Renewable Energy

The province of British Columbia generates most of their electricity through the usage of fossil fuels. The use of renewable energy was to meet our goal of designing a net zero energy building. Prince George has multiple renewable energy options for its residents and businesses, such as a windfarm, that the group to took advantage of.

As stated previously, there is already a biomass generator located on campus. We decided to tap into that and get lots of the energy needed. In British Columbia, the logging industry is exceptionally large. Wood scraps and shavings create a biproduct called hog fuel, which can be utilized as fuel in biomass energy. This coupled with an electrostatic precipitator makes it so that the emissions from the generator are less than that of natural gas. On UNBC campus there is also a wood pellet generator that supplies hot water to campus.

Tesla Powerwall

On this building, we used a combination of solar, wind and other energy sources. One of the biggest problems with renewable energy is that peak production times do not necessarily line up with peak usage times. We helped to alleviate this by installing Tesla Powerwalls.

Building Materials

The structural requirements for the ASHRAE competition are that the exterior walls be masonry mass walls, and that that floors be poured slab on grade. Other than that, the possibilities are open ended. Our main goal was to use materials with the lowest carbon footprint possible in all aspects

ECOPact Concrete

Portland cement accounts for roughly 88 percent of the carbon emissions associated with concrete. The group sourced concrete in the Prince George area, called ECOPact, that replaces much of the cement with fly ash and furnace slag. In addition, recycled construction material is used as aggregate which reduces emissions generated from quarrying and crushing of traditional aggregates and reduces landfill waist. Overall, this technology claims to be able to reduce carbon emissions of concrete by up to 70 percent.

Carbon Injection

The release of carbon into the atmosphere from concrete does not just occur in the production and construction process, it also continues to be released into the concrete long after it has been poured. Therefore, the group decided to implement carbon injected concrete in the floor slabs and CMU walls. By injecting carbon into the concrete, further release of carbon was diminished, and strength was improved. The areas where concrete was used on the floor slabs, spread footings and the foundation wall.

Wood Products

Wood Products were utilized whenever possible to reduce environmental impact. The most obvious benefit of engineered wood is that its renewable. It can be manufactured from trees that would normally be considered “junk” trees or from waste that was produced during the milling process. It also takes less energy to manufacture when compared to steel and concrete, and can absorb carbon from the atmosphere, rather than releasing it. In our design, we specified cross laminated timber walls and heavy timber columns

Large-Scale Engineered Wood Design

Steel

According to the American Institute of Steel Construction, structural steel made in the US contains 93 percent recycled material. It has an excellent strength to weight ratio and reduces labor costs due to ease of construction. Due to the open floor plan of the building, a high strength material was needed to accommodate the long spans required for the roof, ceiling and floors. Therefore, the group has specified steel open web joists.

Recycled and Sustainable Building Materials

We researched many sustainable building materials and chose a few in the key areas of the construction of the building. These materials include but are not limited to using bamboo flooring in select areas, using recycled wood and aluminum for exterior paneling and fascia design, and using cellulose rigid foam board insulation where applicable. There are other ways our building aims to be sustainable, such as the use of renewable energy methods, but overall starting with the building’s materials was a good foundation to achieve sustainability.

STRUCTURAL ENGINEERING DESIGN

The Design Team

ARE 4720- Senior Project

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Building Location

600 Quebec Street, Prince George, British Columbia

The city of Prince George is the largest city in northern British Columbia and is currently investing in new projects and infrastructure to make their downtown more attractive for businesses, arts, culture, and living. This city is at the center of BC's forestry industry with the largest timber supply area in the providence (nearly 20 million acres) and a leader in the manufacturing of engineered wood products.

Building Description

This roughly 50,000 square foot building houses the kitchen and cafeteria for a higher education facility. The main floor plan boasts dining areas and multiple kitchens for a wide variety of food options. The lower level consists of offices and storage spaces. Directly above the central core, there is a third-floor mechanical penthouse one third of the diameter of the floors below.

Material Alternatives

During our early design phase, the team discussed the following four proposed structural systems, their pros and cons, and selected one for the final design. The team is primarily experienced in wood, steel, and concrete design and this was taken into consideration. Each option had an impact on the beam spans, member sizing, framing layout, and more. Also, our design loads like live and seismic loads influenced the options and final decision as they are a concern in Prince George.

Cast-in-Place Concrete

- Noncombustible but additional cost for formwork and labor.

Precast Concrete with Engineered Wood Products

- Modular construction but uncommon design.

All Steel

- Long life span but energy intensive to produce.

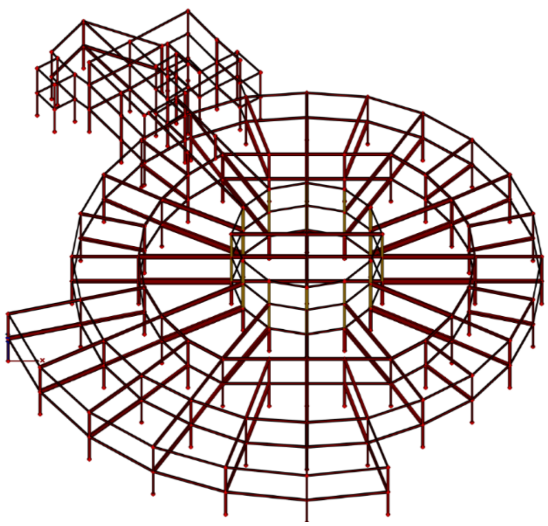
Steel with Engineered Wood Products

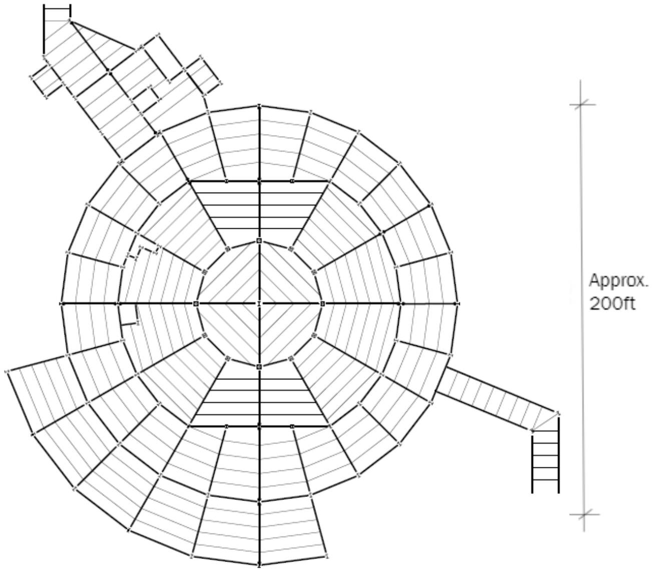
- Locally sourced and recyclable but connections may be difficult.

The system we chose to design was a steel frame with incorporated EWP and is discussed further in the design objective.

Building Layout

This 3-story structure radiates from its core to create a circular floor plan, resulting in some interesting challenges from a structural standpoint. We have chosen to lean into this uniqueness, and our finalized layout takes advantage of the concentric circles that are prevalent throughout each floor.





Design Objective

We sourced local materials and embraced the city's sustainable development goals to design a structure that is just as economical as it is safe. Prince George has always been known for its strong forestry industry which was important for our team to highlight. The combination of structural wood products and salvaged/recycled steel creates a structure that achieves both objectives.

Source

Source

Our structural system utilized a combination of steel and engineered wood products (EWP), both of which are shown above. Steel was used for the beams and joists to carry the loads across large horizontal spans as seen in the layout previously mentioned. Steel offers superior strength when loaded in tension and compression, which lends its use to such bending members.

Engineered wood products, specifically Glulam members, native to the Prince George area are the main column members shown in open areas. Wood is strong in compression, which lends its use to resisting the building's vertical loads.

Applicable Loads:

Snow, rain, dead, live, wind and seismic loads were used to compute and determine the structural member sizes of the building’s frame and foundation. The roof is subject to vertical dead, snow, and rain loads. A portion of the roof’s center resists unbalanced snow and snow drift loads. The floor is subject to dead and live loads. Occupancy live loads consist of the offices, restrooms, mechanical penthouse, dining, corridors, kitchen, and cold storage ranging from 50 PSF to 250 PSF. Lateral loads consist of wind and seismic. Both positive and negative internal wind pressure was determined to be approximately 115 K. Since the building has a circular floor plan wind coming from any direction was assumed to have the same wind load of 115 K. We also determined a total effective seismic weight close to 3335 K, resulting in a seismic base shear of 105 K.

Design Process

This section is a general discussion and overview of the team's design process and the types of decisions we made along the way. The steel structure was designed according to the Load and Resistance Factor Method (LRFD). This is becoming a more common design process when compared to Allowable Stress Design (ASD). For this project all steel framing was designed LRFD and our specialty wood columns we designed with ASD. It is preferred in practice that you limit design to a single method. However, the combination was used because of our team's expertise and resources in wood design are primarily ASD.

We referenced the following codes and design aids during our design process. Our team designed according to American standards we are accustomed to, but because the building is in Cananda it would be critical to reference and design according to the Canadian codes. One code we depended on was the AISC Steel Construction Manual. This is what we went to for the member capacities, section properties, and applied formulas for beams, columns, and connections. We ensured that the steel design aids also referenced AISC when they were selected, and others were from a creditable source.

Canadian Codes	**Referenced Codes**	**Design Aids**
National Building Code of Canada 2015	International Building Code 2018	WebStructural: Steel online Calculator
British Columbia Building Code 2018	ASCE 7-16 Code	AISC Steel Beam Calculator v14.3
CWC Wood Design Manual 2017	NDS for Wood Construction 2018	APA Wood Council Design Charts
CISC Handbook of Steel Construction 11th Ed. 2017	AISC Steel Construction Manual 15th Ed.	Visual Analysis 19th Ed. By IES

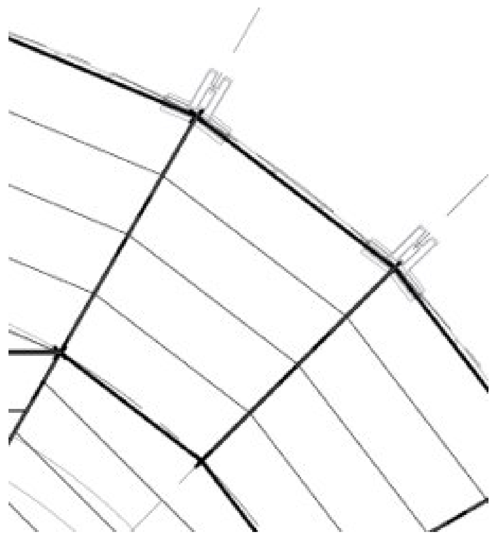
Joists

• W-shapes were selected over open web joists (OWJs) due to joist lengths varying throughout a single bay (custom length OWJs would be very costly).

• Joist spacing was set at 5 feet to allow for reasonable joist depths.

• For simplicity, the joists are the same size throughout a single bay and all connections are simple.

• Sizes range from W8x10 to W18x40.



Beams

• All beams were also selected to be W-shapes.

• Spans range from two feet to fifty feet.

• Connections vary from pinned-pinned to fixed-fixed.

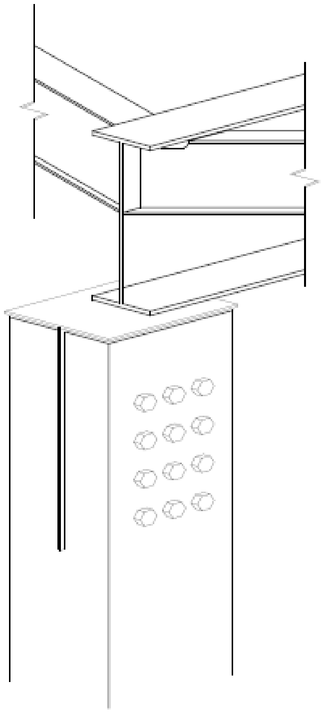
•Sizes range from W8x10 to W30x108.

Columns

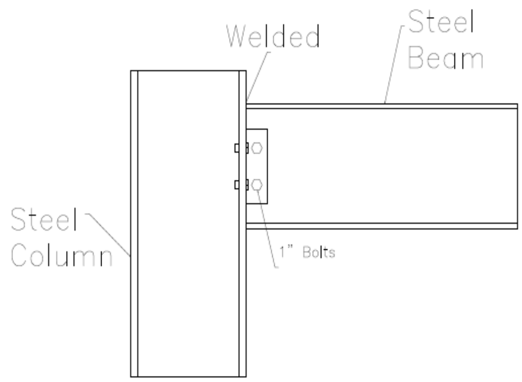
For columns that are fully exposed to occupants, we showcased wood columns to further highlight the importance of the local forestry industry. Other partially exposed or hidden columns were designed in A992 steel to allow for smaller member sizes.

There is one Glulam column size of 10 ¾" x 13 ½" and steel column sizes range from W24x103 to W8x31.

Connections



Typical Wood-Steel
Simple Connection
Orthogonal View



Steel-Steel
Moment Connection

We designed connections to be primarily simple with a mix of several steel-steel connections as fixed in several deliberate locations to provide a Moment Resisting Frame. This connection type can be seen in the figure directly above. A simple connection was utilized for the wood column to steel beam(s) to save time and money. We were challenged with finding a type of connection that would work in this unique instance. Although not common, this arrangement is still possible. We ultimately decided on a knife plate connection as shown in the orthogonal detail to the left. This connection allows for easy disassembly as every bolt can be unbolted and the beam will not have to be braced when doing so. This further emphasizes our sustainability objective because the structure will be able to provide salvaged material when it reaches the end of its useful life.

Foundations

For the foundation system, we chose early on to use a helical pile system. These piles can resist tension and compression loads which is important because this location is prone to earthquake loads. While this is beneficial, we later discovered that we do not anticipate these piles to be in tension due to little to no uplift. We kept with this system because it is still valid for our location and speaks to our design goal as well. These piles are less intrusive than many other foundation systems with less construction cost, and a smaller impact on the environment.