CANOPY
“Building Towards the Future of Canada’s Sustainable Forests”

by

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Abstract

Climate change increasingly continues to inflict negative impacts on our environment by slowly destroying our forest and other related ecosystems. One of the most significant side effects is the deterioration of trees by extreme weather, fires, and insect infestations. In Canada, trees also play an essential role on our economy, relying heavily on the global exportation of lumber. Increasingly, lumber becomes an integral part of many construction projects, as architects continue to focus their attention on mass timber construction in building design. Mass timber is one of the most sustainable and renewable construction materials, which can help sequester carbon and capture greenhouse gases from the atmosphere. In order to keep up with the demands for lumber, it is essential to provide solutions towards maintaining a healthy and diverse tree culture that would contribute towards a robust and thriving forest ecosystem.

This thesis will address the long-term goals of forest management and development towards sustaining the forests in Chibougamau, Quebec. As the Canadian economy continues to supply and produce lumber, this thesis seeks to use architectural methods to promote a robust approach that aids in the facilitation of tree growth research and forestry production for commercial, large-scale economies, and to protect forest health. The design proposal is for a tree nursery and a forestry research center to facilitate the growth of saplings, seed collection, and provide space and resources for forestry research. The proposal aims to contribute to sustainable forestry into the future.
Acknowledgements

I would like to thank my family and friends for their inspiration and encouragement. Thank you to my thesis advisor, Manuel Baez for your constant support and guidance throughout the duration of my thesis dissertation.
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Chapter 1:

Introduction

The emission of greenhouse gases (GHG) released into the earth's atmosphere is driving the negative effect of climate change on Canada's forests. These effects have eliminated certain tree species, changing the balance and health of a forest ecosystem that's needed to regulate carbon exchange. Despite the degradation of trees, wood is still a popular commodity, especially in architecture, due to the rise in production of more mass timber projects. The Canadian Forest is essential to its economy and identity. The thesis will examine why forestry is an integral part of Canada, how climate change has affected the survival of trees, and the benefits of a biodiverse forest ecosystem.

The goal is to develop a tree nursery and research center in Chibougamau, Quebec, to help conserve, reforest, and restore the forest biodiversity towards increasing carbon storage with more trees to combat climate change. The design will include a tree nursery facilitating seed collection and growing of seedlings, a seed vault to preserve forest genetics, a research laboratory studying Quebec’s forest, and a discovery center to educate the public and showcase the resulting work. The building will incorporate a sustainable design approach with net-zero water by harvesting rainwater, net zero energy with solar panels and geothermal cooling and heating, in addition to a mass timber structure, reducing the carbon footprint of the facility while also being
sensitively integrated into its site. The facility aims to promote sustainable forest management by populating the forest with more biodiverse trees for a healthier ecosystem. It starts by transforming the existing monoculture tree plantation ecosystem into a biodiverse ecosystem by replacing the tradition of singular species harvested trees with an appropriate multi-species planting of tree saplings.
Chapter 2:

Canada’s Forestry

Canada has rich forest resources that support communities, the ecology, and the economy. It is the third most forested country in the world with trees covering 40% of the nation’s land area. Canadian forests support a diverse forest ecozone (Figure 1) and is home to 140 native tree species of coniferous, mixed wood, broadleaf and temporally non-treed type forests (Figure 2). Canada’s forest sector is one of the oldest and an essential industry, employing over 184,510 people, while contributing about 25.8 billion dollars to the economy each year. Logging and production of lumber today is fueled by an ever-increasing rise in residential construction, and the growing use of mass timber products in both residential and commercial projects. This chapter will investigate Canada's timber trade and lumber industry history, dating back to the period of the Napoleonic wars of the early 19th century in Britain, through to today’s increased demand for mass timber products.

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2 Ibid page 44.
Figure 1: Forest Ecozones Across Canada

Figure 2: Forest Type
2.1 Brief History

Since the 19th Century, lumber has been a staple in Canada’s economy. From the Napoleonic war during the early 19th century, Britain’s demand for timber increased in order to build their warships after being blocked by the French army from buying wood in the Baltic countries. The war forced England to turn to Canada to set up lumber camps in the Maritimes and central Canada. By the beginning of the 19th century, larger sawn lumber and square timber were major exports, but much of lumber was wasted; between 25-30% of each tree was discarded. During the same period, the paper industry began to rise in prominence. White pine lumber became the chief export to Britain with 9,000 loads (5,500 tons) of lumber in 1805 and 750,000 loads (46,500 tons) of lumber in 1846. St. John, Nova Scotia had 450 vessels specializing in timber trade by 1840. On the west coast, logging began in the 1850s, and was primarily shipped to the Asian Pacific market. During these early stages in the timber industry, harvesting and milling trees was a small independent operation owned and managed by farmers with logging being done during the winters as cheap labor. In addition, the winter months made trees less flexible, therefore, easier to fall when no sap was running through the tree trunk. Most of the laborers were men, since logging was done manually with simple tools such as timber axes and crosscut saws. Horses were used to pull felled logs out of the forests.


5 Ibid
into the rivers to be transported downstream to nearby sawmills or shipping ports. Between 1850-1900, trade with Britain cooled down and made way for an emerging American market. The sawn lumber industry took off and caused changes to lumber operations, most notably the introduction of six large sawmills in Chaudière, Quebec that produced 30 million board feet of wood in 1871 (Figure 03).  

Between 1891 to 1921, the Canadian economy had grown substantially while the population doubled, and timber industries increased capital stocks. During this period, Ontario and Quebec redirected the lumber industry to pulp and paper industries. Spruce trees were abundant and the American market demands grew due to cheaper, more efficient railway transportation systems. As the demand for lumber and paper continued to rise, forestry companies began to extract exponentially more trees to meet economic demands.

By the early to mid-20th century, the government imposed an action plan for the conservation and protection of forests with stricter timber use regulations. From the mid-20th century to the late 1980s, a forest management plan was enforced across Canada. With such government regulations, forestry continues to be a vital part of Canada’s economy today. As of 2019, there are 756,875 hectares

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of forest being harvested, but only 404,524 hectares are replanted with new trees and 8,620 hectares are seeded. Canada is heavily dependent on its forestry industry and has tried to integrate better forest management plans. However, these initiatives have their limitations, especially as climate change, described in Chapter 3, quickly and permanently changes the health and deterioration of forests and trees.

![Figure 3: Ships loading timber, Quebec City, 1860-1870](https://cfs.nrcan.gc.ca/selective-cuttings/68)


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2.2 Timber and Lumber Industry

For the last three centuries in the global forest industry, Canada’s lumber is the number one export in that market. The largest production of lumber is the harvesting of coniferous trees. These trees are logged, passed through a sawmill, and milled into a variety of lumber products and dimensions for construction and millwork. The sawmills produce a by-product of sawdust and shavings, which get sent to pulp and paper factories to be manufactured into everyday goods such as medical gowns, paper products, treatment methods for municipal waste, or to create bioenergy (Figure 4). Today, the Canadian economy is still heavily reliant on its logging industry. It exports 80% of extracted softwood lumber to the United States of America, employs about 28,000 Canadians in the sawmilling industry, and produces 10 billion dollars of softwood lumber exports. British Columbia, Quebec, and Ontario (Figure 5) are the three biggest provinces contributing to the production of lumber. Softwood lumber is extracted from spruce, pine, hemlock, Douglas fir, larch and western red cedar trees. Hardwood lumber is predominantly extracted from birch, maple, and oak trees.

Presently, the Canadian residential construction industry further fuels the demands on the lumber industry, with softwood lumber being the choice building material due to its availability, durability, and lower environmental impact. Additionally, the lumber industry will continue to grow in Canada with

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the increasing use of wood as a means of lowering greenhouse gas (GHG) emissions within the construction field. With the help of modern technologies and techniques, mass timber has gained popularity, tapping people’s appreciation of wood more than steel and concrete.

Figure 4: Sustainably Managed forests to deliver essential products and services to Canadians.
2.3 Rise of Mass Timber

Mass timber technology is changing the construction industry in high-rise residential, commercial, institutional, recreational, industrial, and infrastructure projects all over Canada. Mass timber construction is possible through engineered wood products that are made into large, solid wood panels for structural columns or beams and to use as load-bearing walls, floors, and roof assemblies. Mass timber columns and beams are formed and engineered for high-load strength through such methods as lamination of wood pieces, mechanical fasteners, or structural adhesives.\(^\text{10}\) The concern of rising GHG emission in construction is driving the rise and popularity of using mass timber products.

Mass timber, as the primary building material, can sequester and mitigate more carbon dioxide from the atmosphere than traditional construction materials such as reinforced concrete and steel. Many architects and engineers are following the path of transforming the future of construction to become environmentally sustainable by lowering GHG emissions and reducing by-product waste in construction materials. In his 2013 TEDtalk and “Tall Wood Buildings” publication, architect Michael Green advocates for building more wooden skyscrapers. Green emphasizes how architecture needs to be more sustainable because buildings contribute to 47% of GHG emissions, followed by transportation at 33% emission, and manufacturing industries at 19%. Wood as

a building material is part of the solution since steel and concrete emit 8% of GHG emissions during processing, extracting, and construction.\(^1\) Traditional construction-grade lumber typically holds about 1 ton of carbon dioxide for each cubic meter of wood, and mass timber of a similar size holds the same.\(^2\) Taller buildings and structures are moving towards using wood instead of steel and concrete because of the materials’ lower carbon footprint. With its technological and environmental advantage, mass timber is transforming construction with its qualities and strength. Mass timber withstands loads over a longer span compared to steel and concrete. It is more lightweight and flexible, more resistant to earthquakes, provides more thermal retention to reduce heat loss, and is inherently fire resistant. There are different types of mass timber products available: cross-laminated timber, dowel-laminated timber, nail-laminated timber, glue-laminated timber, laminated veneer lumber, laminated strand lumber, and parallel strand lumber (Figure 6). These mass timber products are harvested and produced the same way as standard dimensional lumber (Figure 7).

In the past, wood frame construction was mainly applied to low-rise and mid-rise residential construction (between 4 and 6 storeys in height) due to building code restrictions for fire resistance and safety. In 2017, more comprehensive fire safety testing amended the building code to approve residential construction

\(^{11}\) Michael Green: Why We Should Build Wooden Skyscrapers, YouTube (TED, 2019), https://www.youtube.com/watch?v=Xi_PD5aZ77Q.

up to 13 storeys. As of 2021, the International Building Code (IBC) has allowed wood buildings to be up to 18 storeys.\textsuperscript{13} In Canada’s 2021 database, information has been compiled from 484 structures, including bridges, towers, and agricultural buildings. Additionally, it also includes 21 facilities manufactured with mass timber.\textsuperscript{14} The three provinces with the most mass timber projects are British Columbia, Quebec, and Ontario. As British Columbia leads the way with the most mass timber projects built so far, Quebec is slowly surpassing it with 25 completed mass timber structures in 2019, a new yearly record within Canada.\textsuperscript{15} As more and more mass timber projects are being built each year, the forestry sector is capitalizing on the production of lumber.

Mass timber is also propelling the forestry sector to plant more fast-growing trees and to utilize the same pine species for quicker production. These demands endanger forest biodiversity through overharvesting and cultivating monocultural plantations. It changes the forest’s ability to maintain a healthy carbon source and retain water, as explained in Chapter 4. Chapter 6 will present a design proposal towards executing a better forest management plan that would promote more tree diversity and support the increasing demands for mass timber projects.


\textsuperscript{14} Ibid, Page 3

\textsuperscript{15} Ibid, Page 35
Figure 6: Type of Mass Timber Products

Figure 7: The Processing Chain of Engineered Timber Products

Chapter 3:

Climate Change and the Forest

The consequences of climate change intensify unpredictable seasonal climate conditions such as intense heatwaves, droughts, floods, intense forest fires, and infestations that affect the balance of a forest’s ecosystem. The main culprit contributing to these unstable weather changes is the constant emissions of GHGs into the atmosphere. To balance carbon exchange, it is necessary to regulate and reduce GHG emissions. Forests can be both a carbon source (emits carbon gases) and a carbon sink (absorbs carbon gases).16 Naturally, forests balance and stabilize carbon emissions in the atmosphere. With the increasing effects of climate change, forests are becoming more of a carbon source, releasing more carbon dioxide into the atmospheres. This effect harms the health of forests around the world. In Canada, the environmental effects of extreme weather conditions, fires, and insect infestations caused by climate change have impacted wildlife and are threatening the forestry sector. These issues will be further explored in this chapter.

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3.1 Environmental Effects

Natural weather disturbances due to climate change have magnified and caused more intense damage to our agriculture, wildlife, and infrastructure. The resulting negative progression in forest health can be observed through aerial photography of forests that reveal large patches of dying trees. These disturbances are from abiotic and biotic causes (Table 1). Abiotic causes are from non-living components in the environment, such as temperature, water, and wind. Biotic causes are from living parts of forest ecosystems, such as insects, fungi, or bacteria.\(^\text{17}\) In a balanced forest ecosystem, some natural deterioration is an integral part of a tree's life cycle. These disturbances are minor in a stable forest ecosystem and contributes to its surrounding biodiversity of different species in the forest's ecosystem. Trees provide habitats for various insects, birds, and animals to feed on and live in. As a tree dies and decomposes, it provides nutrients back to the soil.

Over the last few centuries of human deforesting and logging, in addition to GHG emissions, forest environments have become much more unstable. 362 million hectares (ha) of Canadian forests are at-risk due to extreme weather conditions such as forest fires, that have stripped away 227,277 ha of forest land, and insect infestations, that have affected 14,473,760 ha of Canadian forests.\(^\text{18}\) The rise of abiotic and biotic disturbances is detrimental to Canada's

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\(^\text{18}\) Ibid, Page 8-9
boreal forests, and it will continue to worsen if these intense conditions continue to disturb the balance of Canadian forests.

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<th>Abiotic Disturbances</th>
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<td>Are caused by extreme weather conditions and are nearly impossible to predict</td>
<td>Can be predicted through efficient monitoring</td>
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<tr>
<td>Last only a few hours or days, and kill most trees during this time</td>
<td>May last a decade, so trees take several years to die</td>
</tr>
<tr>
<td>Kill healthy trees</td>
<td>Kill weak trees because they are weakened over several years before death</td>
</tr>
<tr>
<td>Affect all, or nearly all, tree species</td>
<td>Usually affect a limited number of tree species</td>
</tr>
<tr>
<td>Physically disturb soils</td>
<td>Do not physically disturb soils, but insect outbreaks may enhance soil nutrient cycling through caterpillar feces</td>
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**Table 1  Abiotic and Biotic Disturbance in Forests**


**Weather Shifts and Extremes**

The extreme factors of climate change have been intense weather and climatic events such as heavy rainfall, thunderstorms, hailstorms, tornadoes, droughts, and severe heat waves. Wetter spring and fall conditions are forecast to increase, causing heavy precipitation, and increasing the risk of floods. More extended, drier, and hotter summers have caused more drought and frequent forest fires that greatly affected the forest ecosystems and communities. In 2019 and 2022, Eastern Ontario and Western Quebec endured catastrophic weather events of extreme thunderstorms, large hail, intense rainfall and tornadoes. The aftermath has inflicted many mature tree species in different ways (i.e., uprooted, fallen, and windsnapped) which has caused extensive damage to
power lines leading to long-lasting power outages (Figure 8). This is only a tiny
glimpse of what extreme weather can do. Canada was ranked as the ninth
country most threatened by and vulnerable to climate change due to extremes
weather in 2018.\textsuperscript{19} A major reason is because of forest fires that occur due to
scorching hot summers and drier trees that are more susceptible to catching on
fire.

![Figure 8: Windblown Trees](image)


Forest Fires

Forest fires are an integral part of the life cycle of forests. They help promote new tree growth by maintaining a healthy and diverse forest ecosystem. A forest fire has four outstanding benefits: cleaning the forest floor to promote new habitats, killing diseases, killing invasive insects, and promoting new tree growth. A cleaned forest floor is when low fires burn away short shrubs, debris, and dead trees, thus providing more nutrients to the soil, opening up the skyline for more sunlight for new young trees, and increasing water supply to the renewed forest. Specific tree species depend on fires to regenerate by relying on heat to disperse seeds from their cones onto the forest floor. This process of using forest fires is a tree’s method of promoting new growth. In the past decades, forest fires in Canada have caused more damage due to longer, drier, and hotter summers. This ended up causing frequent fires that burned large acres of forests (Figure 9). The lumber industry is one of many contributing factors to the growing intensity of forest fires. After trees are harvested for lumber, pine saplings are replanted in place, creating a monoculture ecosystem. The lack of diversity in tree species within that forest area puts all the surrounding forest in danger of forest fires spreading. The growth of the monoculture tree farm is susceptible to catching fire easily during hot, dry summer temperatures. If just one tree catches fire, all the surrounding trees will burn with it, and there is nothing to stop it. The monoculture pine forest can be equated to a bundle of matchsticks and how quickly they can be set on fire. The intensity of these fires is slowing down forest regeneration due to the vast number of trees burned each year. In Quebec, 59,985 ha of forest area has
burned since 2020.\textsuperscript{20} Quebec is the worst hit province compared to British Columbia and Ontario. This thesis will address the recuperation of all the lost forests and potential lumber in Quebec.

\textbf{Figure 9: Forest Fires in Canada}


Insect Infestation

The presence of insects is an integral part of a productive forest ecosystem that eliminates old, sick, and dying trees, thus helping forest renewal. Many of these are tree-killing insects that usually feed on unhealthy trees, thus contributing to the decomposition process that helps bring nutrients back to the soil. Most healthy living trees can tolerate some insect damage, but the rise of climate change has caused outbreaks that are killing and weakening many trees. With the rise in warm temperature, native and non-native insect species are thriving. The outbreaks are becoming much more intense, frequent, widespread, and longer, putting all forests in a vulnerable state. In this context, these insects are parasitic on forest ecosystems by using the trees as a host for their food source and habitation. Certain insect species that respond to climate change have directly impacted the health of certain tree species. Table 2 below shows the effect of different insect species like the Lymantria Dispar, eastern spruce budworm, jack pine budworm, mountain pine beetle and spruce beetle that have been defoliating Canadian forests from 2009 to 2019. British Columbia was the hardest hit province with mountain pine beetles killing most of their pine trees. The Department of BC Forestry’s solution was to burn the areas heavily infested, but the insects slowly started to travel eastward towards Alberta. As of 2019, Quebec is the province suffering the worst infestation of the Eastern Spruce Budworm outbreak on balsam fir, white, red, and black spruce. This has

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damaged 9.8 million hectares of forest. British Columbia has found solutions in combating their insect infestation through research and action. Quebec would be an ideal province for building a research facility that would address how to reduce the spread of spruce budworm without burning more forest areas. Many of these insect species are destroying mature trees at such a rapid rate that endangers forests biodiversity, resulting in certain pine species that would die and with the potential of becoming extinct in Canada.

Table 2: Forest area (in hectares) containing defoliated or beetle-killed trees for five insects in Canada, 2009–2019


3.2 Impact on Wildlife

Canada’s forests continue to endure damage caused by natural disturbances, and these effects trickle down to wildlife habitation and sources of food. Different animal species rely on old growth and mature trees, with small wildlife, such as coyotes, foxes, rabbits, squirrels, and chipmunks creating their own homes within these forests. Most bird species build nests in the tree tops and feed on seeds from pinecones. Herbivores, like deer, moose and caribou, forage for vegetation grown closely around these mature trees. In recent years, researchers have discovered that the negative impact of natural disturbances on mature trees has changed the forest ecosystem, thus transforming animal habitats and populations.

In Quebec, the animal species directly impacted by climate change is caribou (Figure 10), since their preferred habitat is the old-growth coniferous forests with jack pine and black spruce trees supplying an abundant food source of lichens, muskegs, and peat.\(^{23}\) Also, its habitat helps them to avoid being prey since predators like cougar, coyotes, lynx, and eagles prefer hunting in a younger forest area where deer and moose live. In an old-growth forest, larger trees with a bigger canopy help provide shallower snow and reduce wind load in winter, where caribou can easily dig the ground for lichens. Caribou depend on their habitat for survival, making them more vulnerable to any sort of forest disturbance. The long-term effect of climate change is threatening their habitat

with greater weather variability and severe weather events that cause more freeze-thaw cycles, freezing rain, deep snow, hot summer temperatures, and changes in the forest composition and food supply.\textsuperscript{24} This has caused a decline in the caribou population by 30% over three generations (20 years), making Quebec the most vulnerable province.\textsuperscript{25} As such, Quebec would be the ideal location for a research center for the forestry sector that would address finding a solution that would re-instate a supportive habitat for the caribou. The consequences of climate change will continue to transform not only caribou habitats, but all wildlife habitats, as frequent wildfires and the spread of forest insects are increasing the mortality of trees.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{CaribouPopulationEcology.png}
\caption{Caribou Population Ecology Under the Influences of Changing Climate.}
\end{figure}


\textsuperscript{25} Ibid, Page 2
3.3 Threats to the Forest Sector

The Government of Canada publicly owns 94% of forest land and maintains the supply of timber by managing that land with social, economic, and environmental objectives. The management of timber supply is changing due to the impact of climate change with the increase of harvested trees as a small term solution in combating the spread of insect infestation. As the production of timber increases, it opens up more and more of the forest floor, thus reducing animal habitat, reducing soil quality, and amplifying the risk of environmental disasters such as landslides. The Canadian Council of Forest Ministers is developing sustainable forest management techniques to protect the future of the forest industry and ecosystem from collapse by overseeing and promoting the following values: biological diversity, ecosystem conditioning and productivity, soil and water maintenance, the role of forests in global ecological cycles, economic and social benefits, and society’s responsibility.26 As winters are getting warmer, leading to more precipitation each year, this has reduced the opportunity of the forest industry to harvest timber due to the resulting uneven and slippery road conditions. The industry’s operations to provide more wood under these conditions increases the cost and reduces the availability of lumber to the market. Forest-based communities are the most vulnerable to climate change because of their close ties to the forest areas. These communities are easily impacted by extreme weather events, especially when exposed to wildfires. These fires risk the community’s health and jeopardize

26 Tim Williamson et al., “Climate Change and Canada’s Forests: From Impacts to Adaptation,” Climate change and Canada’s forests: From impacts to adaptation § (2009), https://d1ied5g1xfgpx8.cloudfront.net/pdfs/29616.pdf. Page 44.
their economic ties to the timber industry. As climate change continues to degrade the health of Canadian forestry, the industry and related communities must respond to all the environmental issues associated with these natural disturbances in order to maintain the local economies and to continue to supply lumber and other wood products to the global market.
Chapter 4:

Forest Ecosystem and Forest Management

Canada has one of the most extensive boreal forests in the world, and its abundance of trees helps regulate carbon dioxide emissions into the atmosphere. It can store 186 billion tonnes of carbon alone, but with the effects of climate change, its forest is suffering from related natural disturbances. This chapter will address the essential role of a forest in carbon and hydrologic cycles, how to mitigate the effects of climate change, how good forest management contributes to the growth and health of its ecosystem, and the overall importance of trees.

27 https://naturecanada.ca/discover-nature/canadas-different-environments/canadas-boreal-forest/#:~:text=At%201.3%20billion%20acres%20the,grizzly%20bears%20and%20woodland%20caribou.
4.1 Carbon and Hydrologic Cycles

A forest supports all of its interrelated biodiversity and ecosystems by sustaining and maintaining the crucial balance of these systems that are highly sensitive and susceptible to the effects of climate change. One factors that has led to climate change is humanity's use of fossil fuels that release more GHGs into the atmosphere. These emissions are affecting the forest's equilibrium in properly balancing its carbon source and retention of water. In order to maintain this balance, a forest relies on its trees to stabilize the carbon and hydrologic cycle from causing more damage to our environment.

The role of the forests carbon cycle is to absorb carbon dioxide from the atmosphere during tree growth and to store this carbon in the biomass (Figure 11). During the growth of a tree, photosynthesis allows for the absorption of energy from the sun in order to produce food. Water from the soil is transported from the roots to a tree's needles or leaves to activate the collection of carbon dioxide from the atmosphere and the release of oxygen. But as trees naturally decompose, the biomass emits carbon back to the atmosphere and is absorbed into the soil. Forest fires and deforestation also contribute to the release of carbon, whereas harvesting trees for lumber creates biomass to store carbon until it is decomposed.

The forest hydrologic cycle plays another critical role by helping to regulate surface and groundwater flows and contributing to the maintenance of high-

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water quality through natural filtration\textsuperscript{29} (Figure 12). Trees help to prevent soil erosion through their root system by preventing landslides, floods, and droughts. Additionally, the forest contributes to watersheds by helping to feed rivers with a supply of fresh water, and modulating the air temperature and moisture levels, thus creating a microclimate within the ecosystem.

The carbon and hydrologic cycles are complex systems that are integral to forest ecology and the earth’s biosphere. Without these two cycles, the effects of climate change would be more extreme and frequent, substantially impacting how we live in a negative way. The forest would become less green, making the earth’s atmosphere and water much more polluted. As climate change continues to harm the survival of trees, it will require human interventions to implement and maintain sustainable forest management.

\textsuperscript{29} Ulrich Dangel, \textit{Turning Point in Timber Construction a New Economy} (Basel: Birkhäuser, 2016), Page 12
Figure 11: Forest Carbon Cycle
Note: Markus Hudert and Sven Pfeiffer, Rethinking Wood: Future Dimensions of Timber Assembly (Basel: Birkhäuser, 2019), page 36.

Figure 12: Forest Hydrologic Cycle
4.2 Forest Management

In order to maintain the balance of forest ecosystems and the supply of all wood products in Canada, the forestry sector needs to implement a suitable forestry management plan that regulates harvesting, diversifies different tree species, and replenishes lost trees. The action plan by the Government of Canada is to plant 2 billion trees as a solution to combat climate change in order to achieve their goal of net zero GHG emissions. Additionally, an increase of the forest by 1 billion hectares would limit global warming by 1.5°C by 2050.\(^\text{30}\)

In the last half of the 20th century, tree planting became an integral part of the forest sector in replenishing harvested forest areas. This re-newed growth of trees is foundational to the industry as the demands for lumber and timber products form the bulk of the needs of the construction industry.\(^\text{31}\) Planting more trees is a proactive goal to combat climate change, but it can be dangerous to forest ecology if there is no biodiversity. A tree plantation may look like a forest, but the issue is that a monoculture of the same tree species with younger trees are net emitters of carbon due to the disturbance of the soil and the degradation of the previous ecosystem.\(^\text{32}\)

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\(^\text{31}\) How Trees Talk to Each Other, TED Ideas Worth Spreading (TED, 2016), https://www.ted.com/talks/suzanne_simard_how_trees_talk_to_each_other.

A natural old growth forest has a biodiversity of many tree species that depend on each other while also storing carbon. For example, Douglas fir shares resources with paper birch while they also rely on each other. In most forests, tree species like Douglas fir, Sequoia, Beech, and Oak live in a family band. Susanne Simard’s research on The Mother Tree Project focuses on the mother tree as the oldest tree within a forest. It acts as a centralized hub supporting mycorrhizal fungus that facilitates the connections, communications and resource exchange with neighboring trees. Peter Wohlleben’s research specifies trees within a forest as having a social connection that forms a community. He describes it as a "family network" where trees have a great support system contributing to the growth and older age of the forest. Wohlleben’s and Simard’s research showcase that tree diversity in a forest provides a community that contributes towards a healthier forest ecosystem and facilitates a better carbon cycle.

The implications of forest management is an integral part of the timber industry's efforts towards maintaining old growth forests. Simard’s approach towards better forest management is that the timber industry should maintain a percentage range of 60%, 30%, and 10% of the biggest and oldest tree range to better sustain a healthy forest ecology and to be a carbon sink. Wohlleben’s approach to forestry is by selectivity, harvesting only mid-size trees while keeping the oldest and youngest trees alive and naturally redistributing their

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33 Peter Wohlleben on the Hidden Life of Trees /67, YouTube (For the Wild, 2019), https://www.youtube.com/watch?v=PCTCsogAs6U.

seeds all over the forest for regrowth. This would keep the native species of trees alive and creates less soil disturbance within the forest floor. By providing a sustainable forest management plan for Canada, it is essential to incorporate these core principles by conserving biodiversity, maintaining the productivity and health of the forest ecosystem, maintaining the forest’s ability towards carbon and hydrological cycle, and providing a legal framework for forest conservation. As part of this thesis proposal, Chapter 6 will look into implementing a better forest management plan to transform the existing timber mill with more biodiversity for a sustainable forest ecosystem for the future.
Chapter 5:
Precedent Study

This chapter will highlight feature of precedents case study serving an interest and inspiration toward the design proposal. It will consist of projects like the Bill Fisch Forest Stewardship and Education Center, and Wellesley College Global Flora, and Colorado State Forest Service Nursery.
5.1 Bill Fisch Forest Stewardship and Education Center

Bill Fisch Forest Stewardship and Education Center (BFFSEC) is a facility providing a space for education and a communal meeting place for the residents of the Regional Municipality of York to bring awareness of the forest ecosystem and natural resources (Figures 13 and 15). The building is surrounded by a 90-year-old forest in Whitchurch-Stouffville, Ontario.35 The design team of DIALOG has worked with forest arborists and ecologists to build a sustainable building with the least amount of impact on the surrounding forest during construction. The design concept removes the boundary between the building and forest. The facility reflects on its site with the surrounding forest ecosystem that will maintain a 90-year building lifecycle.36 The building systems and materials are integrated into the sensitive environment as an integral part of the forest.

Figure 13: South Elevation


Figure 14: North Elevation

Figure 15: Interior View
Design Features

The design of this educational center incorporates a sustainable system and material meeting LEED Platinum certification and the Living Building Challenge standard. The sustainable components are captured though its high-performance building envelope, orientation, renewable energy source, net-zero water management, and materials (Figure 16). The building envelop has a high energy performance reducing heating and cooling loads with its highly insulated wall and roof and triple pane glazing. The glazing covers less than 30% of the building face reducing heat loss. The building’s east-west orientation maximizes the use of natural light within the space. The optimization of sunlight is captured by the south-facing glazing to collect heat during the winter, where the building large overhang minimizes lighting exposurer in summer.

Renewable energy source is collected through its thermal and electrical systems (Figure 17). The thermal systems are captured by the use of solar heat gain, natural ventilation, in-floor radiant heating, wood burning hearth and heat recovery ventilator. The electrical systems are capture from photovoltaic solar panels generating 38mWh of clean energy. Net-zero water is captured from harvesting rainwater, using well water, and onsite wastewater treatment (Figure 18). The rainwater from the roof runoff is collected into an underground cistern that’s provides non-potable water for toilets and urinals, whereas the existing well provides portable water for sinks and showers. As part of the building water

treatment, the greywater and blackwater retrieved from all the plumbing fixtures is sent to a sewage collection tank. This water is sent into a septic pump chamber which passes through a 5-micron biofilter and UV filter to trap particulates and eliminate micro-organisms before releasing into the tertiary water infiltration bed back into the earth.38 The entire building is constructed out of cross-laminated timber (CLT) and glulam from black spruce trees (Figure 19).

Figure 16: Sustainability Diagram

Figure 17: Sustainable System Energy

Figure 18: Sustainable System Water
Take-Away

The design of BFFSEC’s system mimics the function of a living organism connecting to its surrounding environment. Craig Applegath, principal at Dialog, envisioned a building functioning like a forest ecosystem as an integral part of nature.\(^{39}\) The building’s connection to the environment is captured by its sustainable design in utilizing the natural element of wind, sunlight, and water. Wind is part of the building’s natural ventilation circulating air through the space as the lungs. Sunlight is captured from the PV roof panel and south-facing glazing to collect energy. Water is collected by rainwater runoff from the roof and existing well for the building’s plumbing system. The use of water within

the building is returned to back to nature. The building design concept is like a living organism connecting to the forest ecosystem that is integrated into the thesis design proposal.
5.2 Wellesley College Global Flora

Wellesley College Global Flora is a greenhouse with a botany lab and a museum housing the collection of dry and tropical plants. Located Wellesley, United States, the greenhouse was established in the 1920s by Dr. Margaret Ferguson and was designed by Kennedy and Violich Architecture.40 Constructed in 2020, a new addition of the Camellia Pavilion was constructed linking the greenhouse and college campus visitor center. The pavilion houses a 140 year-old Durant Camellia tree (Figure 20), whereas the greenhouse is divided into wet and dry biome (Figure 21). The wet biome has a tropical environment with a hilltop plateau, mangrove tank, low mash bog, rainforest canopy, Fernery, and Paludarium (Figure 23). The dry biome has a desert environment with an upland desert, dry terraced cliffs, and succulents (Figure 20). As the greenhouse support these biomes, it is seen as “breathing building” responding to the atmospheric changes within its micro-climates.41 The building has interactive sensor platform collecting data from the plants, soil, air and water for the scientific research community to study and educated the public on the importance of plant environment and ecology.

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Figure 20: Pavilion Houses with Durant Camellia

Figure 21: Site Plan
Figure 22: Greenhouse Interior View of Mangrove Tanks

Figure 23: Greenhouse Interior View of Desert
Design Features

The building has passive and active systems meeting Living Building Challenge's Net Zero Water and Net Zero Energy criteria. The sustainable design is captured by collecting solar rays through the interior north wall as a thermal mass, a vertical green wall, a water system for cooling, a geothermal system for in-floor heating, and energy-efficient ventilation (Figure 24). The curvature of the building maximizes sunlight exposure from the south facing façade. It is constructed from a double layer of transparent ethylene tetrafluoroethylene that allows sunlight to enter the space, with motor-controlled shades that moderate heat gain and operable windows. The windows located at the perimeter base intaking external cool air, while exhausting hot air from the roof peak during the summer (Figure 25). In the winter, these windows are closed allowing solar heat gain to warm up the space (Figure 25). The north wall also aids in regulating heat as a thermal mass when exposed to sunlight. It absorbs heat during the day and releases it back at night. In the wet biome, the north wall is a vertical green wall of Cryptogram absorbing solar energy to transpire water and cool the space. Also, the vertical water feature and ponds provide cooling and humidity control within the wet biome recycled from rainwater. The geothermal system is integrated within the greenhouse concrete floor, balancing the temperature with radiant cooling in the summer and radiant heating in the winter. Air is circulated from the energy-efficient ventilation for passive cooling and heating. An energy recovery unit at the east and west end of the greenhouse recycle the ventilated thermal energy.
Figure 24: Climate Axonometric Diagram

Figure 25: Sunlight Diagrams
Take-Away

The Global Flora design is well integrated into its natural landscape, optimizing sunlight exposure as a passive building system and minimizing the greenhouse’s energy and carbon emissions. This sustainable greenhouse design reduces the negative environmental impact by using less water, energy, and more natural renewable resources. As each biome adopts its microclimate, this greenhouse’s design, function, and systems are well integrated with its natural environment by integrating earth’s natural elements of light, water, air, and earth, executing by solar energy, rainwater, natural ventilation, and geothermal. These elements will inspire the thesis design proposal as a living building. Also, this building can adapt throughout each changing season for a comfortable environment for both people and plants.
5.3 Colorado State Forest Service Nursery

The Colorado State Forest Service (CSFS) Nursery is part of a forestry agency in helping to restore lost forest. The facility is located at the Foothills Campus of Colorado State University in Fort Collins. It is part of the Warner College of Natural Resources at Colorado State University responding to the emerging forest issues (Figure 26).\(^{42}\) The state of Colorado has been warming up to 2°F for the past two decades, contributing to their largest bark beetle outbreak and the ten largest forest fires since 2002. The researcher is predicting further warming by another 2.5°F to 6.5°F by 2020 based on the projection from the Global Climate Models.\(^{43}\) The nursery is part of the Colorado forest management plan providing pine seedlings for their conservation and restoration projects in reforestation. As part of conservation efforts, the tree seedlings will help reforest burned areas, enhance wildlife habitat, protect the soil from erosion, protect the watershed and keep the water clean. The seedling is helping urban, rural, and mountain forest areas for agriculture, communities, livestock, pollinators, water quality, and wildlife.

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42 “Agency Profile,” Colorado State Forest Service (Colorado State University, July 8, 2022), https://csfs.colostate.edu/agency-profile/.

Figure 26: Arial View of CSFS Nursery
Note: “Take a Quick Tour of the CSFS Nursery,” Colorado State Forest Service (Colorado State University, December 3, 2021), Retrieve from: https://csfs.colostate.edu/seedling-tree-nursery/tour-the-nursery/.

Figure 27: Exterior View of Bare-Root Seeding
Key Features

The CSFS Nursery produces over 40 tree species in 130 acres of land for bare-root seedlings, 18,000 square feet of greenhouse for container seedlings, and 6,700 square feet of refrigeration space storing seed, plant material and harvest vegetation. The nursery start with stratification the seeds; a process of soaking away the outer seed coat in preparation for germination planted in either container or bare-roots. Germination is the sprouting of the seed. The production of container seeding is housed in the greenhouse (Figure 28). It is a heavy-duty galvanized pipe frame with polycarbonate panel glazing that is

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spacious and open, controlled with a self-watering system and ventilation system. The container seedlings are produced three times a year. The process starts with 24-inch by 12-inch tray containers with 50 cells plugs filled with pre-mixed soil. The germinated seed is placed inside the plug topping off with more dirt and finished with pea gravel, which will be stored in the greenhouse for about six months to 1 year. It is transported outdoors to be climatization for at least one winter season. The bare-root seeding occurs in the outdoor fields, where the seeds are sown in October to be stratified over the winter (Figure 27). These seedlings will continue to grow in the open field for one to two years. Deciduous tree species grow better in the open field than evergreen. As it leaves shed during the colder season, they are lifted 8 inches out of the ground to be stored in their walk-in coolers until it is ready to be retransplanted.

**Take-Away**

The negative impact of climate change has changed Colorado’s forests as the same with Canada’s forests. Colorado’s forest management plan is to rehabilitate burned landscapes where the fire has affected soil conditions and hydrologic forest function. The forest floor cannot process and absorb water causing extensive soil erosion and flooding, closing their municipal water storage facilities. Human intervention is required to replenish lost forests with the help of a tree nursery. In a natural forest, there are many variable elements affected by climate change endangering the natural tree seed sprouting cycle. Replanting the forest floor with saplings provided by the nursery can speed up the forest regeneration process. This idea will be integrated into the thesis design concept and will follow the production of CSFS Nursery’s sapling process in Chibougamau, Quebec.
Chapter 6:
Design Proposal

This chapter will showcase the design proposal for a tree nursery and research center called “Canopy” (Figure 27). The inspiration of design, performance, and operation is derived from identified needs revealed in my research, and reflects some of the approaches discovered in the precedents studied in Chapter 5. The goal of the Canopy is to create a facility in helping and promoting the conservation, reforestation, and restoration of forest biodiversity by changing the operation of the exiting tree plantation and timber mills in Chibougamau, Quebec.

Figure 29: Exterior Front View of “Canopy”
6.1 Site

"Canopy" is a facility located in Chibougamau, Quebec. It will be the central hub for the Center for Forest Research by connecting, collecting and disseminating research from all the universities with forestry or other associated programs in Quebec (Figure 30). The link to the universities will create a network in spreading the study and practices of restoring and conserving biodiverse within forest ecosystems. The connection from the "Canopy" to the universities is analogous to the tree root system network sharing information and connecting with neighbouring trees. It will embrace a community connecting with the people to nature, as in the meaning of Chibougamau's name, "gathering place."

Chibougamau is a town north of Quebec, centralized in the lumber and mining industry (Figure 31). It is a vital feather within the site since "Canopy" will work with the existing timber mill to revitalize the tree plantation with more diverse tree species. The project aims to change the surrounding plantation from a monoculture tree system to a biodiverse forest. Quebec is not as well connected with its forest management and research as British Columbia since Susanne Simard's research is based on. With the ongoing impact of climate change, Quebec is the best province to address its problems from lost caribou habitat, eastern spruce budworm infection, forest fire, and monoculture tree plantation.
Figure 30: Map of Quebec linking the site to the surrounding university
Figure 31: Site Plan
6.2 Design Concept & Scope

"Canopy" is a multifunctional center promoting and facilitating a better future for Quebec's forests through research and shared findings. It will have a seed vault and nursery helping and supplying seeds and saplings for the forest regeneration processes in maintaining tree biodiversity. Also, there is a research facility and laboratory that will explore and study different strategies to provide a healthier forest ecosystem. The building design will integrate within its surrounding environment and achieve a low carbon footprint equip with self-sustaining renewable energy.

The building's function and operations will have a mutual relationship with the site. This relationship is executed by working with the existing site to provide a balanced and diversified forest ecosystem by transforming the monoculture plantation. Like bees collecting pollen for honey, workers at "Canopy" will collect seeds from the surrounding old-growth forests to develop tree saplings to be planted at the timber mill. As the planted trees mature, a percentage will be selectively harvested, whereas the other trees are left to support the new tree generation. Working with Quebec's old-growth forest will help spread its seeds to diversify the plantations by improving its tree culture and creating multiple growth patterns as an ecological balance when tree harvesting.

"Canopy" design is inspired by Susanne Simard's "The Mother Trees" project. It synthesizes Simard's ideas of tree structure, form, and function. The concept of the "Mother Tree" as the biggest tree in the forest interacting with the adjacent trees to provide nutrition and transmit information through its root system. Like the "Mother Tree", this center will connect to the surrounding railway and highway networks uniting all of Quebec's universities to share ongoing research and ideas for a biodiverse self-sufficient forest.
Approach

“Canopy’s” design is inspired by the tree form where the roof mimics the leafy tree canopy, the structural columns and supports mimic the tree trunk and branches, and the underground mechanical networks mimic the tree root system (Figure 32). The roof structure drapes over the entire building collecting the sunlight with the integrated transparent photovoltaic (PV) solar panel like the leaves of a tree photosynthesizing. The PV solar panels provide electricity to the whole building. The roof within the greenhouse area will harvest rainwater draining into the underground collection system to be filtered and purified for potable water.

The roof is supported by structural columns constructed out of CLT, creating a forest-like environment. To further embrace this theme, CLT structural columns are built from different types of wood species mimicking the biodiversity of a boreal forest. Primary CLT columns are made of laminated sugar maple and yellow birch wood due to their compressive strength (Table 3). Secondary CLT column supports are made from black spruce, jack pine, and tamarack, the most common coniferous tree species in Quebec’s boreal forests. Using different wood species for structural columns will support more tree biodiversity within the timber industry. The building’s interior CLT column blends with the exterior, creating an atmospheric experience as integrated with the forest.

Underground vertical thermal pipes and water wells act like a tree root system digging down into the earth. These underground mechanical systems will provide a renewable resource in facilitation the building operation all year round. “Canopy’s” building system is self-sufficient providing its own power,
water and heating/cooling system. All these features are encapsulated under one roof providing a facility for forest research, seed collection and storage, tree germination and cultivation (Figure 22).

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<th>Tree Species</th>
<th>Average Specific Gravity, Oven Dry Sample</th>
<th>Static Bending Modulus of Elasticity (E)</th>
<th>Impact Bending, Height of Drop Causing Failure (in)</th>
<th>Compress. Parallel to Grain, Max Crushing Strength</th>
<th>Compress. Perpen. to Grain, Fiber Stress at Prop. Limit</th>
<th>Shear Parallel to Grain, Max Shear Strength (psi)</th>
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Table 3: Wood Strength
Figure 32: Design Concept Diagram
Sustainable Features

“Canopy” utilizes 100% renewable resources from solar power, greywater, geothermal, and materials in addressing climate change (Figure 33). The curved roof has a south-facing orientation that captures sunlight all year round and collects sunlight from transparent PV solar panels. The roof harnesses solar power to be an energy-efficient building. In daylight, the building maximizes its utilization of natural solar energy from transparent PV panels. The extra energy collected from the PV solar panels charges the underground batteries. It will help power the building at night and use emergency lighting and backup electricity for potential power outages. The roof also harvests rainwater. In the colder seasons, built-in cable heaters at the low points of the roof will collect melted snow for a potable water source. Rainwater or melted snow will run down the pipes from the roof into an underground collection system or water well to be used for the washroom, plumbing, and nursery irrigation system following the precedent study of BFFSEC.

The heat pump in the basement houses the geothermal system with vertical collectors absorbing the earth’s temperature. The geothermal collectors are integrated into the radiant in-floor cooling and heating throughout all five storeys. The building creates its own natural air circulation by utilizing cross ventilation in the warmer seasons from the greenhouse’s operable windows. The chimney effect from the cool air on the ground floor rises around the open central staircase and transfers the cool air onto each floor above grade. The building’s passive cooling system follows the precedent study of Wellesley College Global Flora.
The building is mainly constructed out of wood with CLT floors, CLT wall panels, and glue-laminated timber columns and roof supports encased in a glass skin. The design reflects the importance of sustainable harvesting and incorporating the use of various local tree species to celebrate forest biodiversity and health. The building stresses on using self-sufficient energy production and powering to be independent from the city grid. The “Canopy” expresses the ideas of a biodiverse forest to contain carbon, produce its own energy, and provide a space for progressive research on construction methods by using different wood species and mass timber technology.
Figure 33: Design Diagram
Purpose

The overall goal is to provide an integrated space that will restore and replant the forests by changing how the forestry process in Quebec's timber industry. "Canopy" will be part of the Centre for Forest Research Association. It will create a united community investigating new practices in protecting forest biodiversity, sustaining carbon storage, conserving water resources, and regenerating forests. The thesis aims to establish a relationship between the biodiverse forest ecosystem by contributing to new tree growth and Canada's need for the lumber economy. This will be captured by working with the existing timber mills to slowly restructure their replanting and harvesting procedure while still providing for Canada's economy, fulfilling humanity's lifestyle needs, and rebalancing a forest ecosystem through better harvesting methods and logging management. The harvesting process will only take 30% of the existing trees and replant them with different species of trees common in the boreal forest supplied by the "Canopy's" nursery. It will transform the monoculture forest harvest methods of selectively extracting trees every 10 to 20 years. This transformation will slowly change the timber mill planting process from one tree species to various tree species and selectively harvest only 30% of the tree. It allows more time for trees to mature and store carbon, retain soil and moisture levels in the ground, and provide more habitats for surrounding animals and plants.
6.3 Programs

The “Canopy” is divided into four main components: the seed vault, the nursery, the discovery center, and the research laboratory (Figures 34 and 35). These facilities are spread out over five floors. The basement has a walk-in freezer, cryogenic lab, prep laboratory, walk-in cooler, electrical room, and mechanical room (Figure 36). A corridor connects the freezer to the cryogenic lab for the seeds long-term storage in the vault, where the seeds is package into a specific container prepared by the prep laboratory. A walk-in cooler will store extra germinated seeds and frozen seeds to be thaw for the nursery. The electrical room houses several large batteries for extra power collected by the PV panels. The mechanical room is divided into two sections: geothermal system and water management system.

The ground floor is divided into public and private spaces (Figure 37). The public space starts from the east entrance directing people to the reception and lobby with an open view of the nursery. It is also connected to a grand central staircase and elevator linking all five floors. The private space such as changing room, walk-in cooler, shipping/receiving, equipment room, garage, and greenhouse will be used by the staff and workers. Also, the greenhouse is part of the indoor nursery processing seeds, sprouting and seedling containment.

The second floor opens to the discovery centre from the main stairs, a multi-purpose/meeting room, and offices (Figure 38). The discovery center and meeting room is open to the public to convey the importance of tree diversity and forest ecosystems. Floors 3 to 5 are for private use of the research laboratory for the staff and researchers. On the third floor has changing rooms,
two labs, a cooler, freezer, a staff kitchenette, and a staff lounge (Figure 39). On the fourth floor has a large research laboratory connected to a small climatized glass greenhouse, a forest forensic lab, and a cooler (Figure 40). On the fifth floor has offices look down to the greenhouse, and accessible public seating space (Figure 41). All these programs created for “Canopy” will help facilitate and aid in restoring Quebec’s Forest ecosystem opening the opportunity for new research, commercial farming of tree diverse, and public engagement within the province.
Figure 36: Basement Plan
Figure 37: Ground Floor Plan
Figure 39: 3rd Floor Plan
Figure 40: 4th Floor Plan
Figure 41: 5th Floor Plan
Seed Vault

The seed vault contains all tree samples and seeds collected from research and cultivation (Figure 42). The space will store different tree species throughout Canada in a specialized walk-in freezer and cryogenic storage tank. Coniferous tree species (pine and spruce) can be stored dry in -20 degrees Celsius freezers (Figure 43). Hardwood tree species like oak and maple are cryogenically frozen in liquid nitrogen tanks of -196 degrees Celsius (Figure 44). The cold temperature freezes the seeds to reduce moisture content and ensure a lowered metabolic activity that keeps the seeds viable over a long period. The “Canopy” will be the centre and safeguard location for tree diversity of reforestation for eastern Canadian forests. The “Canopy” will also work with the National Tree Seed Centre to maintain a dynamic living library of Canada’s genetic forest resources of 13,000 unique seed collections from over 200 tree and shrub species. Seed inventories are essential in forest risk management in the event of a cataclysmic loss of forest land caused by wildfires, eastern spruce budworms, or other widespread natural and man-made disturbances. To ensure resilient and productive tree species continue to evolve and adapt to environmental changes, this space for seed collection is vital for research, conservation, restoration, and reclamation efforts.


Figure 42: Basement Elevation of the Seed Vault

Figure 43: Coniferous Seed Storage Diagrams

Figure 44: Hardwood Seed Storage Diagrams
Nursery

Nursery helps replenish the lost or damaged forests in Quebec as part of reforestation, forest management, and forest conservation. This cultivation spaces will help transform the surrounding forest within the existing timber mill to be more biodiverse in order to maintain a suitable carbon source within Quebec’s forestry industry. The nursery is divided into an outdoor sapling growing farm and an indoor greenhouse.

Similar to the CSFS Nursery, this outdoor field is for bare-root seedlings (Figure 45). Two types of seedlings will be developed: coniferous (i.e., fir, pine, and spruce) and deciduous (i.e., tamarack, maple, birch, and poplar) types are planted in the prepared seedbed. For these seedlings to grow successfully outdoors, it requires proper irrigation, sandy soil, and fertilization for two to three years of their growing cycle. This method is the better option since it can be applied to various tree species, protect the young saplings from heavy frost, and is better suited to reforest a site surrounded by existing, competing mature trees. Once the seedlings are harvested, the stock is kept in the walk-in coolers on the ground floor until it is ready to be replanted in the timber mill forest or to be shipped to other sites in Quebec.

The greenhouse is split into two farming productions: seed collection processing and container seedling growth (Figures 48 and 49). The collection process harvests seeds from individual trees in the nearby parks surrounding an old growth forest. Most tree species do not flower or produce viable seeds every year, so forecasting and cut testing is done each field season to determine
which species should be prioritized.\textsuperscript{47} Seed collection is a key part of maintaining Canada’s biodiversity and seed genetics. Once the seeds are harvested, they will go to the seed vault for long-term storage or go into a seedling growing process where the seeds are cleaned from leftover leaves or needles, or extracted from the cones or outer husks. The seeds will then proceed into testing to determine the amount of moisture content, weight, water activity, excised embryo and tetrazolium.\textsuperscript{48} The excised embryo is a method where the seeds are soaked for 1 to 4 days and the embryos are then excised from the seeds and placed on moist filter paper or blotter discs in petri dishes.\textsuperscript{49} Tetrazolium is a method in evaluating of seed viability to germinate, any extent damages, seed vigor or any other seed problems.\textsuperscript{50} Cleaning and testing the viability of a seed is part of the germination process in preparing the seeds in container plugs for sprouting, hopefully, enabling the seed to turn into a seedling (Figure 46). “Canopy’s” nursery will open up a new network in providing seed conservation and restoration for more genetic diversity and preservation in Quebec’s forests.


\textsuperscript{50} “Tetrazolium Testing,” CD Lifeasible (Lifeasible, 2022), https://www.lifeasible.com/custom-solutions/plant/analytical-services/seed-testing-services/tetrazolium-testing/#:--:text=Tetrazolium%20(TZ)%20testing%20is%20a,or%20other%20seed%20lot%20problems.
Figure 45: Hardwood Bare-Root Seedling Diagrams

Figure 46: Coniferous Container Seedling Diagrams

Figure 47: Ground Floor Elevation of Indoor Greenhouse Nursery
Figure 48: Interior View of the Nursery

Figure 49: Interior View of the Nursery
**Discovery Center**

The discovery center is open to the public and will be a community gathering place in Chibougamau for forest education. This communal space showcase information and research on forest pests, forest ecosystem dynamics, forest productivity, and ecogenomics (Figure 50). Ecogenomics is the studies the structure and functioning of a genome to understanding the relationship between the organism and its biotic and abiotic environments.\(^{51}\) This space will display information and specimens of the current state of Quebec's forests and showcase how forest is affected by climate change especially with insect infestation as a major stressor to Quebec’s forests explained Chapter 3.

The first exhibit, the "Forest Ecosystem Dynamics" will display information and data on the effects and history of forest fires, the essential role trees play in forest biodiversity, and carbon cycling. The second exhibit, "Forest Productivity" will showcase information on sustainable forest management on tree harvesting, cultivation, and replanting. As part of this exhibition, the discovery centre meeting room will be the space that provides forest management education to the residents of Chibougamau and workers of the existing timber mill. Lastly, the "Ecogenomics Exhibit" will showcase the researchers' work and data on the genetic makeup of forest pests, genetic diversity in commercially-produced tree species, and the impacts of global market demands on timber. The goal of the discovery center is to invite people

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and researchers to participate in preserving a healthier forest ecosystem for the future in Canada.

Figure 50: 2nd Floor Elevation of the Discovery Center

Research Center and Laboratory
The research center and laboratory will focus its studies and research on Quebec’s Forest and seed management (Figure 51). It will have laboratories, freezers, coolers, a self-isolated and climatized greenhouse, and a dark growing room for research on seed and tree genetics, forest pests, and forest forensics. The research on seed and tree genetics will explore trials on seed testing to discover limitations and improvements for tree growth, research in genetic variety adapting to resistance to diseases, improving seed technology and longevity, and tree genetic hybridization. “Canopy” provides ample space for research: on forest pests and diseases affecting specific tree species, analyzing resistance levels caused by pests and environmental stress, isolating native or exotic pests to minimize deforesting, and engineering tree species to better adapt to climate change. A forest forensics lab is to investigate crimes and test on how human, climatic, and geologic actions affect Quebec’s forest. “Canopy’s” research laboratory will work with ecologists, scientists, biologists,
and environmentalists in making advancements for better forest health and improving tree diversity in a controlled environment to analyze data and testing.

Figure 51: 3rd, 4th & 5th Floor Elevation of the Research Greenhouse & Laboratory
Chapter 7:

Conclusion

In Canada's timber industry, the monoculture tree plantations are deteriorating the health of old-growth forests. An action plan is required as the harmful effects of climate change (i.e., extreme weather, fires, and insect infestations) are also degrading these forests. These environmental effects are eliminating trees at a rapid rate and have changed the health of forest ecosystems. An old-growth forest has a strong ability to absorb carbon from the atmosphere, which reduces the emission of GHGs. In the long term, forests are better at storing carbon, which helps reduces the effects of climate change.

Timber industries require large hectares of forest to process lumber and with the harvesting of trees causing disturbances to the forest floor, more carbon is being released into the atmosphere. The rise of mass timber construction is increasing the demand for lumber, resulting in the timber industry harvesting even more trees. Old-growth forests are slowly being deforested in favour of tree plantations where the production of the same tree species converts these forests into a green desert. The lack of biodiversity from such a monoculture tree plantation hinders the forest's ability to self-regulate and self-sustain its carbon storage.

"Canopy" is a facility aiding in conserving, reforesting, and restoring forest biodiversity by changing how Chibougamau's existing timber mill operates with
its tree plantations. As a long-term goal, it will replenish the harvested area with more diverse tree species and help promote a healthier forest ecosystem to combat climate change. In order to reduce carbon emissions, "Canopy" is self-sufficient, generating its electricity through solar panels, providing its water source by collecting rainwater, and generating its cooling and heating system through geothermal energy.

The design is inspired by the tree's natural ability to spread its leaf canopy toward the sun and spread its root system underground. "Canopy" mimics the form and function of a tree; it will embrace the life and death cycle. Like the "Mother Tree", it acts as the centralized hub supporting, connecting, and communicating with the neighbouring trees. At the end of its life cycle, the next largest tree will take its place to support the next generation. The future of "Canopy" will embrace the "Mother Tree" concept, creating a community that connects to the neighbouring city to facilitate biodiversity in Quebec's Forest and combat climate change.

Figure 52: Exterior Back View of “Canopy”
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