Trees, Walls, *and Home*

[Designing Wooden Walls for Ontario]

by

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A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Master in Architecture
in
Master in Architectural Studies [MAS]

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Abstract: This thesis is about designing, through drawing and fabricating, a High-Performance Wooden Wall for Ontario. To achieve this goal, the thesis is grounded in the following premises.

A) **The correlation between location and material.** The Forest Regions have engineered the different tree genus by enduring each tree under a specific location and climate. This natural technology has been distributed accordingly throughout Canada.

B) **The use of naturally engineered materials.** In Canadian weather, when the winter is cold, and the interior of the building is warm, the difference in temperature produces higher pressure in the envelope, forcing air through the wall and stimulating its cleansing. This tissue-like condition of the fiber is ideal for air-tight building envelopes and the main reason to use wood in this form.

C) **The efficiency of form.** The waste and stability of the material can be optimized by reconsidering the way trees are cut and turned into pieces. This thesis proposes the trapezoid as a primary part to assemble panels.

This thesis will argue that science should be behind the decision while making a wall and that a high-performance wall should be treated as an artifact.

Themes: Canada's Forest Regions and trees distribution, Mass timber building envelopes, Drawing and prototyping

Content by chapter

Part One - Previous Studies The use of wood for high-performance construction has gained significant acceptance over the last decades. Surprisingly, Canada has remained passive and has given considerably less attention to the case. The content of this chapter is dedicated to research how is wood being used in high R-value walls in North America and Canada and explores the 39 certified Passive House cases in Canada. Similarly, this chapter explores innovative cases around the globe to compare how others have experienced and used this material.

Part Two - Location and Material Canadian nature has produced nine different Forest Regions. Each Forest Region consists of different tree genus, grouped and distributed in different proportions. From a material point of view, each forest region represents the "material palette" to each location and can be mapped out to assemble a suitable wall. This Chapter records this investigation and concludes by listing the materials to be used as a wall assembly for Ontario.

Part Three - Material and Form The tissue-like condition of the wood fiber is a quality of the cellular structure of the wood. From a cellular perspective, wood behaves in relation to multiple stimuli recorded scientifically as the hygrothermal properties of wood. This chapter enters into this scientific field by studying these properties and proposing conceptual applications to be incorporated in the design.

Part Four - Form and Process This chapter is divided in three parts including part, panel, and wall. Each piece advances through drawing and making the design of a High-performance Wooden Wall for Ontario by incorporating the knowledge gained in the previous chapters.

Acknowledgements

To my mother Mariella and father, Victor.

I would like to extend my gratitude to my professors and colleges, whose comments and direction have enriched and inspired this thesis.

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Introduction: On designing a wooden wall.

What is a wall and why is this thesis committed to the design of high-performance wooden walls? Philosophically, this thesis explores the design of a wall in parallel to a shift in the perception of material; from the **hylomorphic model**, to a **model of correspondence**. In the case of the hylomorphic, hylo (mater) and morphic (form) are fundamentally driven by human perception, where humanity infuses objects with "human form". In the model of correspondence, humanity participates in the on-going transformation between the material and the material world.

In designing a wall, both models become visible as the investigation requests to analyze what things are and how humanity relate to them in order to produce an object. Following these quests, Aristotle developed a system to confront "everything from human production and human action," [1] named the *casual investigations.* Aristotle's remarkable success emerged from the influence of the "categories" where "things" are decomposed into multiple yet related groups. This way, in casting a bronze statue, **the material cause** is "that out of which," e.g., the bronze of a statue is made. **The formal cause** is "the form," "the account of what-it-is-to-be," e.g., the shape of a statue. **The efficient cause is** "the primary source of the change or rest," e.g., the artisan, the art of bronze-casting the statue, the man who gives advice, the father of the child. And **the final cause** is "the end, that for the sake of which a thing is done," e.g., health is the end of walking, losing weight, purging, drugs, and surgical tools. [2] The influence of Aristotle's work resulted in the predominant vision of this world ready for the production of "human-objects".

In the process of **correspondence**, Tim Ingold explains a different course. While flying a kite, the kite represents the qualities of the material, its lightness. The currents of wind, present yet not always equal, represents the dynamic conditions of this world, the environment. Humanity, represents as an entity that induces change, by shaping the material into an aerodynamic form, but not exclusively. A kite while naturally move by constant presence of wind, but it sustains high in the sky at the moment that humanity, kite and wind, correspond each other by moving constantly in agreed directions, resulting in object-action of flying a kite.

In making a wall, both models applied almost effortlessly by including the "cause" **location**. The consecutive questions of what is a wall? How does it sustain itself? How is it going to be made? What form will it have and even is a wall really needed? Are then extended to the field of performance? How does a wall, in the constant presence of human and environmental action, behaves?

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[1] Aristotle. 2015. *Stanford Encyclopedia of Philosophy* . Andrea Falcon. Accessed Feb 5, 2018. https://plato.stanford.edu/entries/aristotle-causality/#FouCau.

[2] Ibid.

Thus location expands Aristotle’s conceptualization by including the environment, objects are transformed by the hands of the maker, who recognizes himself not as the author, but as participant agent in the on-going changes of this world. For Tim Ingold, this relation is explained in the difference between **interaction** and **correspondence**. For Ingold, in **interaction,** form is produced **“**between brains, bodies, and objects in the world,”[3] emerging from the hylomorphic model, while in **correspondence,** participants follow material-flow through sensory awareness. [4] In correspondence, the role of the maker is “to bringing forth of potentials immanent in a world in perpetual change.” [5] This thesis will argue that in making a wall, interaction and correspondence are complementary but performance is an act of correspondence.

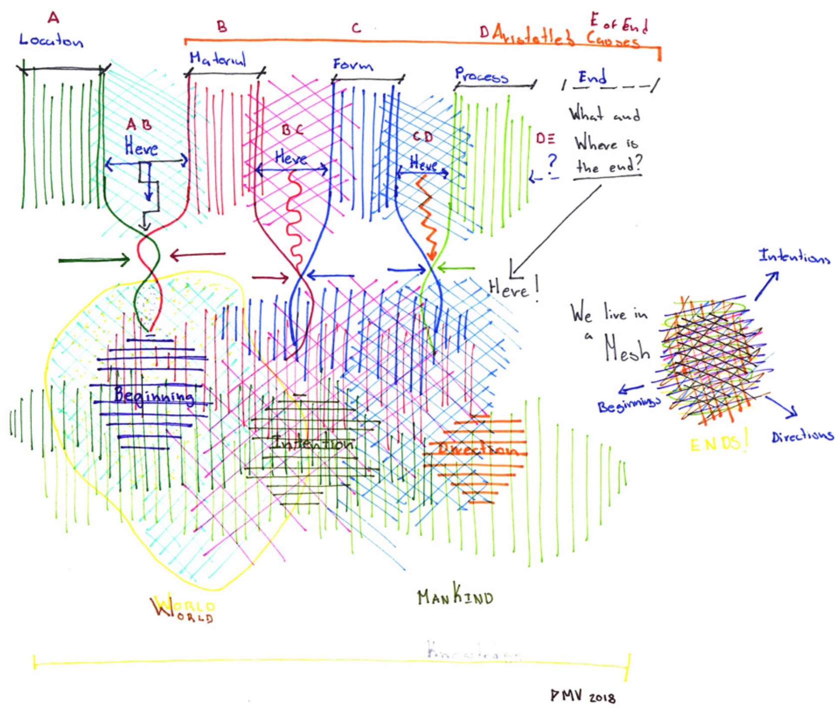

Fig [1] – **Correspondence/mess knowledge** (2018)
Structure of the thesis. By Pablo Medina Villanueva

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[3] Ingold , Tim . 2013. *Making, Anthropology, Archeology, Art and Architecture.* New York: Taylor and Francis Group. Pg. 98
[4] Ibid.
[5] Ibid. Pg. 31

The ways of the Craftsman and the path of the Scientist.

"Far from standing aloof, imposing his designs on a world that is ready and waiting to receive them, the most he can do is to intervene in worldly processes that are already going on, and which give rise to the forms of the living world that we see all around us." [6]

How is material understood then? Ingold explains that while in interaction, material follows the tradition of the *chemis*t as "it desires to know **what material is**", in correspondence, material follows the desire of *craftsmen* "as it desires to know **what it does"**. In wood products, the chemist manifest by exploring the material by decomposing it into to the minimal particles and recombining it into multiple combinations. The craftsmen manifest by following material behavior and assembling pieces into an integral form.

The chemist tradition is evident through the emergence of *engineered wood*; into the intention to make something out of the amalgamation re-combination of wood dust. Fiberboard (FB), oriented strand board (OSB), and particleboard (PB) are all different combinations of wood, dust and glued, recombined as panels. The craftsman, while using material for what it does, remains assembling timber. It is curious that in general, timber remained in buildings, as softwood hidden in walls, used to build frames. However, are light wood frames a fair representation of what wood does?

To look at this in detail, in addition to the ways of the craftsman, I suggest the ways of the scientist. In the case of the scientist, desire rests within the understanding material behavior. It relies upon his fascination by looking up-close to the origin and form of the cellular structure, and from far, to the forest regions as an integrated ecosystem. As an additional example, a geneticist argues that "fiber modify their cellular structure by enduring the winds and other natural conditions surround it." [7] In the act of correspondence, the material holds in its fibers the physical memory of its site. In conclusion, this thesis will argue that high-performance walls should be treated as artifacts and scientific objects of this world.

[6] Ingold , Tim . 2013. *Making, Anthropology, Archeology, Art and Architecture.* New York: Taylor and Francis Group. Pg. 21
[7] In a conversation with Charles Nasmith, Educator, Scientist and Biotechnologist. Field and Molecular Plant Pathologist.

Part One

Previous Studies

“Materials do ***not exist***, in the manner of objects, as static entities with diagnostic attributes; they are not ‘little bits of nature’, awaiting the mark of an external force like culture or history for their completion. Rather, as substances-in-becoming they carry on or perdure, forever overtaking the formal destinations that, at one time or another, have been assigned to them, and undergoing continual modulation as they do so. Whatever the objective forms in which they ‘***already an ongoing historicity***” [8]

Karen Barad

[8] Ingold , Tim . 2013. *Making, Anthropology, Archeology, Art and Architecture.* New York: Taylor and Francis Group. Pg. 31 As stated by Karen Barad (2003)

2.1 **Simulations** – High R-value walls for North America

In June of 2010, Jonathan Smegal and John Straube published a research report titled "*High-R Walls for the Pacific Northwest – A Hygrothermal Analysis of Various Exterior Wall Systems*" for the Canadian ***Building Science Corporations*** (BSC). This report considers a number of "promising wall systems that can meet the requirement for better thermal control." [9] What appoints this research as different according to the authors is that "unlike previous studies, this one considers performance in a more realistic matter, including some two and three-dimensional heat flow and analysis of the relative risk of moisture damage." [10]

Smegol and Straube study was based on the premises that in some cases, "adding more insulation may result in an increased risk of moisture related issues when the exterior surface of the enclosure is kept colder in cold weather, and the interior surfaces are kept cooler in warms weather." [11] This difference of temperature and the impossibility to circulate "through" the wall resulted in increased condensation. The "increased freeze-thaw potential or decay potential of the assembly in different situations." [12] Increasing the R-Value of a wall by increasing the amount of insulation and the consequent thickness of the wall may result in better insulations but, most times, are not the answer for long-term performance. On the other hand, the development of highly impermeable materials and membranes is not exempt from the same issue.

The report by Straube and Smegal analyses seventeen high R-value walls (listed below) from the Pacific Northwest but not exclusively, providing in-debt evaluations and notes of each type. The criteria of analysis included a comparison matrix used to compare different wall systems adding value between 1 (poor performance) and 5 (excellent performance) assigned after each review of the categories that are thermal control, durability (wetting/drying), constructability, cost and material use.

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[9] *Smegal's, Jonathan, and John Straube. 2010. High-R Walls for the Pacific Northwest - A Hygrothermal Analysis of various wall Systems. Research Report, Portlant: Building Science Coorporation. Pg. 1*

[10] *Ibid.*

[11] *Ibid.*

[12] *Ibid.*

High-R Walls for the Pacific Northwest - Hygrothermal Analysis of various wall Systems.
Research Report, Portlant: Building Science Coorporation. Source: Smegal's, Jonathan, and John Straube. 2010.

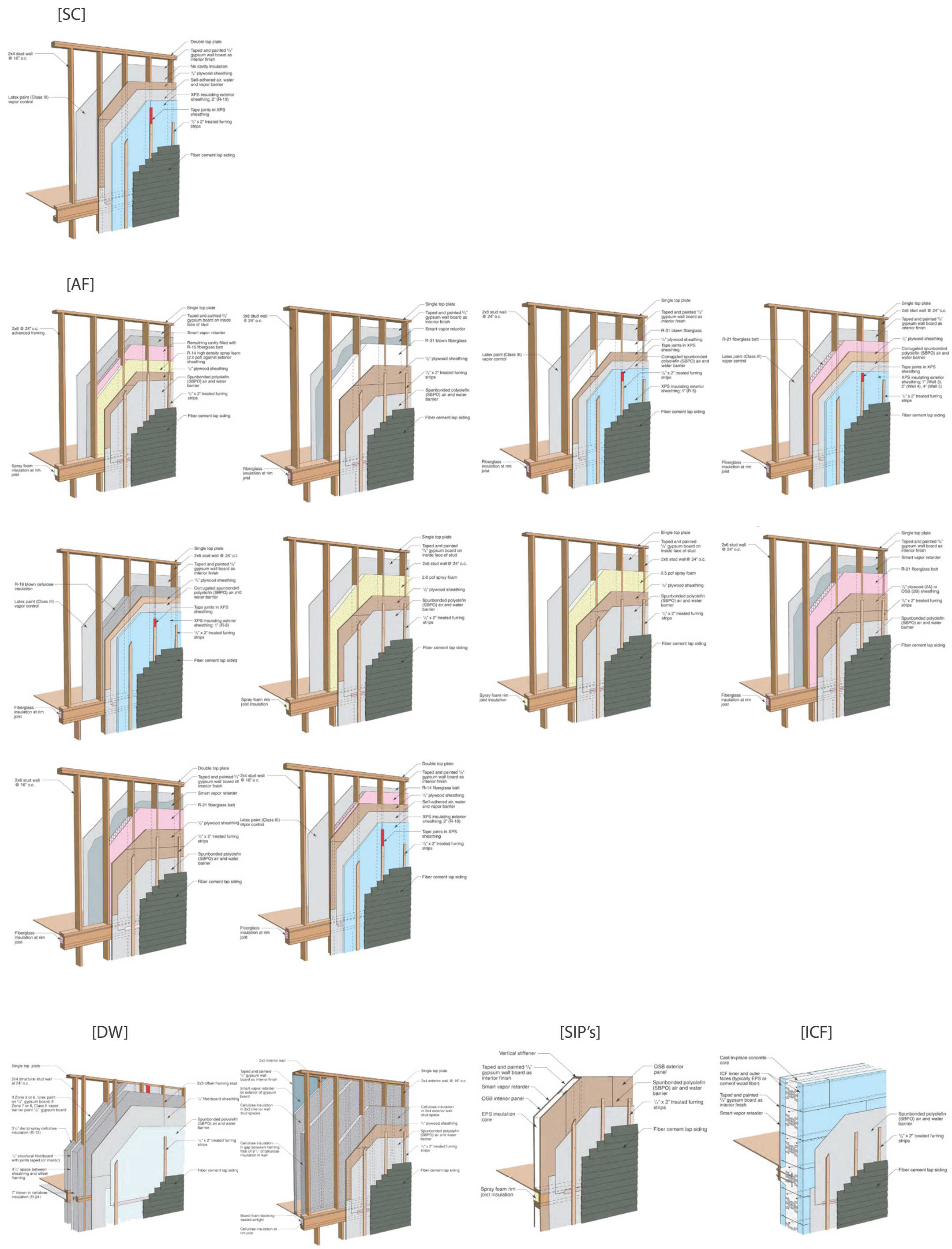


Fig [2] - **High Performance Assembles simulated by Smeagal and Straube** (2010)
Source: *Abstracted from High-R Walls for the Pacific Northwest - A Hygrothermal Analysis of various wall Systems. Research Report, Portlant: Building Science Coorporation. Edit by Pablo Medina Villanueva (2018)*

According to the Oak Ridge National Labs (ORNL), there are five approaches to estimate the R-value gradually more precise including: *"Installed Insulation R-value:* Commonly refereed in building codes and used by industry. This is simply the R-value labeled on the product installed in the assembly. *Center of Cavity R-value*: The R-value at the line through an assembly that contains the most insulation, and the least framing, typically, the middle of a stud-bay in framed construction. *Clear wall R-value:* R-value of an assembly containing only insulation and minimum necessary framing materials at a precise section with no windows, corners, columns, architectural details, or interfaces with roofs, foundations or other walls. *Whole-wall R value*: R value for the whole opaque assembly including all additional structural elements (such as double studs), and typical enclosure interface details, including wall/wall (corners), wall/roof and wall/floor connections. *True R Value:* "The R-value of an enclosure assembly that includes all thermal bridging, air leakage, wind washing, convective loops, radiation enhancements, thermal and hydric mass, and installations defects." [13]

To produce more significant comparisons, the authors consider a more complex analysis, yet simulated, the approach of *Whole-wall R-value* using THERM 5.2, a two-dimensional steady-state finite software developed by Berkeley National Laboratory at the University of California, capable of including the effect of thermal bridging and different framing details (Tab 1).

Building Science Corporation

by Smegal's, Jonathan, and John Straube.

Portlant Oregon - 2010

High-R Walls for the Pacific Northwest - A Hygrothermal Analysis of various wall Systems

Wall	Wall Type	Wall comparison matrix: Thermal Control	Durability (wetting/drying)	Constructability	Cost	Material use	Total	Installed Insulation R-value	Framing Factor %	Whole Insulation R-value	$	Hours of Potential Condensation [in 1 yr.]
1	Standard construction [SC] with 2x6	2	3	5	5	4	47	**21**	25	16.2	$ 6.79	2851
2	Advanced framing [AF]	2	3	5	5	5	48	**21**	19	17.2	$ 6.67	2851
2b	[AF] with OSB sheathing										$ 6.57	2903
3	[AF] with 1" of exterior XPS insulation	3	4	4	4	4	49	**26**	19	22.2	$ 7.92	997
4	[AF] with 2" of exterior XPS insulation	4	4	3	3	4	47	**31**	19	27.2	$ 8.85	214
5	[AF] with 4" of exterior XPS insulation	5	5	2	2	3	48	**41**	19	37.3	$ 11.68	0
6	[AF] with 1" of exterior XPS insulation and blown cellulose in the stud cavity	3	4	4	3	5	47	**24**	19	21.9	$ 8.83	730
7	[AF] with 2x8 construction	3	3	5	3	3	47	**31**	19	22.2	$ 7.98	3019
8	[AF] with 2x8 construction and 1" of exterior XPS insulation	4	3	4	3	3	44	**36**	19	27.2	$ 9.23	1496
9	[SC] with 2x4 framing, 2" of exterior XPS insulation and no insulation in the stud cavity	1	4	3	3	4	38	**10**	19	12.6	$ 9.82	0
10	[SC] with 2x4 framing, 2" of exterior XPS insulation and fiberglass batt insulation in the stud cavity	3	4	3	1	4	38	**24**	19	21.5	$ 13.08	68
11	[AF] with 0.5 pcf stray foam	2	4	4	4	3	45	**23**	25	16.3	$ 8.43	0
12	[AF] with 2.0 pcf stray foam	2	4	3	2	3	37	**35**	25	19	$ 11.43	0
13	Hybrid wall [HW] with 2.0 pcf spray foam and fiberglass batt (flash and batt)	2	4	4	3	3	42	**28**	19	18.5	$ 8.60	56
14	Double Stud [DW] wall with an exterior structural wall	4	2	3	2	2	34	**34**	19	29.9	$ 11.47	3015
15	[DW] with an interior structural wall	4	2	2	2	2	32	**34**	19	30.3	$ 11.81	2924
16	Structural Insulated Panels [SIP's]	3	5	3	2	3	44	**24**	0	21.5	$ 10.61	0
17	Insulated concrete forms [ICF]	2	5	3	1	3	38	**16**	0	16.4	$ 19.31	0

Tab [1] - **Comparison of Seventeen High R-Value Walls** (2010)

Source: Abstracted from "High-R Walls for the Pacific Northwest – A Hygrothermal Analysis of Various Exterior Wall Systems" by Jonathan Smegal and John Straube. Research Report, Canadian Building Science Corporation Press, (2010)

[13] *Smegal's, Jonathan, and John Straube. 2010. High-R Walls for the Pacific Northwest - A Hygrothermal Analysis of various wall Systems. Research Report, Portlant: Building Science Coorporation. Pg. 1*

As often happens in simulations, the overall result of this research is compromised for two main reasons. First, the qualification used to validate one system over another considers similar numerical weights for distinctive categories. For example, its initial cost more critical than durability? Second, the groups are not studied or explained in depth. For instance, what parameters were used to determine constructability? Is constructability considering the potential of Numerically Controlled prefabrication? A simple method of observation and experience could challenge the overall results that according to Strube and Smeagol validate and legitimizes the conventional construction (ST) over other more complex systems like Double stud wall (DS) or advanced framing (AF). But still, the author's comments on the subject of the potential condensation, durability, and thermal control offer a rich and satisfying comparison.

The richness of Smegol's and Straube's research is the comparison of the most common and recognized High R-value walls used in North America. Seventeen cases were simulated as multilayers systems, providing solutions one by one, to the different problems that compromise the integrity of a wall. From thermal control, water and vapor barrier, wind, and structure, all the seventeen studies deal with these problems layer by layer. In previous studies, Straube suggested that the multiple layer system is in itself part of the problem. The connection between one layer and another, are rarely appropriately integrated and vapor and moisture build up in this cavities deteriorating the material surface. Reducing the number of layers is an ideal form to mitigate this problem, but how many would be needed? Straube advises that as an overall, only two layers are required, the structure and the control layers. [14] This research concludes that the mechanical properties (structure) and the hygrothermal properties (control layers) are both related to the material, and the study of high-performance enclosures is in itself the study and use of high-performance materials.

[14] Straube, John. 2012. *High Performance Enclosures.* Building Science Press. Pg. 21

2.2 **In Practice** - *Passive House* buildings in Canada

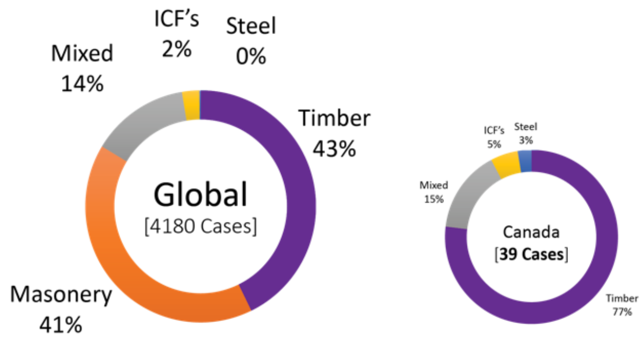


Fig [3] - **Construction typology comparison for PH in Canada and abroad** (2017)
Source: Abstracted from *Passive House Database. Passive House Database. October 16. Accessed October 16, 2017*

Regarding research made ***in practice*** in Canada, the private sector and the *Passive House (PH) community* has accomplished significant success. The Passive House Standard stands for quality, comfort and energy efficiency. "Passive Houses require very little energy to achieve a comfortable temperature year round making conventional heating and air conditioning systems obsolete. While delivering superior levels of comfort, the Passive House Standard also protects the building structure." [15] The *Passive House Institute* has generated a criteria that the building has to meet before and after construction to be certified including: "*Space Heating Demand:* Not to exceed 15kWh annually OR 10W (peak demand) per square meter of usable living space. *Space Cooling Demand:* Roughly matches the heat demand with an additional, climate-dependent allowance for dehumidification. *Primary Energy Demand:* Not to exceed 120kWh annually for all domestic applications (heating, cooling, hot water and domestic electricity) per square meter of usable living space. *Airtightness:* Maximum of 0.6 air changes per hour at 50 Pascal's pressure (as verified with an onsite pressure test in both pressurized and depressurized states). *Thermal Comfort:* Thermal comfort must be met for all living areas year-round with not more than 10% of the hours in any given year over 25°C." [16] According to the *Passive House (PH) Database*, ***only 39 of the 4180 certified PHs in the world are in Canada*** (as of September 2017). [17] From to this record, 74 % of these buildings are timber construction, while the rest uses timber as a complement to a mixed construction system. On a global scale, this scenario is somewhat not that different with 43% being of wood and 41% of masonry.

[15] *Passivhaus Dienstleistung GmbH, the Passive House Institute. 2017. Passive House Database. October 16. Accessed October 16, 2017. https://passivhausprojekte.de/index.php?lang=en.*
[16] *Passive House Institute . 2016. Criteria for the Passive House, EnerPHit and PHI low energy building standard. Darmstadt, Aug 15. Pg 5*
[17] Passivhaus Dienstleistung GmbH, the Passive House Institute. 2017. *Passive House Database.* October 16. Accessed October 16, 2017. https://passivhausprojekte.de/index.php?lang=en.

From the research "in practice" of these 39 cases, we can abstract much valuable information. The first and most important is that regarding PH, in Canada there has not been much "practice." In total Canada, the second largest land extension under the northern climate, and only the .08 % of the total PH in the world. This result is significant since PH has been recognized as the leading high-performance certification in the world, and countries with a significantly warmer climate like Spain and Italy double Canada with their percentage.

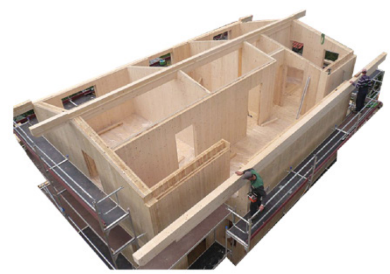
The second most visible statement is that in Canada, like in the rest of the world, the most reliable construction typology for PH is timber. Why is timber such an important material and how is wood being used? From the previous report "Hygrothermal Analysis of Various Exterior Wall Systems" by Straube and Sméagol, we can conclude that in North America, wood is being used to build frames. This result is not surprising at all, but is the rest of the world using it the same way? If we look at Germany, founder and leader in PH movement we can notice that wood is used as mass timber construction. In Canada and the world, the principal argument against the use of timber in this way is the availability of these resources (wood), and that wood is delicate to the exposure of water and moisture. The first argument can be discredited easily since Canada's richness and abundance of wood can be seen all across the country where human and industry has not even have access yet. The second argument against wood, as Dr. Bruce Hoadley states, relies on his statement that "90% of all problems with wood involve moisture is a conservative estimate." [18] However, in the case of PH buildings, Dr. Hoadley's suggestion is not wrong but imprecise. Wood, if protected, is not a problem at all. The success in Germans designs is in understanding the principle of keeping the wood dry.

The hygrothermal properties (HP) introduced by Straube and Smegal's are inherent in any material and include the thermal conductivity, specific heat capacity, and water vapor resistance factor. In other words, these properties represent the material behavior towards heat and moisture, the most significant challenge in the use of wood for buildings. If climate's temperature and humidity are inherent and dynamic in every case, this means that every site is dealing with this condition in one way or another.

[18] *Hoadley, R. Bruce. 2000. Understanding Wood, A craftman's guide to wood technology . Newtown : The Taunton Press, Inc. pg. 111*

2.3 **Global search** – Research on prefabricated wood structures

Process	Geometry	Material
Can we build a house using only one tool?	What is the mos efficient form ?	If you were to choose one material what would it be?



WikiHouse

MetsäWood

Thoma

Fig [4] – **Wood use for high-performance construction**, study cases
Left - **Wikihouse by** Alastair Parvin and Nick Lerodiaconou
Middle - **SI Modular** by Hans-Ludwing Stell
Right – **Holz100** by Erwin Thoma

To expand my sight, I started a global research of systems with the common goal of using wood for High-performance envelopes. Through this effort I discovered the British architects Alastair Parvin and Nick Lerodiaconou and their work known as the ***Wikihouse.*** The wikihouse's main characteristic are the simplification of process (CNC) and material (18 mm plywood), to prefabricate entire frames or box beams from puzzle-like pieces to build entire buildings. [19] The second exploration lead me to the German architect Hans-Ludwing Stell and his system **SI Modular**. This system centers its efforts in the *geometric efficiency by prefabricating I-joint structures* to minimize the use of material "to under 40%." [20] SI Modular allows to assemble ***double stud wall*** systems that can be insulated after the assembly of the panels. The third exploration lead to the Austrian engineer Erwin Thoma, who methodically explores the use and performance of wood as a single *material* to prefabricate high performance wooden envelopes known as **Holz 100**.[21]

[19] Alastir Parvi, Nick Lerodiaconou. 2009. *WikiHouse Foundation.* Accessed 2017. https://wikihouse.cc/.
[20] Stell, Hans-Ludwing. 2011. STELLINNOVATION GmbH. Accessed 2017. http://www.si-modular.net/.
[21] Thoma, Erwin. 2015. *A future with natural wood, traditional and scientific facts about trees.* Translated by Iris Detenhoff. Mullumbimby: Moontime Diary

This three study cases have demonstrated suitable for PH standards but differ among each other on their focus of their research. While the Wikihouse searches for **process**, SI Modular aims for **geometry** and Holz100 goes in-depth with **material**.

Can a system be adapted to **any site?** Holz100 would argue that each house is different and they have to be made one by one and shipped only until certain distance. This difference speaks of the relation of the material to the site but also to the relation of the end cause and the location. If we looked back at the times of the craftsman centuries ago, selecting a location was always the first act to settle a home. This leads me to believe that building a house is in a certain way, a response to the site to allow humanity to settle. It seems clear that today, construction systems and sites are disassociated as they can be used and adapt to make homes virtually "anywhere." Is it true? Can we adapt building frames to partially any site? Or is it that the places have been transformed so much that we do not need to respond to them anymore? Is innovation in responding to the site or in avoiding it?

2.4 Wood Industry – Condition and use of the resource

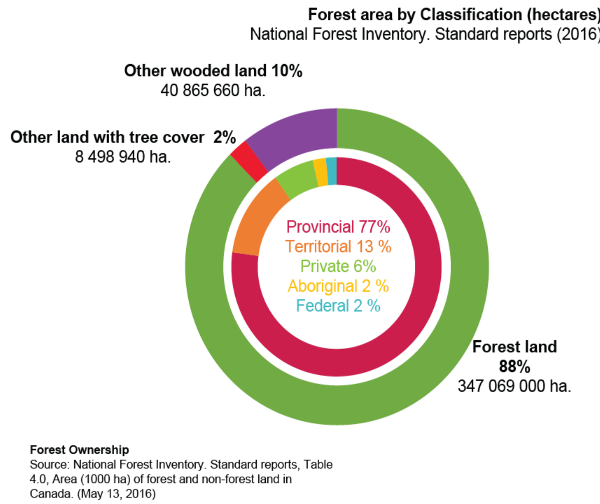


Fig [5]- **Forest classification and ownership** (2016)
Source: Abstracted from *National Forest Inventory St*andar reports

According to *Natural Resources Canada* and the *National Forest Inventory* the wood industry had annual revenue of over $60 Billion (CAD) reported in 2014, (divided into pulp and paper products, wood fabricated materials and primary wood products). United States is Canada's principal client with a continuously increasing trade of $22 Billion (CAD) per year followed by China, Japan, and European Union. But how much forest is there to trade and who owns it? According to the *National Forest Database* (NFD), the forest is divided into three types of land including the **Forest land** "land spanning more than 0.5 hectares where the tree canopy covers more than 10% of the total land area, and the trees can grow to a height of more than 5 meters. It does not include land that is predominantly urban or used for agricultural purposes." [22] **Other lands with tree cover** include "areas of land where tree canopies cover more than 10% of the total area and the trees, when mature, can grow to a height of at least 5 meters. Includes treed areas on farms, in parks and gardens, and around buildings." [23] **And other wooded lands** "including areas of land where: 1) tree canopies cover 5%–10% of the total area and the trees, when mature, can grow to a height above 5 meters; or 2) shrubs, bushes, and trees together cover more than 10% of the area. These areas include treed wetlands (swamps) and land with slow-growing and scattered trees." [24] The NFD reported in 2016 an inventory area of 166 million ha. Certified and potentially designated land for future harvesting, [25] this represents 47% of the total Forest Land in the country.

[22] Inventory, Canada's National Forest. 2013. *Stadistical summaries for Canada.* 12. Accessed 12 2017. https://nfi.nfis.org/en/standardreports.
[23] Ibid.
[24] Ibid.
[25] Canada, Stadistics. 2015. *Merchandise trade data (special extraction), monthly data.* Trade sources and information, Ottawa: Natural Resources Canada .

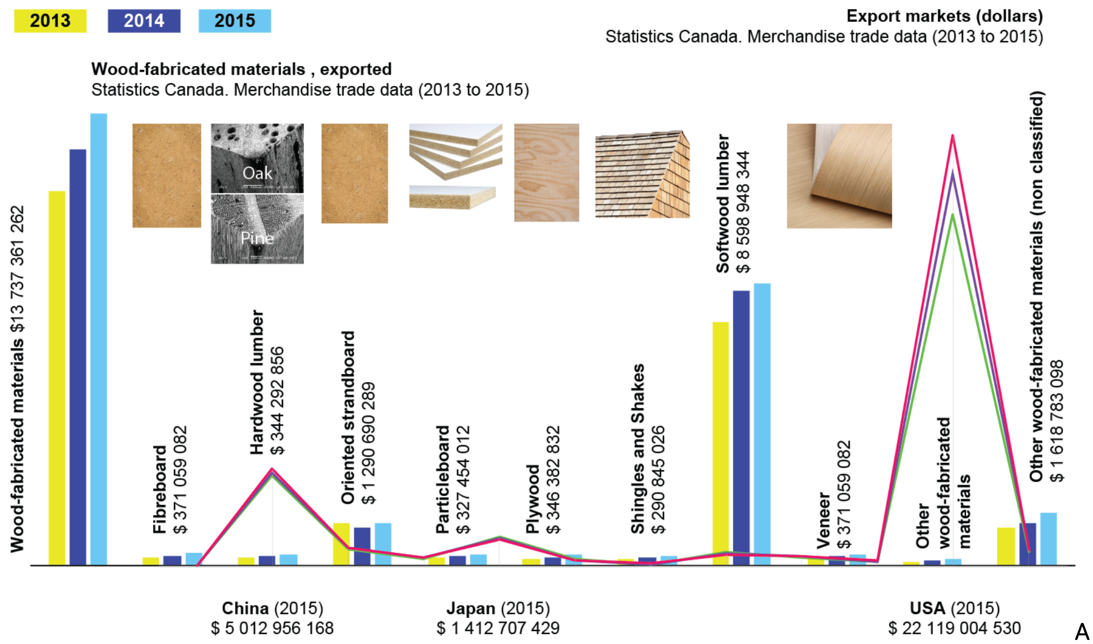


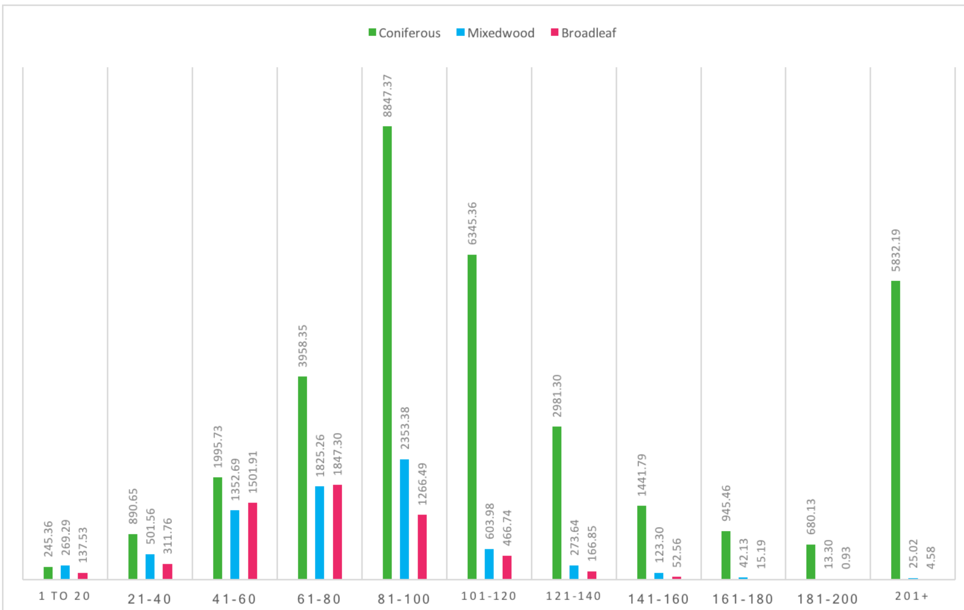
Fig [6] – **Canada's Merchandise trade** (2013 to 2015)
Source: Abstracted from Statistics Canada (2013-2015). Merchandise trade data (special extraction), monthly data.
Edit by: Pablo Medina Villanueva (2018)

The *National Forest Inventory* (NFI) reported that the provincial territories owned 77% of the land (all types), 13% was territorial, 6% was private, 2 % aboriginal and 2 % federal. [26] The forest ownership reported by the NFI makes clear the Providences lead the direction and intention of the land and their sources. Canada forest contain "about ***47 million cubic meters of wood.***" [27] The *Boreal Shield* ecozone contains almost one third of Canada's total wood volume, "with more than 15 million m3 of wood."[28] Statistics Canada through Merchandise Trade Data 2013 to 2015, reported a monthly trade of close to 8 million m3 of structural panels, 16.8 million tons of wood pulp and 62.9 millions m3 of soft lumber. [29]

Through the present statistics, we can picture many facts. Firstly, the land and its sources are mainly controlled by the provinces. Second, the overall market is divided into pulp and paper products and wood products. From wood products, there is a strong emphasis on the production of oriented strand board (OSB), plywood, particle board (PB) veneer and other wood fabricated materials. It would be easy to assume wood sub-products are mainly manufactured

[26] Inventory, Canada's National Forest. 2013. *Stadistical summaries for Canada.* 12. Accessed 12 2017. https://nfi.nfis.org/en/standardreports.
[27] Ibid.
[28] Ibid.
[29] Canada, Statistics. 2016. *Lumber production, shipments and stocks, by Canada and provinces.* Domestic production and consumption information, CANSIM table 303-0064: , Ottawa: Natural Resources Canada .

from the waste of the lumber as is being cut and processed. Third, softwood is Canada's primary wood resource with a production of 250 % more material than the domestic demand. [30] Wood, if well managed, is already the most sustainable construction material in the country. But how much wood is in Canada exactly, where is it and what type of species are in the land. If we pretend to use the material according to sustainable principles, we first need to understand the codependence of each terrestrial Ecozone, the forest types including coniferous, mixed wood and broadleaf and their age and location. Crossing this research, we can notice the abundance of softwood spread through the Boreal forest horizontally almost all across Canada.



A

Tab [2] - **Total tree volume (million m^3) on forest land by forest type, age class, and terrestrial ecozone in Canada** (2013)

Source: Abstracted from Canada's National Forest Inventory, revised 2006 baseline (Version 3, December 2013) (http://nfi.nfis.org)

During the *Paris Agreement*, it was agreed that the forest is one of our primary Carbone dioxide (CO2) mitigators, and we should under no circumstance forget this fact. But what does this mean exactly? It says that in every tree, the forest has the capacity on to store CO2. This capacity variates depending on the species, location but primordially on its size and volume linked to its age. Mature trees from around 60 to 100 years, have reached most of the capacity to store CO2, is perhaps this the "right time" to harvest? From this perspective, doesn't it makes sense to sequester C02 in buildings?

[30] Canada, Statistics. 2016. *Lumber production, shipments and stocks, by Canada and provinces.* Domestic production and consumption information, CANSIM table 303-0064: , Ottawa: Natural Resources Canada

Previously, Straube and Sméagol commented that in North America, high-performance enclosures are using wood to fabricate light softwood frames, the most combustible uses of wood in construction, while other countries with significantly less resources like Germany and Finland are using timber to build entire walls. In timber construction, durability should be a main concern. To build structures that last 100 years or as long as the trees life cycle does? The construction industry will argue that that wood is not used the same way for two reasons. First, the wood is too expensive and second since there is not enough machinery and knowledge to fabricate this way.

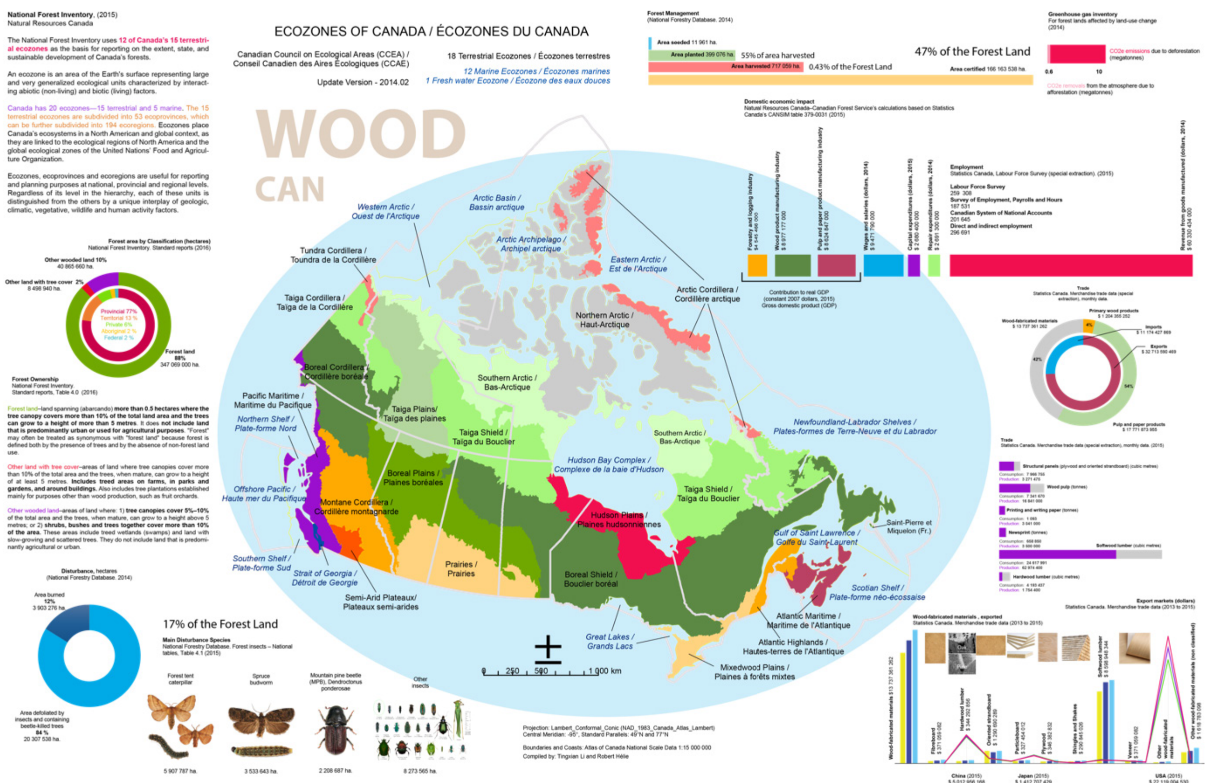


Fig [7] - **Overview of Canada's Wood Industry**

Original Sources:

- *A1 - Canadian Council on Ecological Areas* (CCEA) Feb 2014 -Lambert_Conformal_Conic (NAD_1983_Canada_Atlas_Lambert)

- A2 - Graphic information abstracted from Statistics Canada including:

- **Greenhouse gas inventory** - Environment and Climate Change Canada's National Inventory Report 1990–2014 uses Natural Resources Canada–Canadian Forest Service's National Forest Carbon Monitoring, Accounting and Report System data and analysis.
- **Domestic consumption** (Canada) - Consumption figures for a range of products, calculated by Natural Resources Canada. (2013, 2014, 2015)
- **Disturbance (Canada)** - National Forestry Database. Forest insects – National tables, Table 4.1, Area within which moderate to severe defoliation occurs including area of beetle-killed trees by insects and province/territory, 1975–2015. (June 29, 2016)
- **Domestic economic impact (Canada)-** Statistics Canada. CANSIM table 027-0009: Canada Mortgage and Housing Corporation, housing starts, under construction and completions, all areas. (March 16, 2016)
- **Forest industry employment (Canada**) - Statistics Canada. CANSIM table 281-0024: Survey of Employment, Payrolls and Hours (SEPH), employment by type of employee and detailed North American Industry Classification System (NAICS). (March
- **National Forest inventory -** National Forest Inventory. Standard reports, Table 4.0, Area (1000 ha) of forest and non-forest land in Canada. (May 13, 2016)
- **Domestic production and investment (Canada**) - Statistics Canada. CANSIM table 303-0064: Lumber production, shipments and stocks, by Canada and provinces. (March 7, 2016)
- **Forest management (Canada)** - National Forestry Database. Silviculture – National tables, Table 6.1, Silvicultural statistics by province/territory 1990–2015.
- **Trade (Canada)** - Source: Statistics Canada. Merchandise trade data (special extraction), monthly data.

Edit by: Pablo Medina Villanueva (2018)

Part Two

Location and Material

"I gleaned these insights from my experience of processing many thousands of threes, from the forest to the finished item. The formula is always the same: observe nature and act accordingly." [31]

Erwin Thoma

[31] Thoma, Erwin. 2015. *A future with natural wood, traditional and scientific facts about trees.* Translated by Iris Detenhoff. Mullumbimby: Moontime Diary Pg. 56

3.1 Canada's plant hardiness zones – **Growing trees by climate**

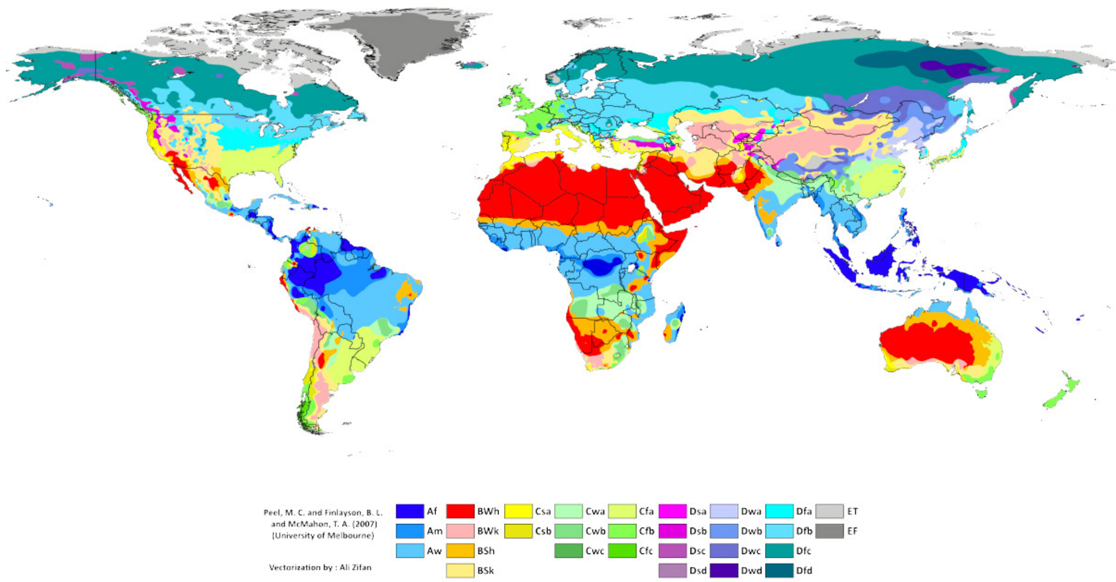


Fig [8] - **Köppen and Geiger Climate Classification** (2007)
Sources: Data by Climate classification revisited: from Köppen to Trewartha . Michal Belda*, Eva Holtanová, Tomáš Halenka, Jaroslava Kalvová - Charles University in Prague, Dept. of Meteorology and Environment Protection, 18200 Prague, Czech Republic. Map source: Peel, M.C. Finlayson, B.L. McMahon, T.A. (2007) – University of Melbourne

In the *Köppen and Geiger Climate Classification*, Canada is located between the Humid Continental, Subarctic and Tundra climates. Canadian climate remains an average five to six months below zero every year, and reaches "minimum temperatures of -30 and – 40 Celsius in more than half of the country." [32] In practical terms, and according to the ***ASHRAE 90.1-2010, Prescriptive Energy Code Requirements,*** "with the exception of British Columbia, Canada belongs to Climate Zones number 6, 7A/7B and 8, with a minimum R-value requirement of 19.6, 19.6 and 27.8 respectably." [33] These climate conditions are shared with countries like Finland, Norway, Sweden, and Germany where *High Performance Construction* has been widely adopted.

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[32] McKenney, D.W, Hutchinson, M.F., Kesteven,J.L. . 2010. "Plan Hardiness Zone Maps and Extreme Minimum Temperature Zones." Natural Resources Canada . Accessed 12 20, 2017. http://www.planthardiness.gc.ca/index.pl?m=1&lang=en

[33] Graham Finch, Mike Wilson, James Higgins. 2013. "Thermal Bridging of Masonry Veneer Claddings and Energy Code Compliance." RDH Building Science. 06 12. Accessed 12 20, 2017. https://www.slideshare.net/RDHBuildings/thermal-bridging-of-masonry-veneer-claddings-and-energy-code-compliance.

Canada's Plant Hardiness Zones and Extreme Minimum Temperature Zones (2014)

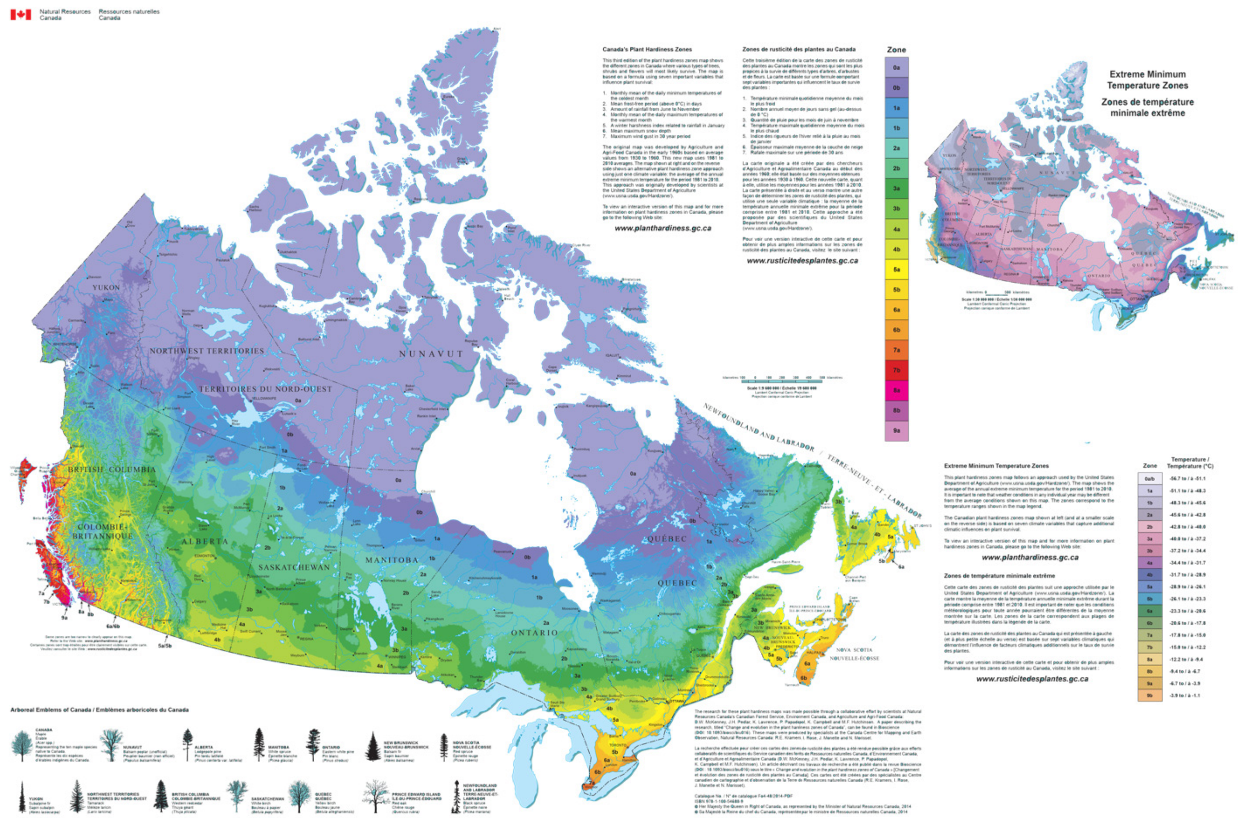

Fig [9] - Canada's Plant Hardiness Zones and Extreme Minimum Temperature Zones (2014)
Sources: Natural Resources Canada (2014): Collaborative effort by scientists at Natural Resources Canada's Canadian Forest Service, Environment Canada, and Agriculture and Agri-Food Canada: D.W. McKenney, J.H. Pedlar, K. Lawrence, P. Papadopol, K. Campbell and M.F. Hutchinson. Maps source: Natural Resources Canada: http://planthardiness.gc.ca/ph_main.pl?m=1
Edited by: Pablo Medina Villanueva (2018)

The climatic conditions across the country offered a variety of insights of what can grow in each particular zone captured in the map titled Canada's Plant Hardiness Zones by the *Natural Resources Canada*. It is not a surprise that Climatic Zones and the Forest Regions are so intrinsically related. Would it be possible that every region provides the endemic material needed to build suitable homes? Is there a relation between the species composition and the assembly of High-Performance Construction? This research departure from the observation that the forest and its trees have been previously engineered its climate and environment and that this relation should be investigated.

3.2 **Canada's genus** –Dominant species across Canada

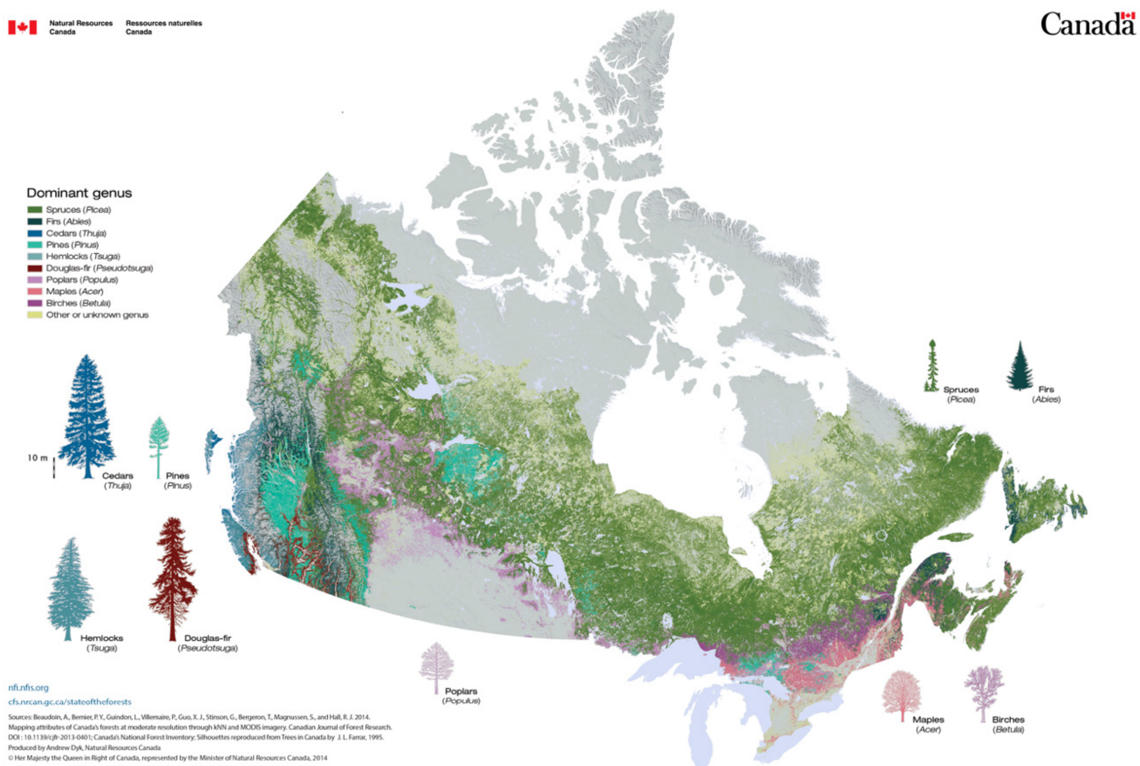

Fig [10] - Forest composition across Canada
Original source: Forest composition across Canada. 2014. Natural Resources Canada, Canadian Forest Service http://cfs.nrcan.gc.ca/publications?id=35727, Edited by: Pablo Medina Villanueva (2018)

Canada is composed of 18 interconnected terrestrial ecozones, each enclosing interacting abiotic (non-living) objects and biotic (living) species. Canada's internal forest fabric includes eight Forest Region and two non-forest including the Great Lakes-St Lawrance, Arcadian, Carolinian, Subalpine, Columbia, Montane, Coastal and the great Boreal forest, and to the north, the none-forest of the tundra and the grasslands. Each forest regions contains a balanced proportion of tree species endured by geologic and climatic conditions specific to each land. Overall, this vastly interconnected mesh is subdivided into four hybridize forest types including the coniferous, mixedwood, temporarily non-treed and broadleaf for a "total of 347 000 000 ha." [34]

[34] Inventory, Canada's National Forest. 2013. Stadistical summaries for Canada. 12. Accessed 12 2017. https://nfi.nfis.org/en/standardreports.

In Canada, the most abundant specie is spruce. "Fast-growing tree in lower-lying areas in nutrient-rich soil with growth rings that have up to 3 cm spacing between them, the finer and more interwoven a fiber structure is, the more elastic, smoother, tighter and longer lasting is the fabric." [35] Moreover, what about the other species? How many, how old, and how are they distributed in a specific place?

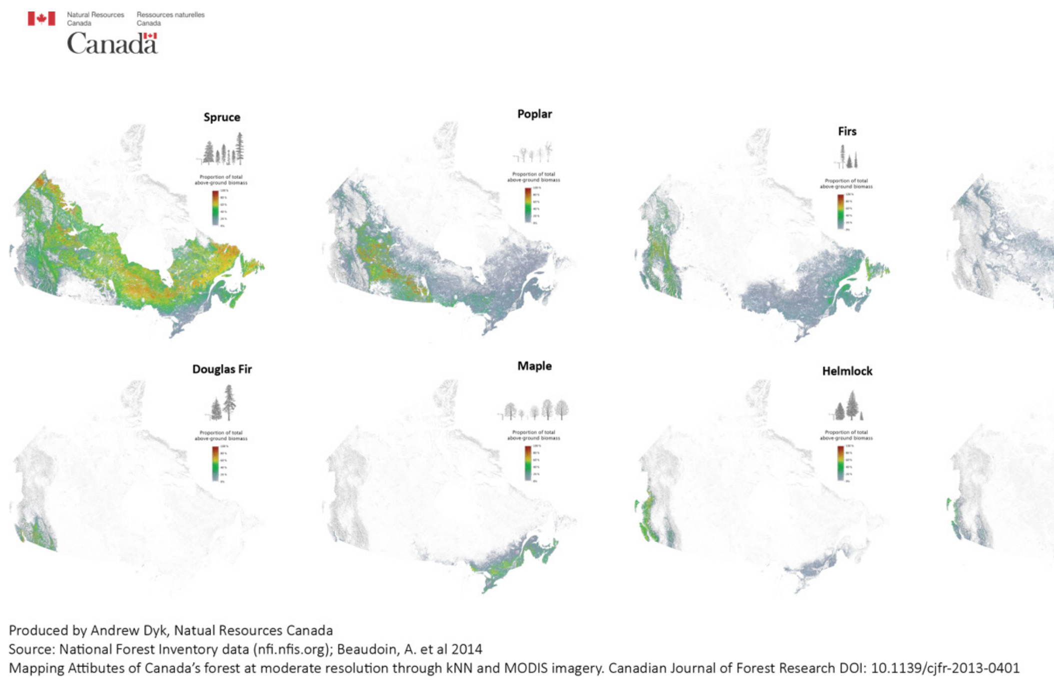

Fig [11] - Specie distribution across Canada (2014)
Original source: Forest composition across Canada. 2014. Natural Resources Canada, Canadian Forest Service http://cfs.nrcan.gc.ca/publications?id=35727, Edited by: Pablo Medina Villanueva (2018)

In a collaborative effort, the Natural Resources Canada and the Canada Forest Inventory, and team of researches including Dr. Andreaw Dyk "have applied a statistical technique (k-nearest-neighbours or kNN) to data from MODIS satellite images, climate data layers and topographic data layers taken from NFI [photo plots] covering 1% of the territory to estimate the forest attributes" [36] for the remaining 99% of the forest area producing the maps and quantifications. (Fig 11, Tab 3)

[35] Ibid pg. 47
[36] Inventory, Canada's National Forest. 2013. *Stadistical summaries for Canada.* 12. Accessed 12 2017. https://nfi.nfis.org/en/standardreports.

Table 16.0. Total tree volume (million m3) by species group and age class in Canada.

SPECIES GROUP	20-Jan	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161-180	181-200	201+	TOTAL
Spruce	44.82	460.78	1280.78	2745.06	8214.48	5227.36	1866.86	727.39	431.4	283.42	1100.61	22382.96
Pine	92.83	274.75	547.32	994.53	1142.86	831.28	759.1	445.48	237.75	118.19	166.52	5610.61
Fir	27.8	208.75	371.39	399.83	365.92	192.73	167.72	151.12	156.26	154.38	1303.4	3499.3
Hemlock	0.3	45.74	105.32	152.85	105.65	88.24	75.26	56.57	39.24	44.64	2027.46	2741.27
Douglas-fir	1.48	41.11	111.52	216.38	220.93	271.11	232.73	122.08	91.93	49.72	293.76	1652.75
Larch	2.57	12.1	34.17	57.52	64.93	55.78	29.92	15.46	8.33	3.31	13.7	297.79
Cedar & other conifers	1.35	19.44	57.12	49.73	65.84	40.54	22.75	17.76	15.84	31.77	945.35	1267.49
Unspecified conifers	227.34	107.8	8.08	0.57	0.04							343.83
Poplar	66.28	325.38	1359.28	2192.02	1465.1	519.09	176.52	44.34	14.46	3.75	10.23	6176.45
Birch	17.42	118.32	450.93	493.43	387.08	70.96	29.34	5.09	1.95	0.35	0.47	1575.34
Maple	17.07	60.35	466.18	257.17	398.71	101.31	59.02	32.01	5.58	4.86	0.3	1402.56
Other hardwoods	18.17	19.06	57.33	71.77	36.28	17.73	2.57	0.36	0.11			223.38
Unspecified hardwoods	88.8	10.56	1.17	0.15	0							100.68
Unclassified	46.07											46.07
Total	652.3	1704.14	4850.59	7631.01	12467.82	7416.13	3421.79	1617.66	1002.85	694.39	5861.8	47320.48

Source: Canada's National Forest Inventory, revised 2006 baseline (Version 3, December 2013) (http://nfi.nfis.org)
https://nfi.nfis.org/resources/general/summaries/en/pdf/CA3_T16_LSAGE20_VOL_en.pdf

Tab [3] - **Total tree volume (million m3) by specie group and age in Canada** (Data) (2014)

Original source: Forest composition across Canada. 2014. Natural Resources Canada, Canadian Forest Service http://cfs.nrcan.gc.ca/publications?id=35727, Edited by: Pablo Medina Villanueva (2018)

3.3 **The forest palette** – Trees distribution according to the Forest Regions

Fig [12] – Forest Regions across Canada
Source: National Resources Canada. http://www.nrcan.gc.ca/forests/measuring-reporting/classification/13179

Previously, I made emphasis on how climate and location had an influence on the environment. If we are looking at trees only, this correlation can be described through the ***forest regions***. These regions are geographic areas with similar dominant tree species and unlike Eco zones, are classified mainly on the nature of vegetation and forest composition, avoiding incorporation a wider range of environmental variables. Canada is divided into eight forest regions including the boreal forest, Great Lakes-St Lawrence, Arcadian, Carolinian, Subalpine, Columbia, Montane and Costal and two none forests regions including the Tundra and Grasslands. Through the map above, we can understand how forest relate and how they are distributed across Canada. The first visible assumption is that the Boreal forest stretches almost entirely across the country from East to West. Could this mean that wood from this region could be used almost entirely around the country? Is not a surprise that the dominant genus in the forest region is spruce and that for the same reason, is the most broadly used for building construction not just in Canada and North America but across the world? What about the rest of the forest regions, what are the main dominant genus in them? Through the correlation of climate zone and forest region we can recognize that every location has a particular combination of wood species and therefore, its material and way to build.

This thesis suggests that architectural construction, specifically wall compositions and performance could relate directly to the different genus combined within each forest region. Also suggest that material wise, the wood walls should be made differently. Nordic climate gives place to the ***Temperate coniferous forest*** that is found in the regions with warm summers and cool winters and adequate rainfall to sustain a forest including the *Boreal forest region*. The trees growing in this forest are predominantly coniferous forests, evergreen conifers predominate, while some are a mix of conifers and broadleaf evergreen trees and/or broadleaf deciduous trees including cedar, cypress, Douglas fir, fir, juniper, pine, spruce, redwood and yew. The West and East-Coasts with warm breeze and water coming from the sea are mainly dominated by deciduous trees and the ***mixed wood forest*** including the forest regions of the subalpine, Columbia, Arcadia and Coast. Southern Ontario and Ottawa belong to the ***broadleaf forest*** with a temperate climate such as the Great Lakes-St Lawrence and Carolinian. (Fig 12, 13,14)

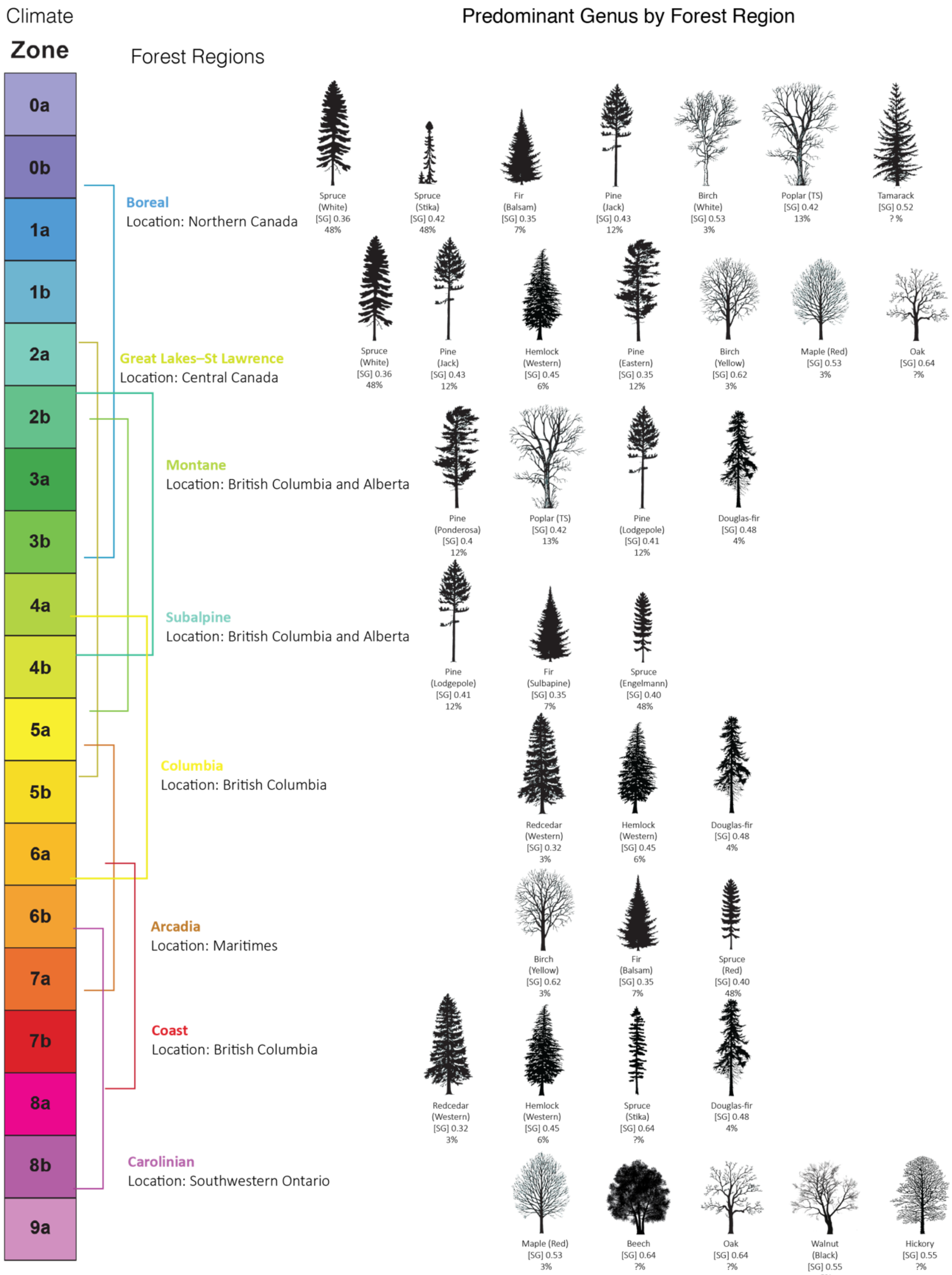

Fig [13] - **Forest region, climate zone and genus distribution**

Original source: Natural Resources Canada, edited by Pablo Medina Villanueva (2018)
http://www.nrcan.gc.ca/forests/measuring-reporting/classification/13179

3.4 Ontario's material – **Species available in Great Lakes St. Laurent**

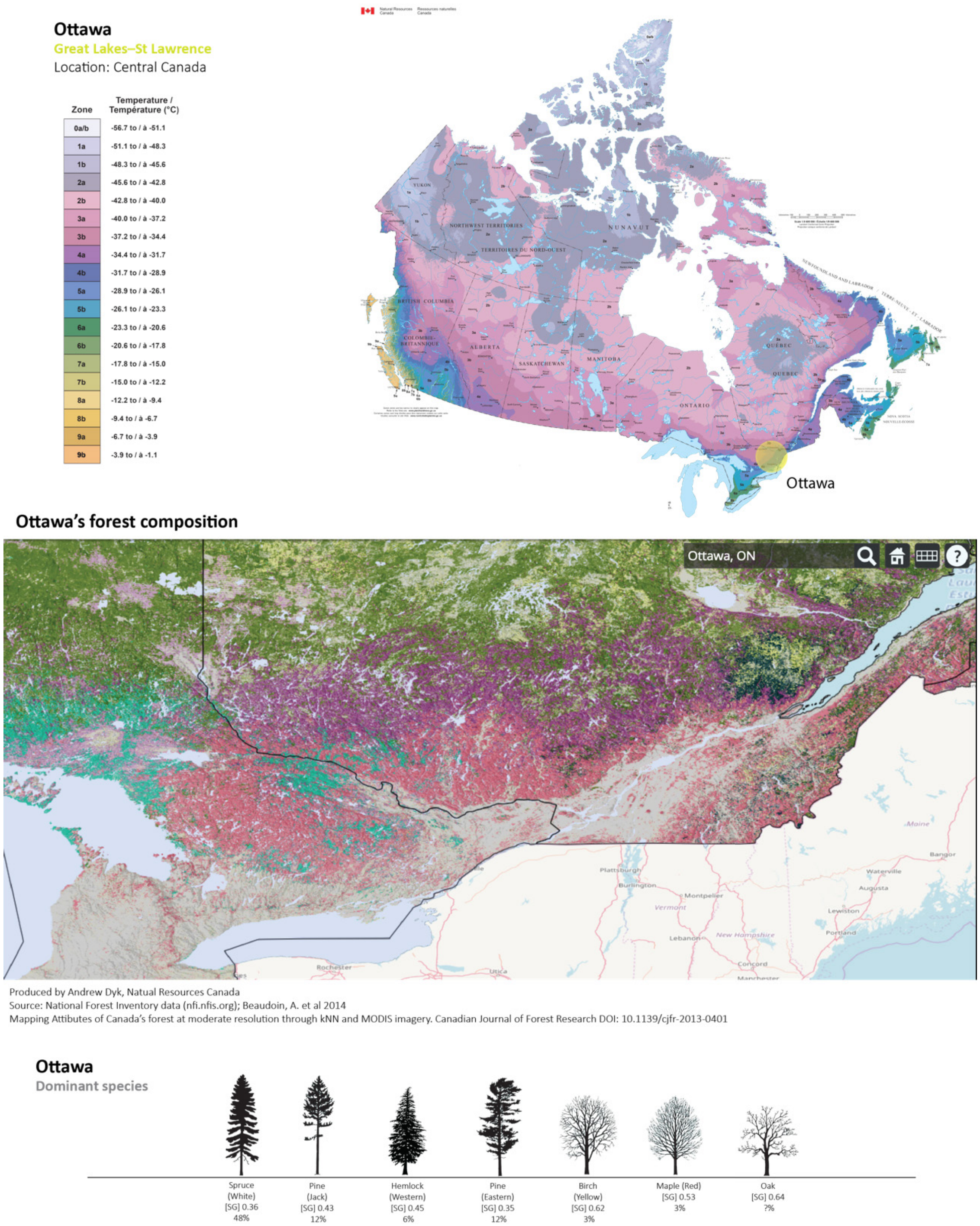

Fig [14] - **Great Lakes- St Laurence. Forest composition and climatic correlation**
Original source: Natural Resources Canada, edited by Pablo Medina Villanueva (2018)
http://www.nrcan.gc.ca/forests/measuring-reporting/classification/13179

Part Three

Material and Form

"Making is a process of correspondence: not the imposition of preconceived form on raw material substance, but the drawing out or bringing forth of potentials immanent in a world of becoming." [37]

Tim Ingold

[37] Ingold , Tim . 2013. *Making, Anthropology, Archeology, Art and Architecture.* New York: Taylor and Francis Group. Pg. 31

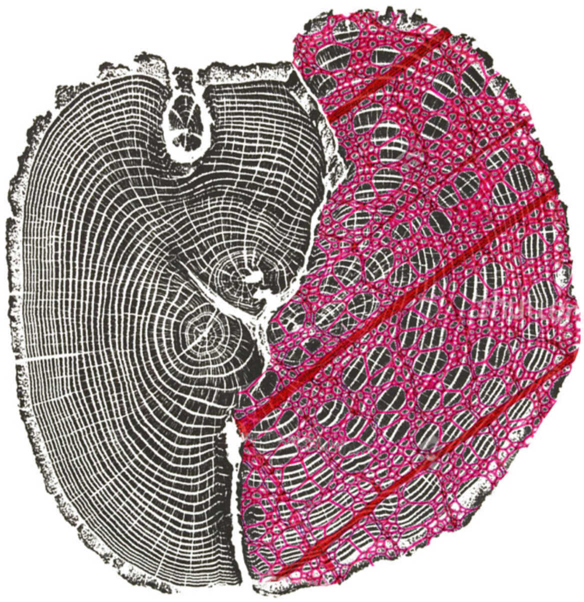

Fig [15] - **Breath through**. Concept drawing (2018)
By Pablo Medina Villanueva

4.1 **Breath through** – Internal surface area

The *Internal surface area* of wood is the result of the tissue-like arrangement of the fiber, and is the engineering behind the cleansing of the air in the atmosphere. "Wood, similar to human lungs, has an incredibly fine cellular system, consisting of thin membranes and intercellular spaces. Cell membranes themselves are a system of pores and fine tubules resulting in this delicate texture." [38] The large cellular mesh is the most remarkable quality of this material and the reason behind its incredible tensile strength but is not the only advantage.

[38] Forest Products Laboratory. 2010. *Wood Handbook, Wood as an Engineering Material* . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. 4- Pg. 1

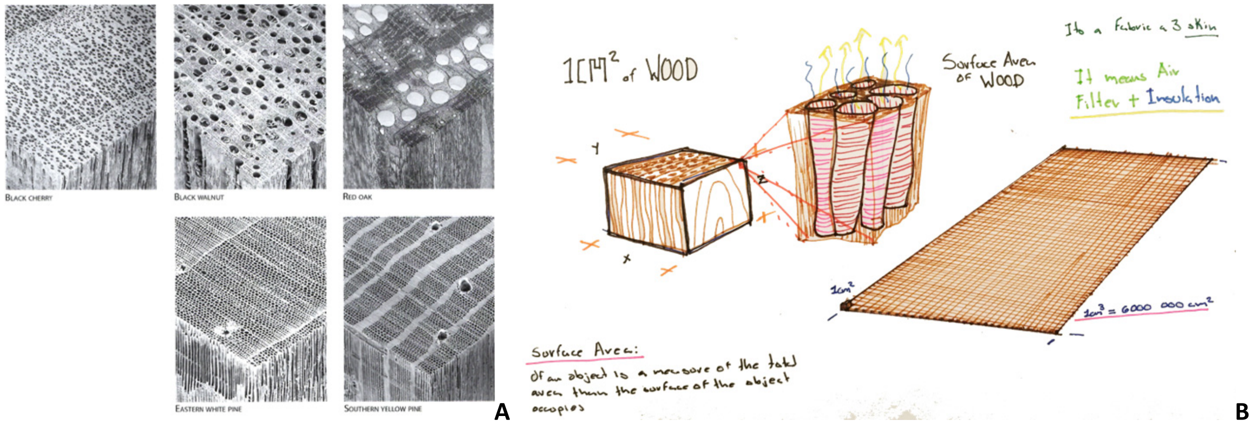

Fig [16] – **Internal surface area** (2018)
A (Right) – Characteristic cell structure and the difference between hardwoods and softwood in Cross-sectional surface with a scanning electron microscope. (Photos by Wilfred Cote) Source: Hoadley, R. Bruce. (2000). Understanding Wood, A craftman's guide to wood technology . Newtown : The Taunton Press, Inc. pg 17
B (Left) – Sketch - Total surface area in 1 cm3 of wood and behavior of fiber to the exposure of water. By Pablo Medina Villanueva (2017)

According to Thoma, "one cubic centimeter of cellulose (percentage-wise the most important ingredient of wood) has the unimaginable internal surface area of approximately six million square centimeters. This fine structure has the effect of a sponge and acts as an air filter. Wood absorbs and filters harmful and smelly substances, retains and releases moisture and reduces electromagnetic smog inside the house." [39] (Fig 16)

According to Thoma, Architects and Engineers need to consider that "skin is supposed to breathe and must not be clogged or "sealed" by airtight coatings, paints and glues. Otherwise, wood suffocates similarly to the lungs of a heavy smoker." [40] An experiment by Thoma showed that 0.4 m2 of untreated wooden cladding per m3 room volume absorbed Formaldehyde from the atmosphere with an impressive rate. "Without airing the room, the formaldehyde levels were reduced by 1.2 ppm (equivalent to the smoke of 25 cigarettes) to 0.1 ppm. This result equals the reduction of 1/12 of the original concentration" [41] In the wooden walls, when the exterior temperature is low and the interior high, the temperature differential produces higher pressure in the envelope, forcing air through the wall and stimulating the cleansing of the air. When the weather is hot and humid, the fibers expand allowing more circulation through the wall. This tissue-like engineering results in the self-regulating capacity of the wood and an ideal match for airtight enclosures.

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[39] Thoma, Erwin. 2015. *A future with natural wood, traditional and scientific facts about trees.* Translated by Iris Detenhoff. Mullumbimby: Moontime Diary pg. 91
[40] Ibid. Pg. 93
[41] Ibid.

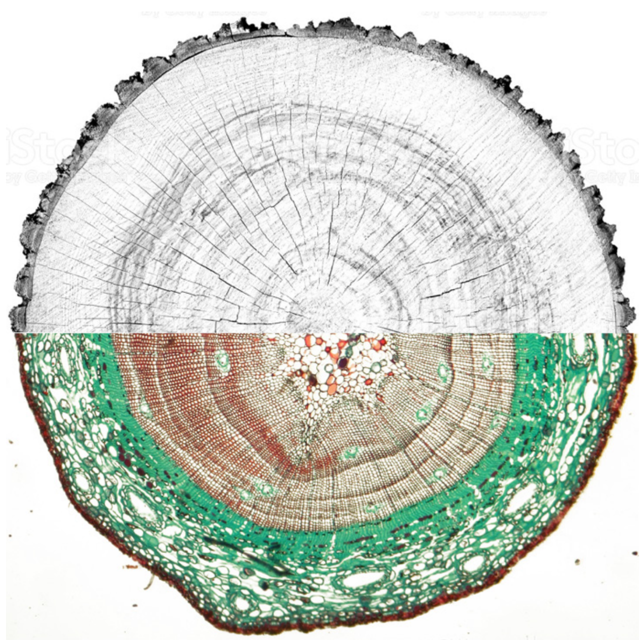

Fig [17] - **Bodies of water.** Concept drawing. (2018)
By Pablo Medina Villanueva

4.2 **Bodies of water** – Specific gravity and moisture content

The cavities between cells where sap is distributed are called the **pits** and are divided between the membrane, aperture and chamber [Figure **C**]. This thin cell walls have a significant importance depending whether they are open or close, since these apertures hold the sap and water alliterating significantly in the **moisture content (MC)** within the wood. In trees recently cut commonly identified as green wood, "the MC can range from about 30% to more than 200%." [42] To understand this behavior, we need to understand moisture inside of the wood fibers.

[42] Forest Products Laboratory. 2010. *Wood Handbook, Wood as an Engineering Material* . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. 4- Pg. 1

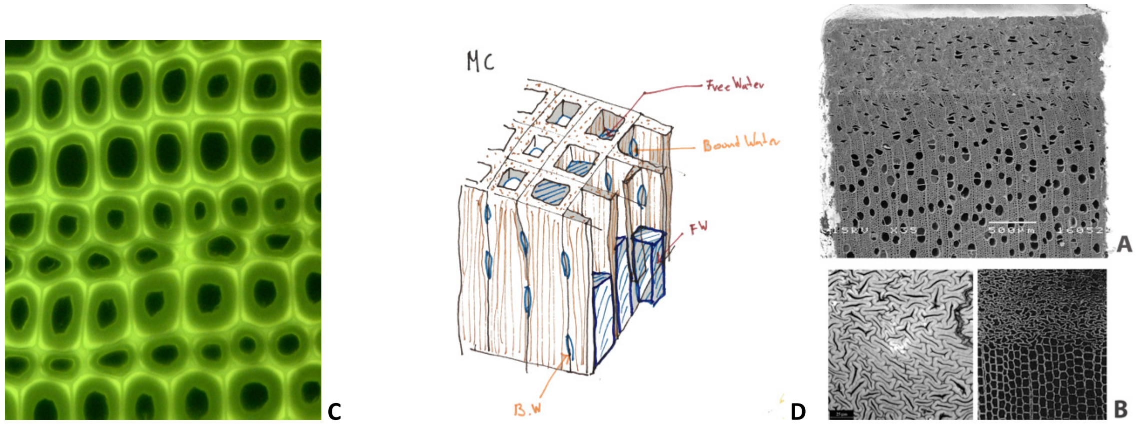

Fig [18] – Wood fibers and water content

C (Middle)- Wood cells, as they appear under a fluorescence microscope. Lignin, the bright green areas between the cells, acts as a "glue" that holds them together. Source: Uppsala University, Sweden. (2013) Published by Bradley George
D (Bottom)Sketch - Moisture inside the Lumina and cavities – Bound water and free water by Pablo Medina Villanueva (2018)
A (Top) – Bulk Densification in process. Cross-section views of poplar (Populous deltoids Bartr ex.) at 35x magnification after surface densification showing cell deformation close to the surface) Source: Neyses B (2016).
B (Bottom)- Thermo-hydro-mechanical treatment. Micrograph of uniformly densified spruce latewood cells after compression at 140°C. Source: Navi and Heger 200599. Navi , P. and Heger , F. (2005)

Moisture can exist in wood as free water (liquid water or water vapor in cell lumina and cavities) or as ***bound water*** (held by intermolecular attraction within cell walls) [Figure **D**]. "The moisture content at which only the cell walls are completely saturated (all bound water) but no water exists in cell lumina is called the *fiber saturation point."* [43]

In wood, both mass and volume depend on the relation between the density of the fiber and the moisture content visible as the specific gravity. *Specific gravity* (G) "is scientifically defined as the ratio of the density of a substance to the density of water own at a specified reference temperature, typically 4 °C (39 °F)." [44] Specific Gravity (G) explains the relationship between the density and the structural integrity but also the dynamic behavior as the reaction to water and moisture resulting in shrinkage. This would also mean that shrinkage could be significantly reduced if the Lumina and the pits are closed. The treatment known as *bulk densification* (Fig 18, A, D, B) modifies the pits by collapsing the wood cells through a process known as *thermo-hydro-mechanical* where heat, steam and mechanical pressure are applied in different phases to compress the cells. Besides reducing the lumina capacity to store Sap and water, this process also affects the material chemically. "With the cells collapsed and the cavities closed, the wood reduces its moisture content from the free water such as the bound water resulting in promising moisture and water barrier and a good fit exterior layer in the wall."[45]

[43] Forest Products Laboratory. 2010. *Wood Handbook, Wood as an Engineering Material* . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. 4 Pg. 9
[44] Ibid.
[45] Thermowood - http://www.thermowood.ca/

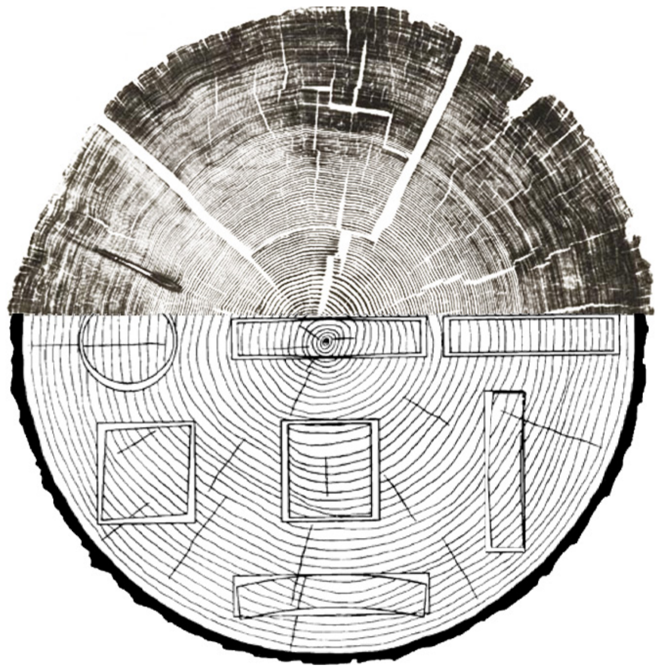

Fig [19] - **Balancing wood**. Concept drawing (2018)
By Pablo Medina Villanueva

4.3 **Balancing wood** – Equilibrium moisture content and dimensional stability

When wood is protected from contact with liquid water and shaded from sunlight, its moisture content remains stable. If the wood is exposed to the environment, it reacts in relation to the *relative humidity* (RH) and *temperature* of the surrounding air. In a cellular level, this relation can be explained as the cell will gain or loses moisture as it interacts with the weather. When the cell has reached a point when it is not winning or losing moisture, it is called **equilibrium moisture content** (EMC). In regards to dimensional stability, wood is an anisotropic material. It shrinks (swells) most in the direction of the annual growth rings (tangentially), about half as much across the rings (radially), and only slightly along the grain (longitudinally).

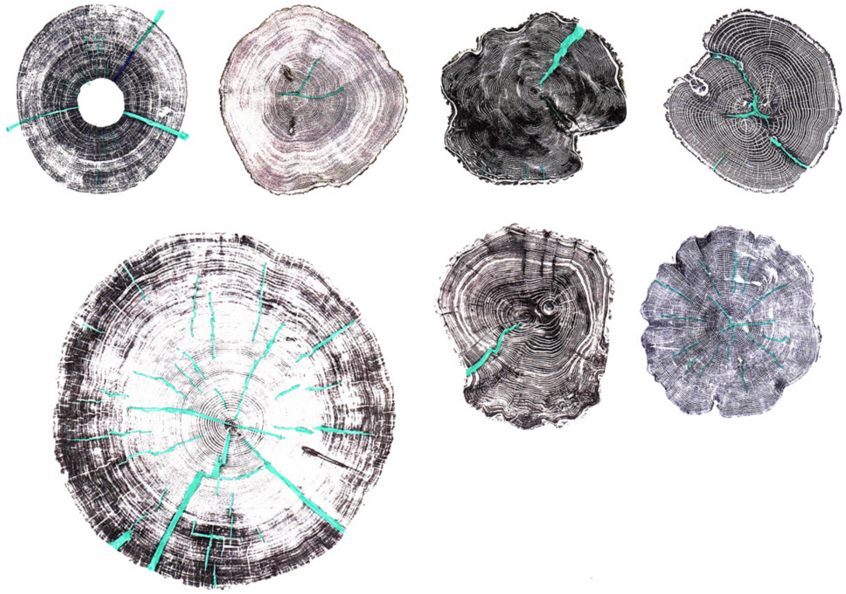

Fig [20] – **Failure due to moisture content** (2018)
Source: Trees footprint by Brian Nash Gill. Edited by Pablo Medina Villanueva

In the case of buildings, is important to consider that exposed walls interact with both, long-term (seasonal) and short-term (daily) changes. In Ottawa for example, the RH and temperature can variate drastically depending on the season and even though the same day. The *Ottawa Weather Station* has register RH changes from a maximum of 100% to a minimum of 25% during the same month of March in 2017. [46] During the whole yearly cycle, an average of 66 to 77% RH can be estimated, but how reliable are average percentages when the changes are so drastic and so fast? Adding complexity to the challenging climate. It is crucial to established strategies to stabilize the wood.

The combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and the curvature of annual rings. These different expansions and contractions are manifest as transversal cracks when the wood is drying [Figure 20] as Hoadley explains "because of heartwood extractives, the sapwood dries first and shrinks more, resulting in radial sapwood checks. when the heartwood dries, the sot opens wide." [47]

According to the *United States Department of Agriculture* (USDA), in green softwood like Spruce Sitka, the MC in the heartwood is closely estimated to 41% while the sapwood is 142%. While in the case of green hardwoods like Maple

[46] Ottawa Weather Stats (2018), Relative Humidity – Monthly data for Ottawa (Kanata-Orleans). https://ottawa.weatherstats.ca/charts/relative_humidity-monthly.html
[47] Hoadley, R. Bruce. 2000. *Understanding Wood, A craftman's guide to wood technology* . Newtown : The Taunton Press, Inc.

Silver, MC is 58% for heartwood and 97% in the sapwood. [48] This natural distribution is MC between the heartwood, and the sapwood is consistent through trees but the values variate between species. From the perspective of MC, the results make evident the distinction of at two different types of wood within a single tree. One stable and resilient to fungus and insects and the other soft and malleable. In Ottawa, the weather behaves dynamically and requires dynamic solutions. Is crucial to understand that wood needs to correspond to this behavior instead of setting strategies to avoid it. From this angle, understand how to compensate these expansions by allowing some tolerance between the parts and the assembly is a practical way to interact but not the only. Below I have listed a blend of ideas suggested by other authors and this thesis.

- **Keep the wood dry**. The most important and more basic idea is to keep the wood dry. Depending on the design of the assembly this can be done by creating a barrier or allowing the wood to ventilate to dry it as fast as is possible.
- **Correspond to the weather with local timber.** In Ottawa, exposed wood MC variates between 12 to 16%. Using local wood that has grown under this climate is a form of correspondence to the environment. As a general rule, softwood responds better to humid environments.
- **Sectioning wood following the radial fiber.** The wood shrinks and swells in response to the gain or loss of humidity. This behavior happens according to the radial structure of the tree, "the combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and the curvature of annual rings." Cutting the timber by following the direction of this radial structure, from center to exterior, would guaranty a proportional deformation and an improvement in the stability of the material.
- **Harvest in winter.** Another critical variable is the time and technique of drying the wood. When drying the wood is essential to do it slowly and seasonally. Engineer Thoma suggests that cutting at the right time "was in winter, ideally when the moon was waning, just before the new moon in Capricorn. This happens to be around Christmas, New Year every year" allowing the tree to lose most of his moisture naturally and over a reasonable period.
- **Use the sapwood and heartwood accordingly.** Understanding the different moisture capacities of sapwood and heartwood could also mean that they should be used differently. Depending on the relative humidity of the site, sapwood and heartwood can be exchange and utilized interiorly or exteriorly. In Ottawa, with a yearly relative humidity of 65%, it makes sense to use the sapwood for the exterior walls and the heartwood for the interior.

[48] Forest Products Laboratory. 2010. *Wood Handbook, Wood as an Engineering Material* . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. *4 – Pg. 2*

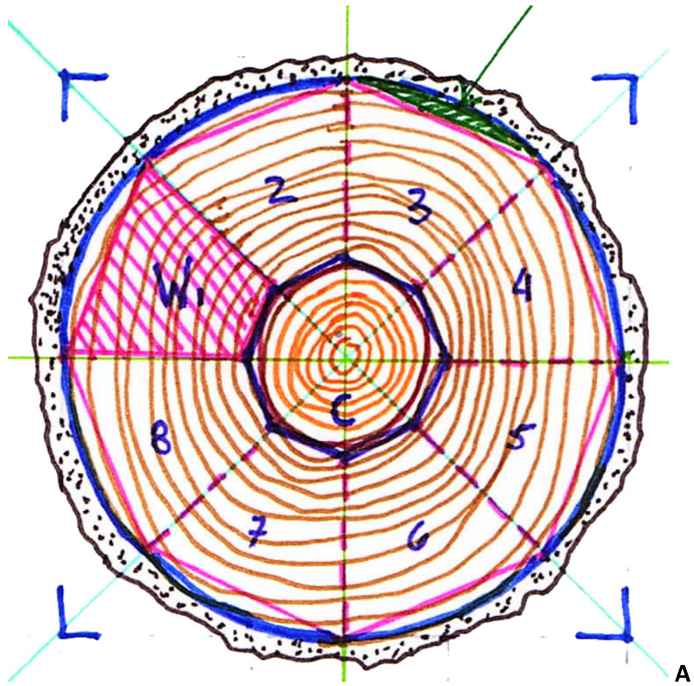

Fig [21] - **The trapezoid.** Concept drawing (2018)
By Pablo Medina Villanueva

4.4 **Slicing (**dividing**) a tree** – Tensile strength

The cell walls in wood, unlike the lumen, which is a void space, are highly regular structures, from one cell type to another, between species, and even when comparing softwoods and hardwoods. The difference between softwood and hardwood is mainly in the density of the fibers but also in the square (softwood) versus the oval (hardwood) shape of the fibers. In both cases, the plant cells do not exist individually in nature; "instead they are adjacent to many other cells, and this association of thousands of cells, taken together, forms an organ such as a leaf." [49] Each of the individual cells must coherently adhere to others to ensure that the cells can act as a unified whole, permitting the movement of biochemicals and water. [50] The wood cell wall consists of three regions: **the middle lamella, the primary wall, and the secondary wall** subdivided into three walls identified as **S1, S2,** and **S3**.

[49] US Forest Service. 2005. "Structure and Function of Wood." *ResearchGate* 18-19.
[50] Ibid.

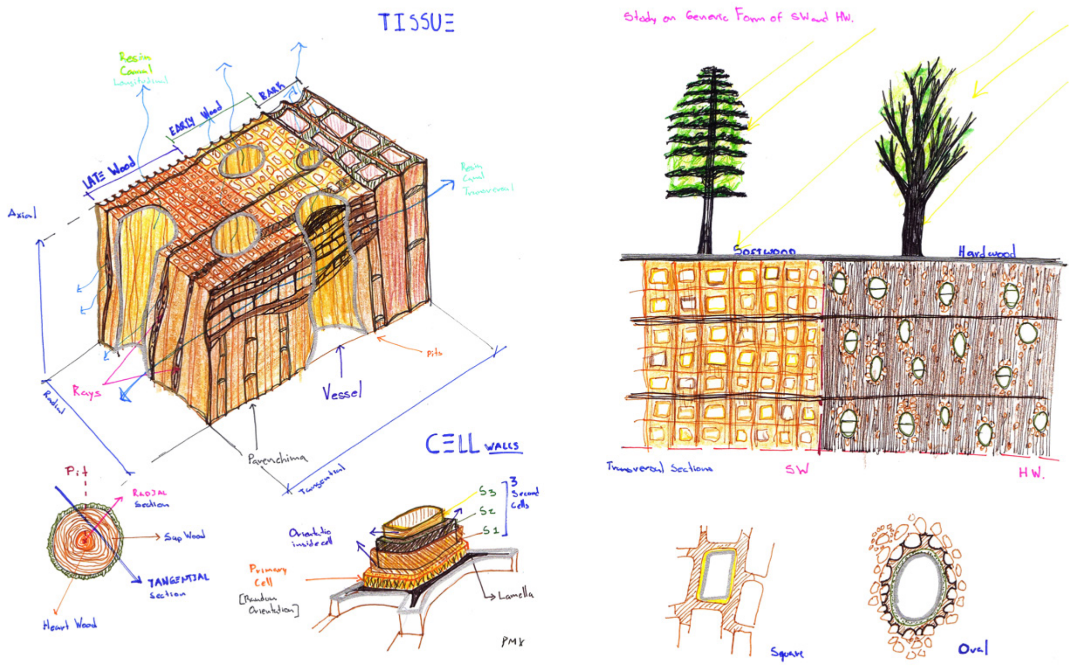

*Fig [22] - **Softwood cell, fiber, tissue** (2018)*
By Pablo Medina Villanueva

In each region, "the cell wall has three major components: cellulose microfibrils, hemicelluloses, and a matrix or encrusting material, typical pectin in primary walls and lignin in secondary walls." [51] ***The middle lamella*** is the outer layer of the wall and is mainly constituted by the lignin holding the cells together. The next layer is the **primary wall** and is characterized by a largely random orientation of cellulose micro fibrils, "as thin threads wound round and round a balloon in no particular order, where any microfibril angle from **0 to 90 degrees** relative to the long axis of the cell". [52] The remaining cell is **the secondary cell** and is composed of three layers "as the protoplast lays down the cell wall layers; it progressively reduces the lumen volume." [53] The first secondary cell wall layer is the **S1** and characterized by a large microfibril angle laid down helically, and "the angle between the mean microfibril direction and the long axis of the cell is large: **50 to 70 degrees."** [54] The next wall layer **S2** is the thickest secondary cell wall layer and it makes the greatest contribution to the overall properties of the cell wall. "It is characterized by a lower lignin percentage and a low microfibril angle: **5 to 30 degrees."** [55] **S3** layer is a relatively thin and the microfibril angle is relatively high to 70+ degrees.

[51] US Forest Service. 2005. "Structure and Function of Wood." *ResearchGate* 18-19.
[52] Ibid.
[53] Ibid.
[54] Ibid.
[55] Ibid.

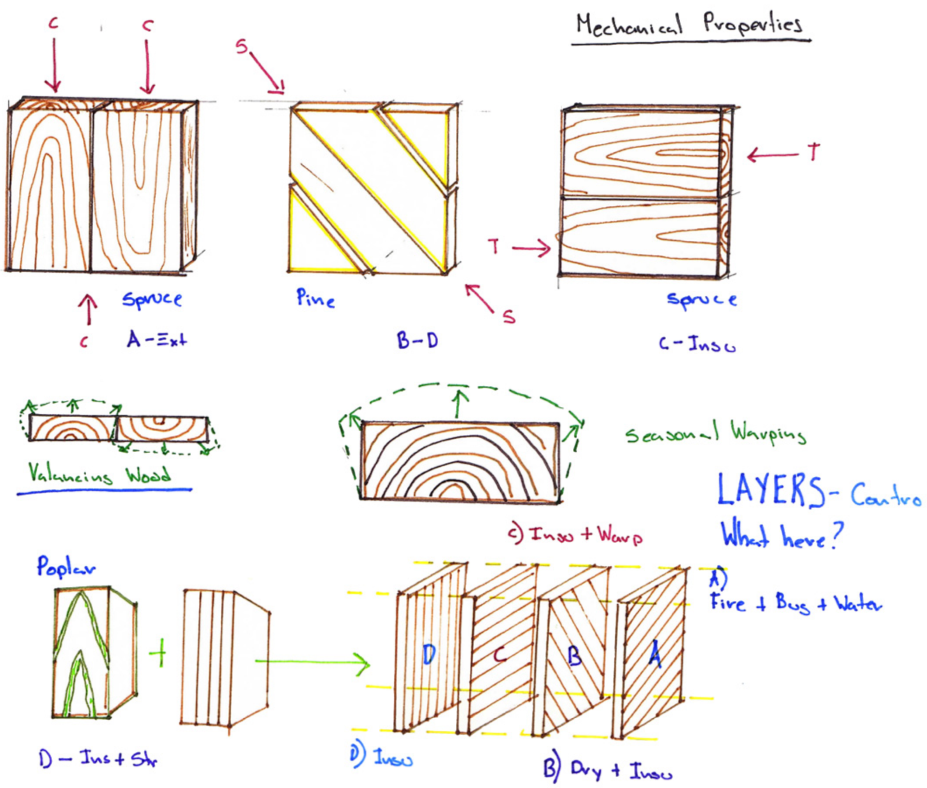

Fig [23] –**Mass timber arrangement** (2018)
Top – Arrangement of the different layers and angles
Middle **–** Geometry and fibers corresponding to expansion
Bottom – Mass timber. Multiple layers of softwood and one of hardwood
By Pablo Medina Villanueva

Engendering the cell is engineering the wall. The benefits of the multiple layers of the variable angle cell structure are vast and still under investigation. The most researched and well know is its correlation to tensile strength. In growing up vertically, or building multiple levels, or making a wall, the technology of the cell should be applied to correspond to the structural forces of compression, tension, and torsion by placing the panels responding to these forces [Figure 23].

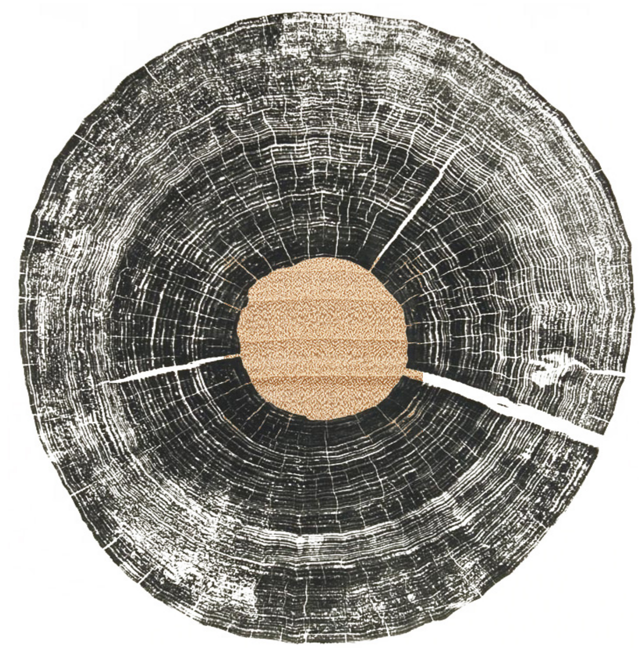

Fig [24] - **Pressure dowel.** Concept drawing (2018)
By Pablo Medina Villanueva

4.6 **Pressure joints** – Capillary action

Water interacts strongly with the wood cell wall and forms a concave meniscus (curved surface) within the lumen. The mechanism of water absorption is called *capillary action or wicking*. "This interaction combined with the water–air surface tension creates a pressure that draws water up the lumina." [56] The rate in which liquid is absorbed depends on several factors. The most important are the direction of the lumina in relation to the water (grain longitudinal to the water is most effective) and the rate at which air can escape from wood, as water displaces the air in the lumina. [57]

[56] Forest Products Laboratory. 2010. *Wood Handbook, Wood as an Engineering Material* . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. *General Technical Report FPL-GRT – 190 4 – Pg. 4*
[57] Ibid. 4 Pg. 5

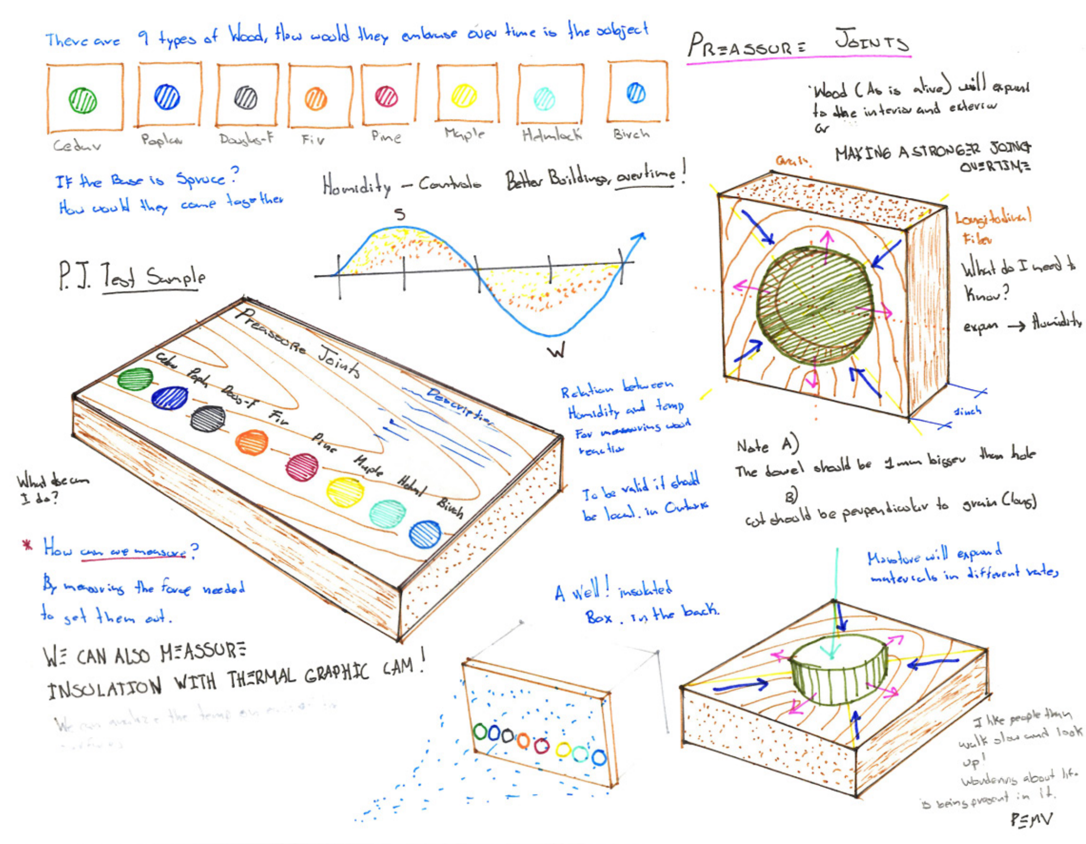

Fig [25] - **Pressure joint study** – Nine combinations of dowels on a base of spruce. (2018)
By Pablo Medina Villanueva

Pressure joints: In buildings, the capillary action can be used through the use of dowels and joints. Since different materials expand at different rates, the pressure difference and the resulting expansion can be used to secure and connect the layers perpendicularly (Figure 25).

Over time, this pressure difference could also mean better bounds. Additionally, the direction in which different fibers interact in these joints represents an additional opportunity to increase the pressure difference by turning the fibers from the dowels perpendicular to the wall, giving a broader aperture to the capillary action more to expand. Since water can also damage the wall, the dowel should be made of hardwood to reduce the capillary action daily, but improve it over time. It is also reasonable to avoid completely exposed of the dowel to the exterior of the envelope.

Fig [26]- **Mass insulation.** Concept drawing (2018)
By Pablo Medina Villanueva

4.7 **Mass insulation** – Thermal properties

Aside from the structural qualities of a material, the insulation properties are the most desired in North America. The thermal properties exist in two forms, as ***thermal conductivity*** (k) or **U- Value** defined as "the measure of the rate of heat flow (W m–2 or Btu h–1 ft–2) through a ***building surface*** composed of multiple materials, subjected to unit temperature difference (K or °F) across unit thickness (m or in.)." [58] And as **thermal resistivity** or **R-Value** that is simply the reciprocal property of the thermal conductivity given to a material over certain thickness. In the case of wood, the thermal conductivity of woods is significantly less that of metals and concrete, for example, "the conductivity of structural softwood lumber at 12% moisture content is in the range of 0.10 to 0.14 W m–1 K–1 (0.7 to 1.0 Btu in. h–1 ft–2 °F–1) compared with 216 (1,500) for aluminum, 45 (310) for steel, 0.9 (6) for concrete, 1 (7) for glass, 0.7 (5) for plaster, and 0.036 (0.25) for mineral wool." [59] Still, the insulation capacity of wood looks insufficient to correspond to this climate.

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[58] Forest Products Laboratory. 2010. *Wood Handbook, Wood as an Engineering Material* . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. *General Technical Report FPL-GRT – 190 4 – Pg. 10*
[59] Ibid. 4 - Pg. 11

In regards to the R-value of trees, there is not a big difference between the different tree species as there is between the general softwood and hardwood. In the context of a complete forest region, this distinction accentuates. While the Boreal forest tends to be composed of a slightly less conductive palette of softwoods with a majority of pines, spruces, and larch, the Carolinian or Costal forest have a higher conductivity resulting from a predominant palette of hardwoods. This difference suggests that in colder climes, trees have adapted its fibers to fast seasonal growth, while, in humid and costal climates, the trees have grown by following a temper climate. This conclusion can also be observed by looking at the difference between the early and late wood within each species.

Forest Regions Canada

R - Value - Thermal conductivity of predominant hardwoods and softwoods in Canada
[12 % MC]

Subalpine
British Columbia and Alberta

Montane
British Columbia and Alberta

Great Lakes–St Lawrence
Central Canada

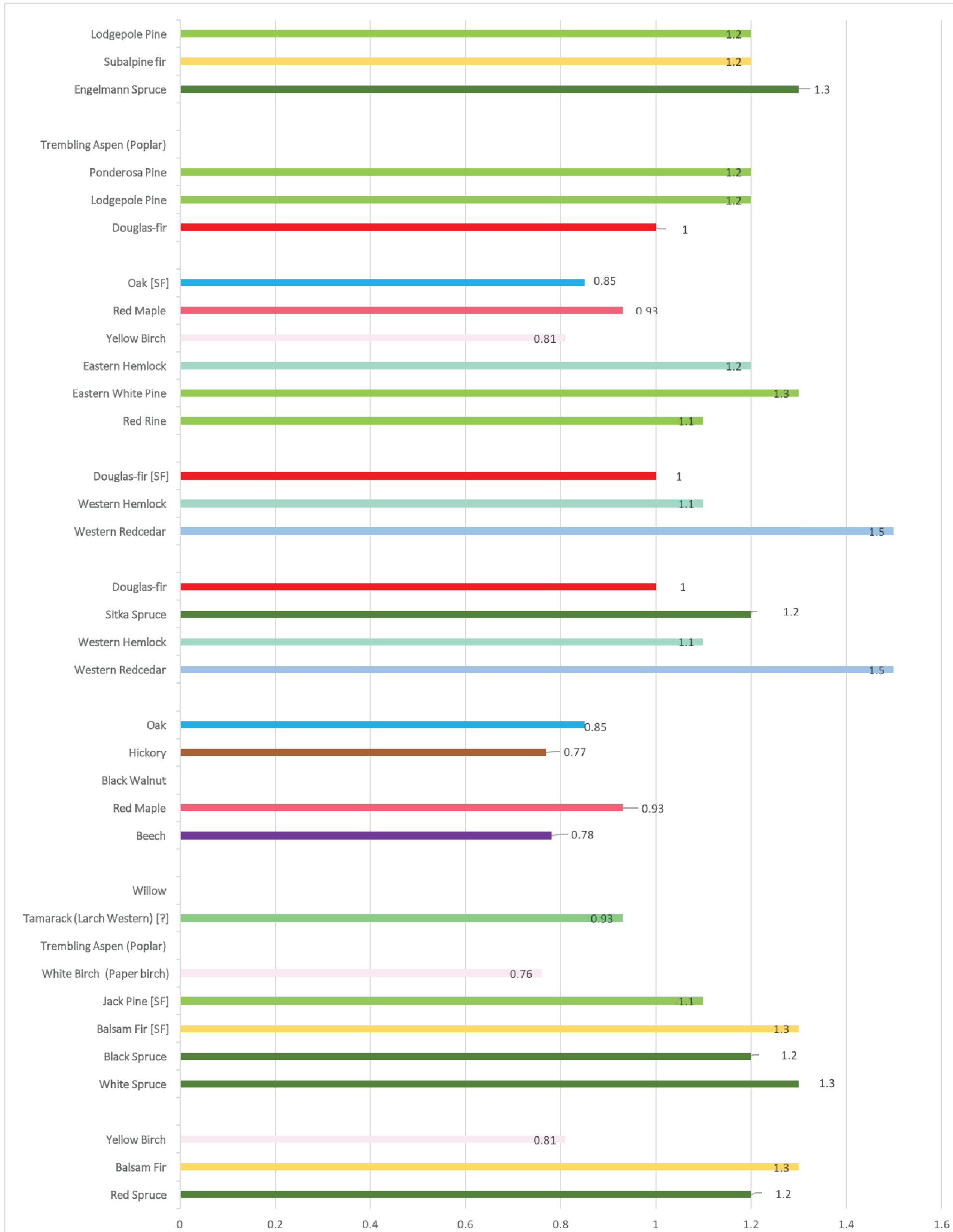
Columbia
British Columbia

Coast
British Columbia

Carolinian
Southwestern Ontario

Boreal
Northern Canada

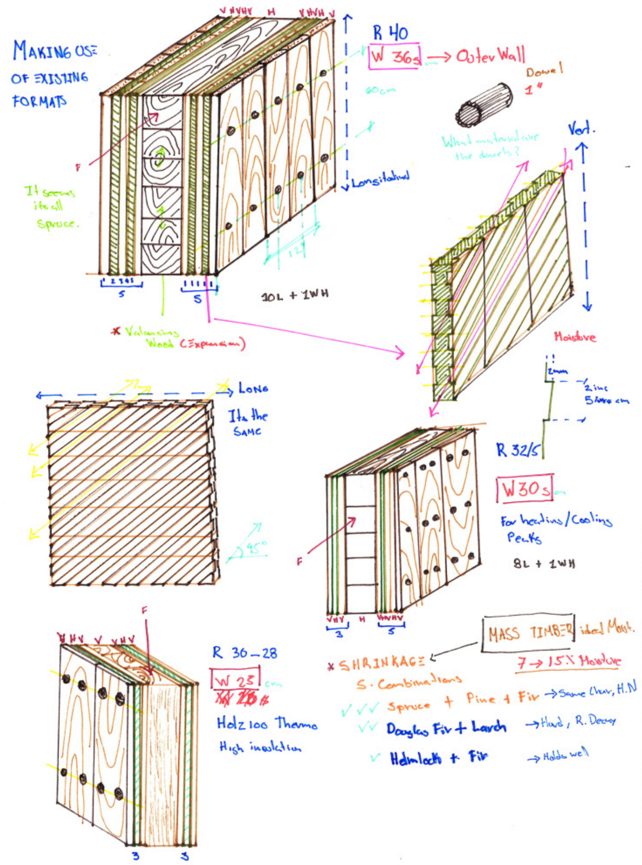
Acadian
Maritimes



Source: Forest Products Laboratory USA (2010) Wood Handbook, Wood as an Engineering Material . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. General Technical Report FPL-GRT – 190 4 – Pg. 14

Note: Values in this table are approximate and should be used with caution; actual conductivities may vary by as much as 20%. The specific gravities also do not represent species averages.

Tab [4] **-** *R-value by forest region and specie* ***(2010)***



A

B

Fig [27] - **Holz100, study case** (2017)
A (Left) Sketch – Graphic Study of Holz100 wall types including W36s, W30s and W 25**,** by Pablo Medina Villanueva (2017)
B (Top) – Holz100, Nine wall types. (Middle) - 25 Outer Wall. (Bottom) - High-Performance Wall (prototype unknown) Source: Holz 100 wall types by Thoma. https://www.thoma.at/holz100-wandtypen/

How would a high performance wall look like? The patent **Holz 100** by Thoma [Figure 28, right] consist of 9 wall types variating in arrangement, composition and thicknesses. According to my research, his highest R-value wall (W36s) reaches R 40 within a thinness of 44 cm (17.3 inches) and is composed by 2.4 cm Larch rough saw as exterior wall, 37 cm spruce and 4 cm interior Larch as fire safety. [60] The specific details on how this is possible are protected by the patent but it gives us an insight of the thermal-dynamics occurring in mass timber assemblies. The thermal conductivity of wood is affected by a number of basic factors: density, moisture content, extractive content, grain direction, structural irregularities such as checks and knots, fibril angle, and temperature. In general, **thermal conductivity increases as density, moisture content, temperature, or extractive content of the wood increases.** [61]

[60] Thoma, Erwin. 2015. *A future with natural wood, traditional and scientific facts about trees.* Translated by Iris Detenhoff. Mullumbimby: Moontime Diary Pg. 126
[61] Forest Products Laboratory. 2010. *Wood Handbook, Wood as an Engineering Material* . Madison , Wisconsin: Department of Agriculture, Forest Service, Forest Products Laboratory. *General Technical Report FPL-GRT – 190 4 – Pg. 11*

Part Four

Form and Process

“Modularity is the appropriate agreement of the components of the building itself and the **correspondence** of the separate parts to the form of the whole scheme based on one of the parts selected as the standard unit. Just as in a human body, the nature of its harmony is modular.” [62]

Vitruvius

[62] Vitruvius. 2009. **On Architectura**. Translated by Richard Schodield. Pinguin Books Pg. 21

5.1 **Part -** The trapezoid as basic unit

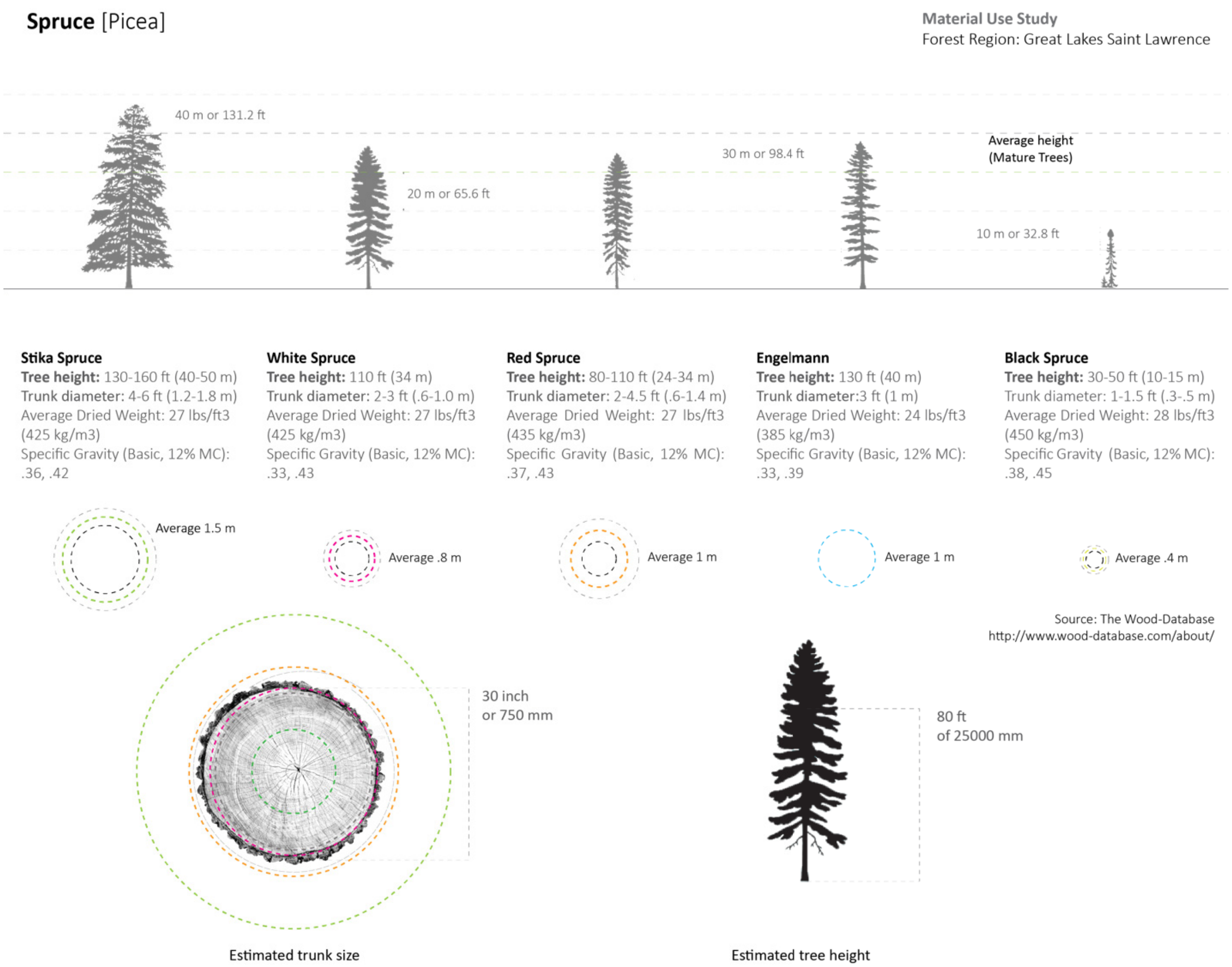


Fig [28] – **Dimension analysis of the dominant spruce species in the Canada** (2018)
Top – Studies on material use

To produce a part from existing trees the first thing to consider is types and their dimensions. To communicate this idea correctly, this study had investigated the case of spruces from the Ontario's forest region only. The Great Lakes-St. Lawrence has five different types of spruce, and they all variate in their trunk shapes and trees forms. Besides this, it is possible to determine an approximate trunk diameter and tree height. If we exclude the case of black spruce, mature spruces have an approximate diameter of 30 inches or 750 mm. In the case of the height, and without considering one-third of the top since it has a considerably smaller trunk diameter, spruces have an approximate height of 80 ft. or 25 mt. As a result, each mature tree can be cut ten times in sections of 8 ft. standard construction dimension. (Fig. 28)

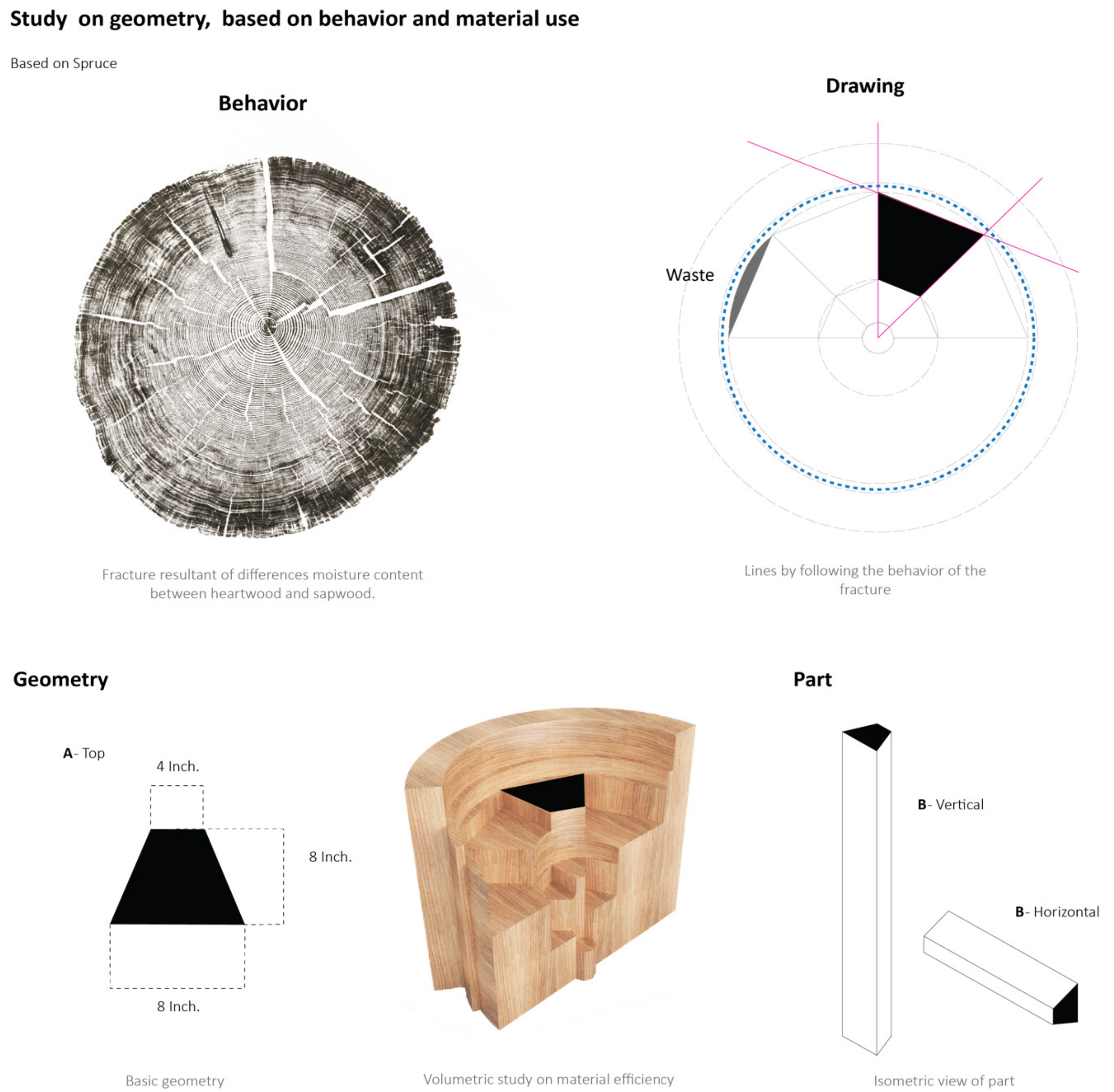


Fig [29] – **The trapezoid,** (2018)
Top – Geometric form emerging due to the different moisture content in heartwood and sapwood
Bottom – Transition of the trapezoid to a part.

By drawing lines from the center of the tree trunk to the exterior, this lines will naturally intersect with the radial lines of the growth rings. From a transversal view, this lines will produce the shape of a trapezoid. (Fig 29) The geometric shape follows the behavior of the natural fractures resulting from the different moisture content between heartwood and sapwood. By following this behavior, the trapezoid suggests a more stable form that the traditional square shapes. Additionally, cutting spruces in this form can minimize the material waste significantly (left top) and produce useful parts for the panel. This form will allow us to generate 8 pieces for each cut and 80 from a complete mature spruce. The center of trunk can be use similarly, in smaller trapezoid sections or as columns.

5.2 **Panel** – Layers and joints

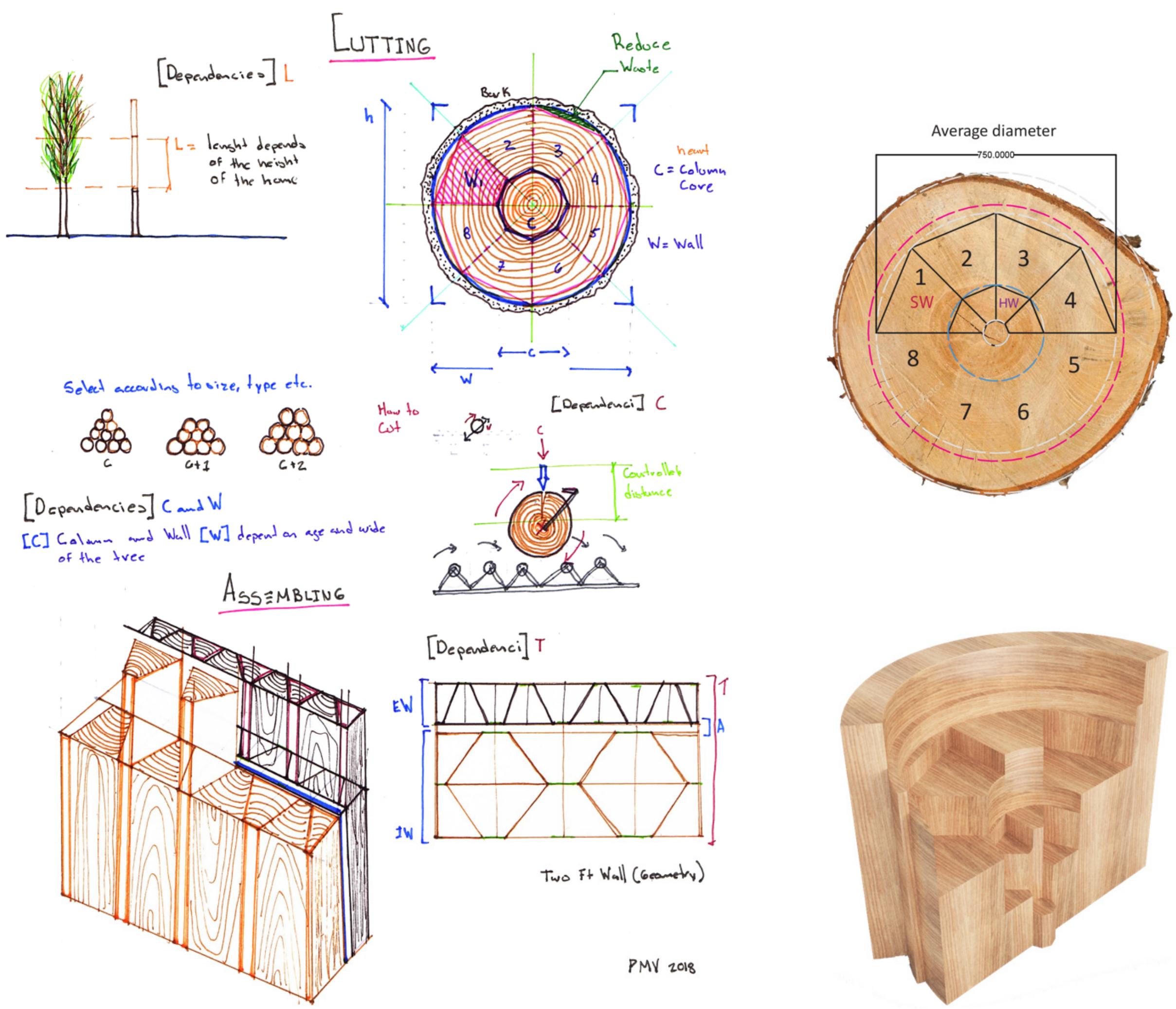
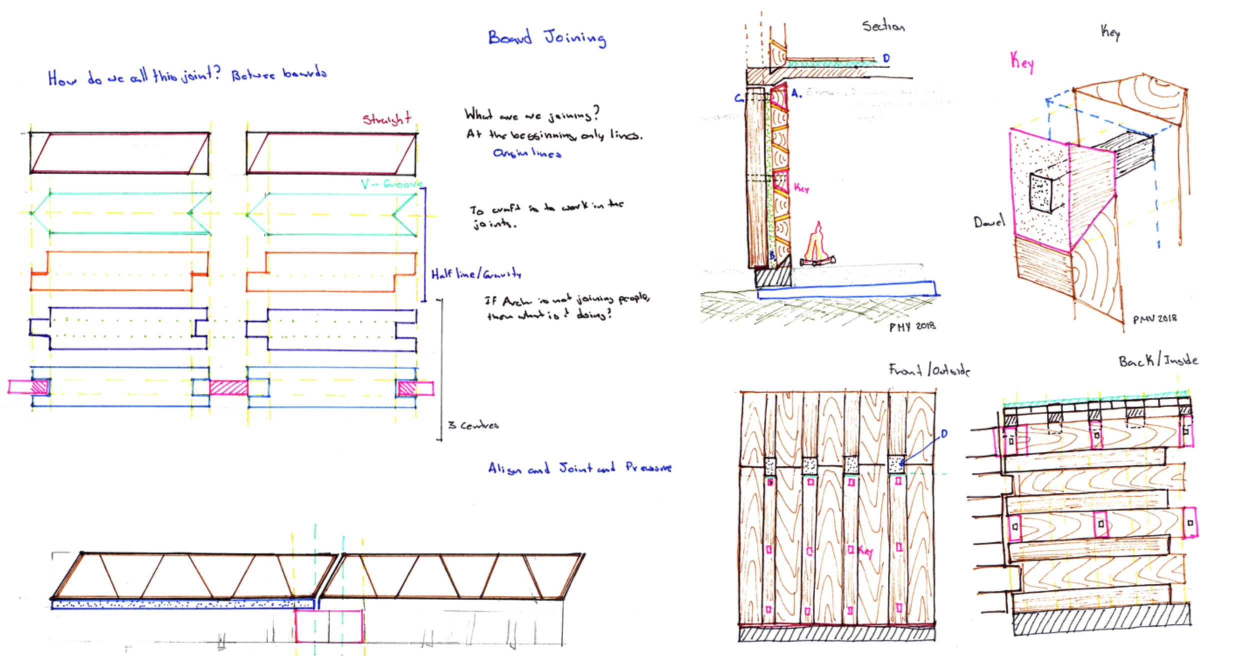


Fig [30] – **Studies of material use by using the trapezoid** (2018)
Right – Conceptual drawing, Arrangement of the panels using the trapezoids
Left – Simulation presenting how the trunk is cut
By Pablo Medina Villanueva

The shape of the trapezoid can be arranging accordingly (top left) to produce **layers.** The arrangement makes use of the shape by creating correlated forms. There are multiple benefits to this arrangement. First, the pieces are assembled on site and or glue (if needed) on a factory improving the bond by extending the area for the adhesive. (Fig. 31) An additional consideration is that each layer should be fabricated on the same material and should intercalate the direction of the fiber rights to allow correspondence in the expansion.



A B

Fig [31] – **Studies of panel alignment and joints** (2018)
Left – Studies of panel connection
Right – Studies on joints and fiber arrangements
By Pablo Medina Villanueva

Each layer varies in thickness and angle according to the structural and insulating needs. The first (exterior) layer arranges the trapezoids to receive the vertical forces of compression. The second (middle) layer is the drying and insulation layer. Since the thickness of a wooden wall also depends on its insulation, it is essential to plan for future exploration of insulation materials. **Current studies of charred wood as insulation or compacted sawdust seem promising materials for the insulation layer (may extend this research)**. The third layer is hardwood and arranges the trapezoids horizontally leaving the edges dented to assemble the walls. The layers within the panel are connected transversally due to square hardwood dowels. (Figure 31 - Top left)

From a top view, the **panel** is composed of multiple layers including the exterior, middle and interior mentioned previously. The figure (Fig. 32) show multiple options of corresponding panels concluding by the bottom option, a tree layer panel composed of vertical trapezoids for the exterior wall, insulation and horizontal trapezoid as the interior layer. This arrangement, and due to the use of the trapezoid, allows the lateral and superior alignment to other panels (figure, left) such as the transference of the mechanical forces of compression, tension and torsion.

5.3 **Wall** – High-performance Wooden Wall for Ontario

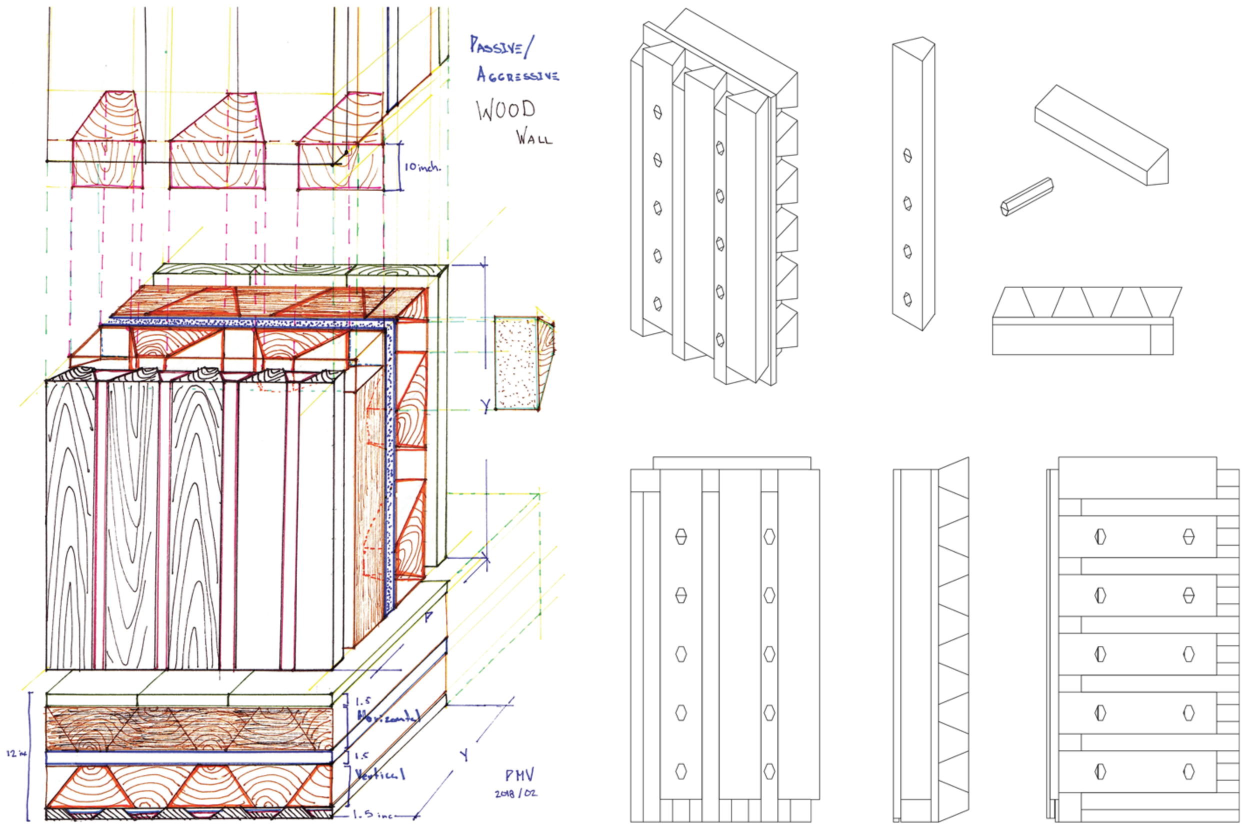


Fig [32] – **Prototype three**, Conceptual drawing (2018)
Left – Conceptual drawing
Right – Assembly details
By Pablo Medina Villanueva

This thesis proposes to assemble the wall in the following form. The exterior layer is one inch of thermo-hydro-mechanical treatment wood, with drying channels in the back. The second layer, consisting of 8 inches of spruce [vertical trapezoid] to transfer the compression forces. The third layer, or insulation layer, consist of 120 mm of wood-fiber insulation board. The final and interior layer consists of 8 inches of poplar [horizontal trapezoid] to counter the torsion and bending forces. The system is joint transversally by maple hardwood dowels. This system aims it correspond through material densities (compress fiber, softwood, loose fiber, and hardwood) to the insulation needs, while allows the system to filtrate and cleanses the air. Additionally, it follows the natural tendency of the fibers allowing shrinking and swelling. The joints are thought to endure overtime or disassemble to the basic unit if needed. The panel details, fiber arrangement and panel connections are shown below. (Fig. 33, 34, 35)

Assembly details

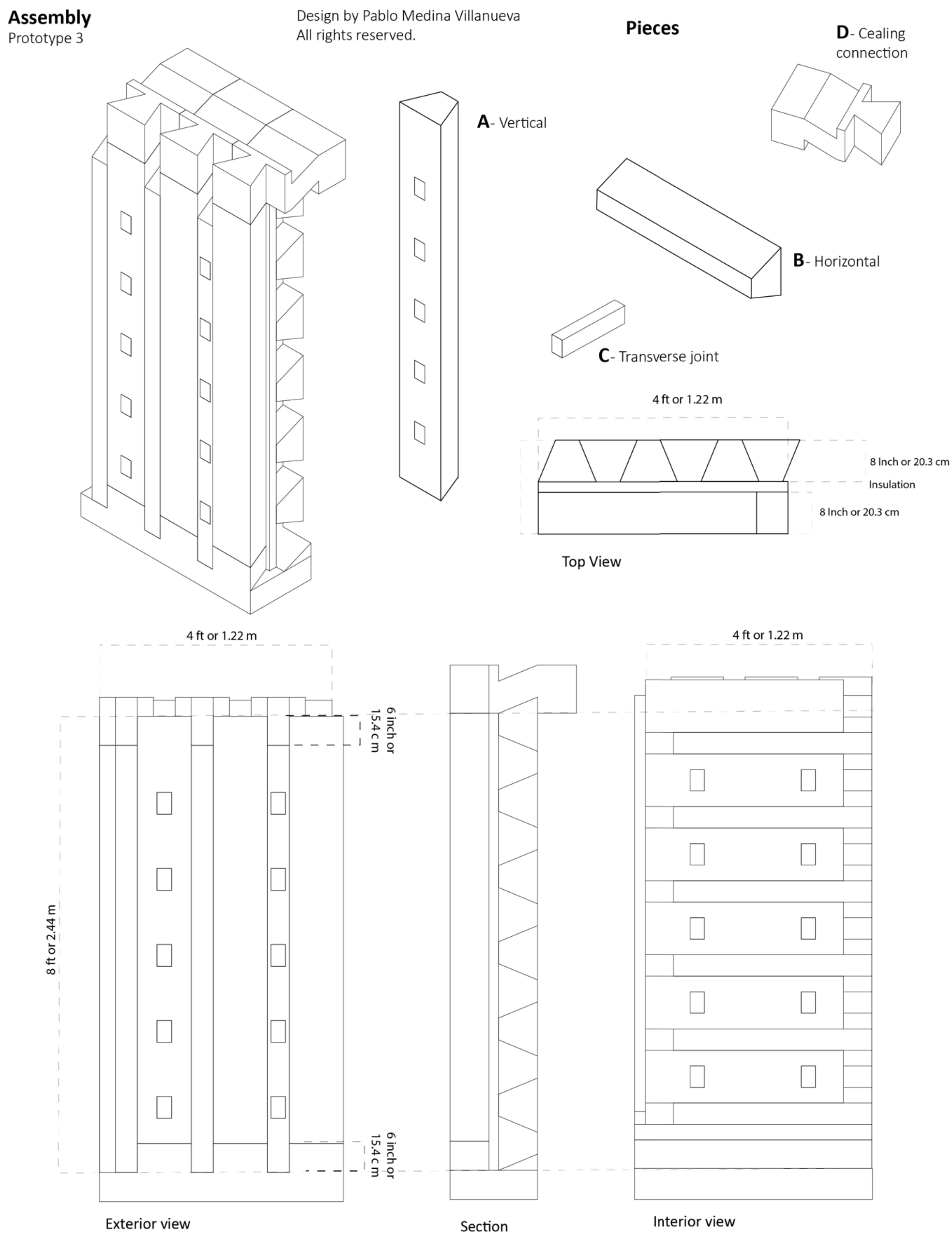


Fig [33] – **Prototype three**, Panel parts and assembly (2018)
By Pablo Medina Villanueva

Fiber arrangement

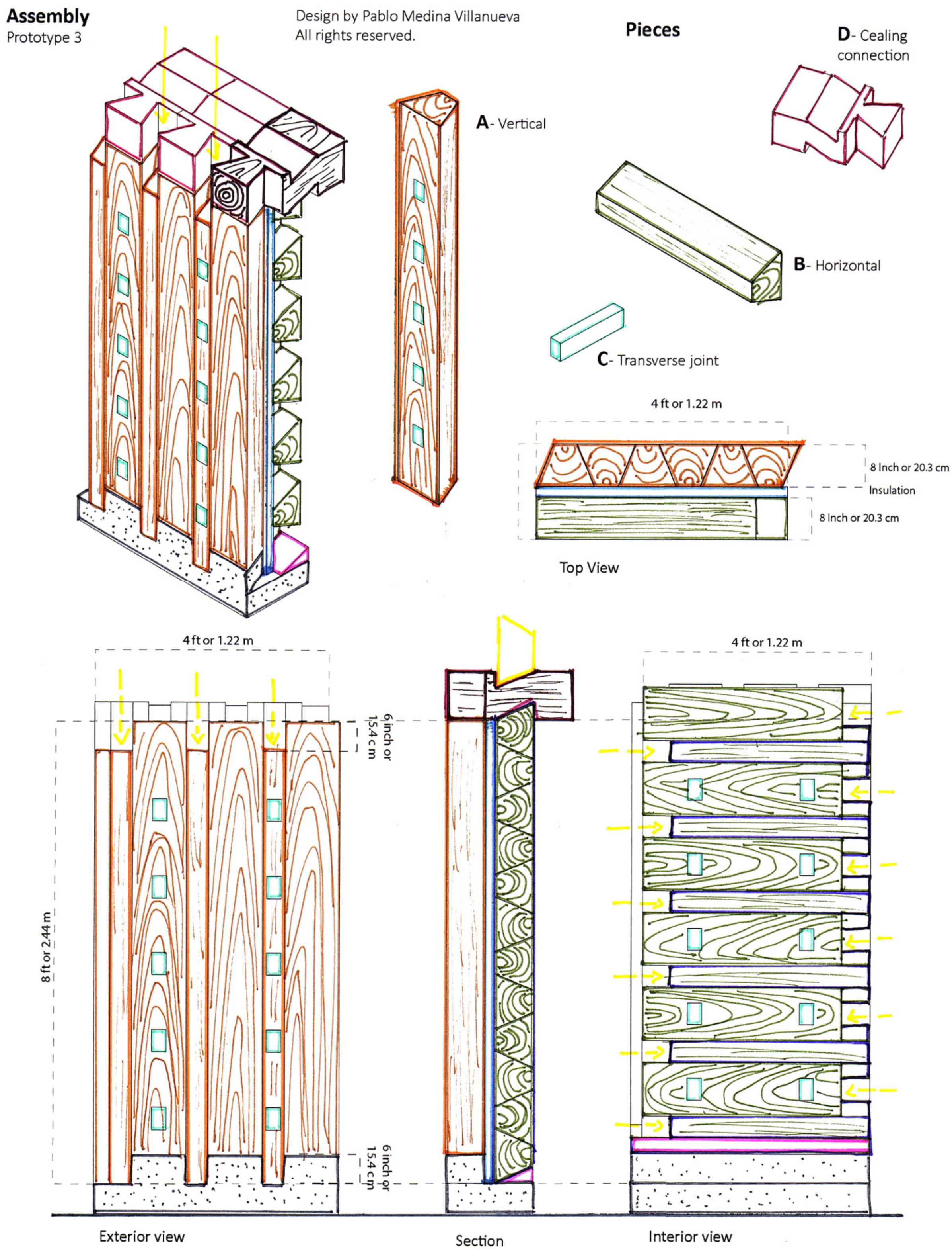


Fig [34] – **Prototype three**, Fiber direction on stabilized panel (2018)
By Pablo Medina Villanueva

Panel connections

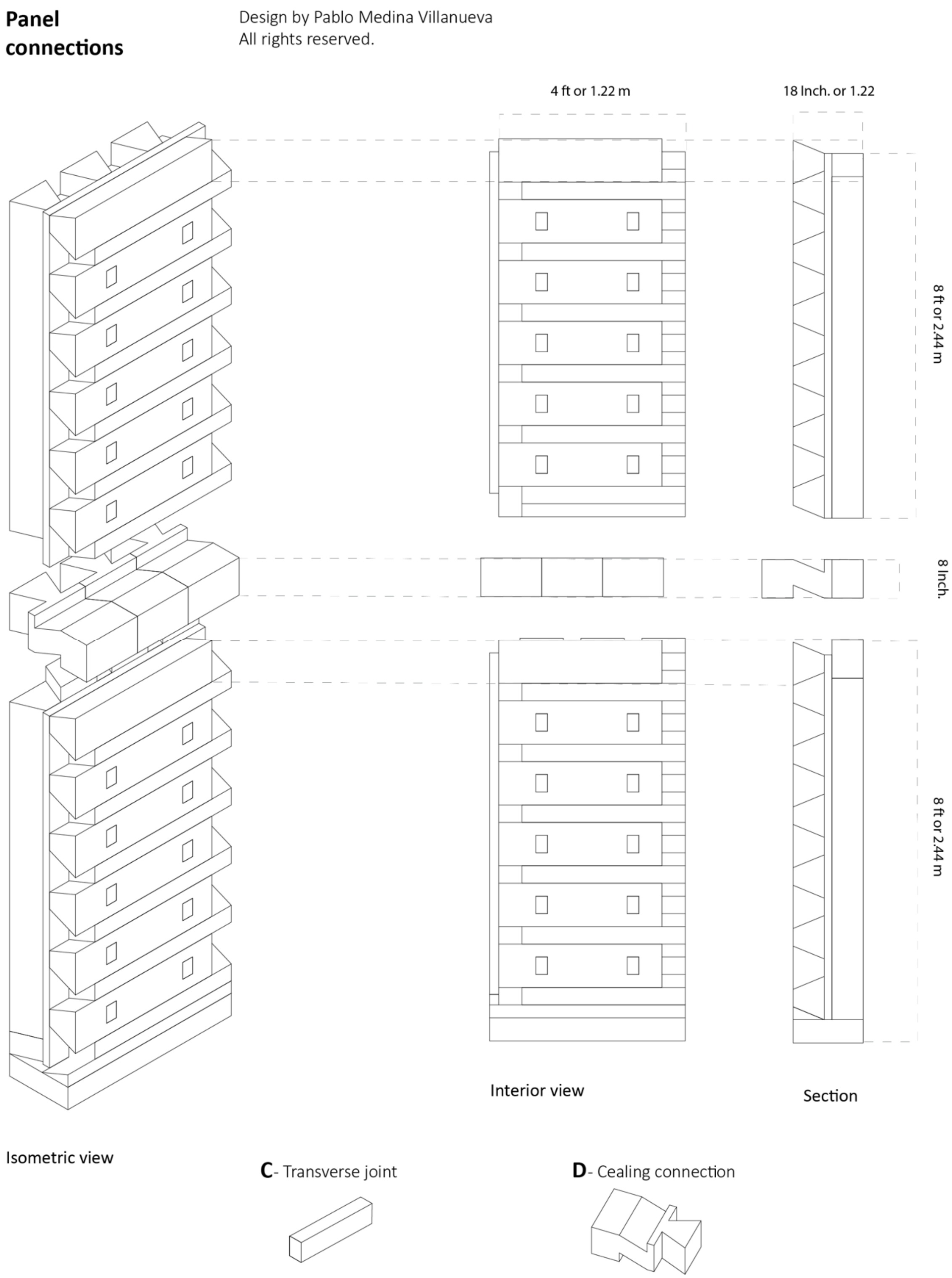


Fig [35] – **Prototype three**, Wall and ceiling connections (2018)
By Pablo Medina Villanueva

3D Printed Model

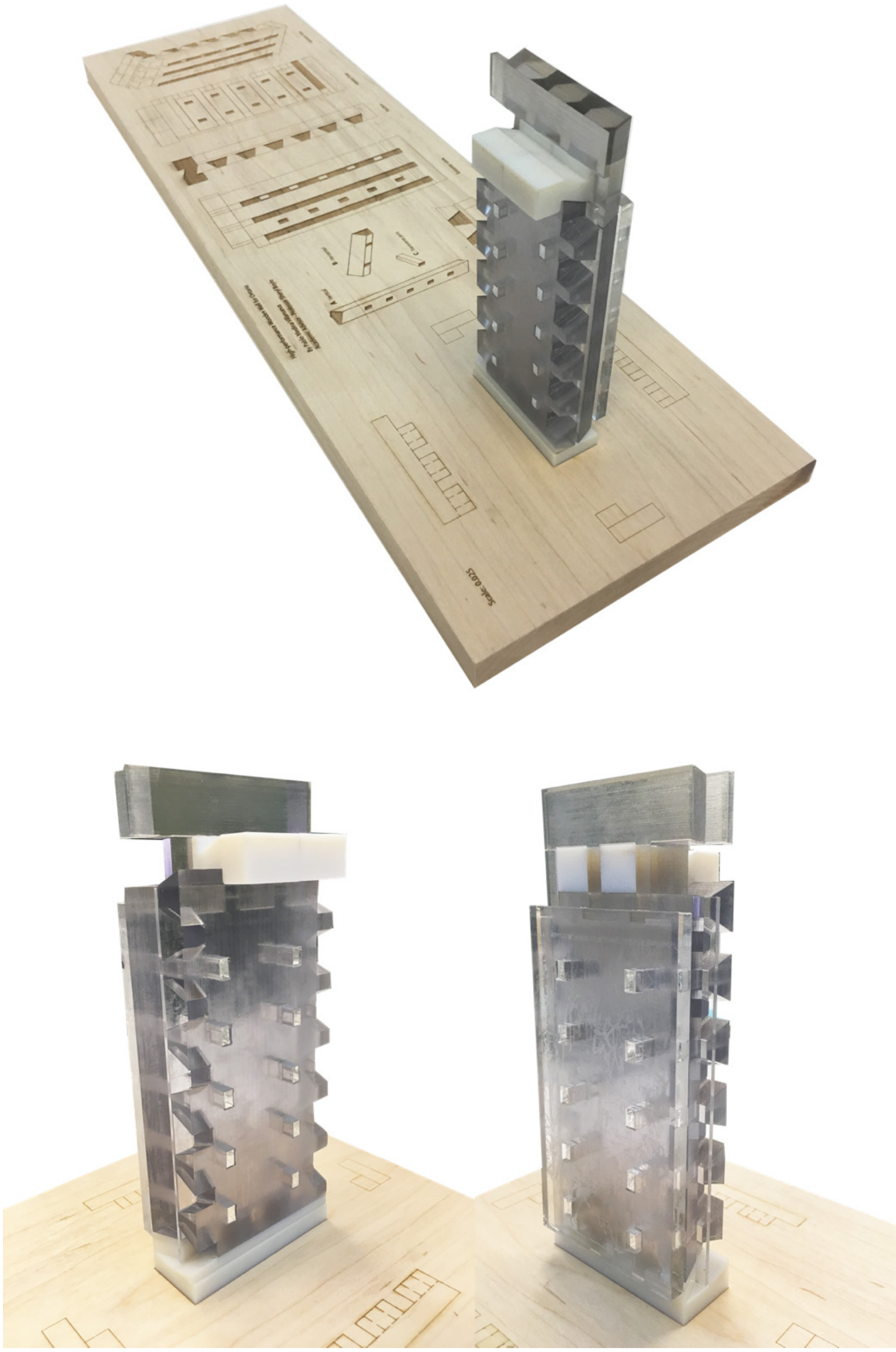


Fig [36] – **Prototype three**, 3D printed model (2018)
By Pablo Medina Villanueva

Fig [37] – **Prototype three**, 3D printed model by layers (2018)
By Pablo Medina Villanueva

5.4 **Built Prototype**– On scale 2 x 2 ft. prototype

Fig [38] – **Prototype three**, Layers previous assembly (2018)
Exterior layer – 1 inch. Torrefied/densified softwood
Structural – 5 Inch Vertical Spruce/pine
Insulation – 5-inch Fiberwood insulation
Interior - 5 inch. horizontal Poplar
By Pablo Medina Villanueva

Fig [39] – **Prototype three**, Isometric A (2018)
By Pablo Medina Villanueva

Fig [40] – **Prototype three**, Isometric B (2018)
By Pablo Medina Villanueva

Fig [41] – **Prototype three**, Isometric C (2018)
By Pablo Medina Villanueva

Fig [42] – **Prototype three**, Isometric D (2018)
By Pablo Medina Villanueva

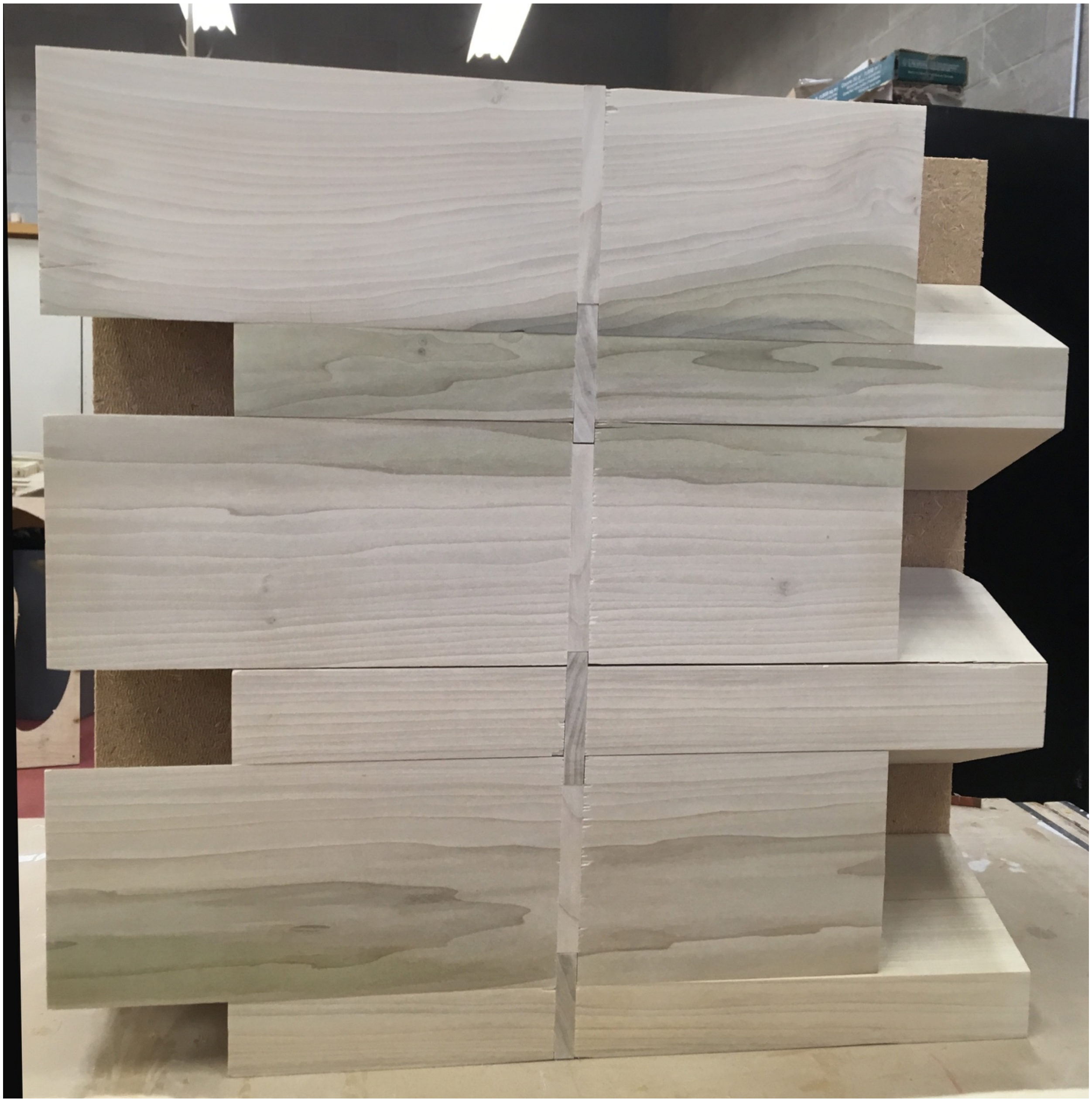


Fig [43] – **Prototype three**, Isometric E (2018)
By Pablo Medina Villanueva

5.4 **Dew Point** – Analysis on mass timber walls

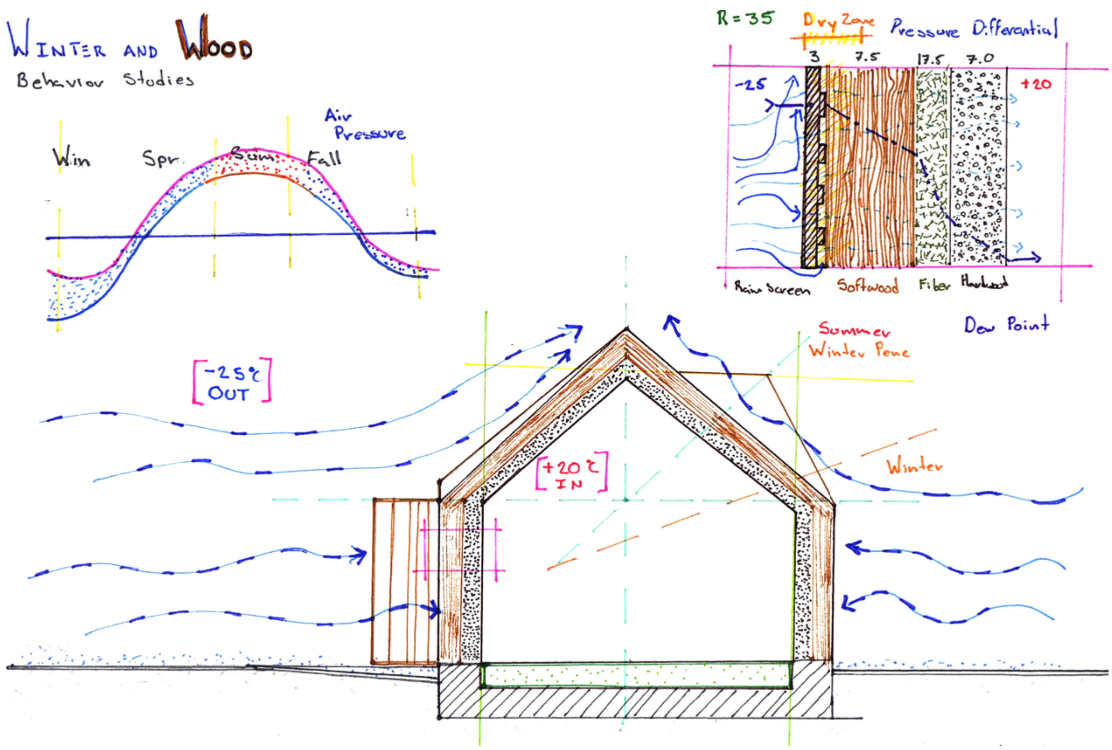


Fig [44] – **Wooden envelope** (2018)
Top – Conceptual drawing of the performance of the building envelope

The problems associated with the building enclosure are commonly associated with the dew point. The dew point is the place in which the interior and exterior temperature peak resulting in the condensation of the airborne water turned into liquid water. This effect progresses overtime becoming moisture and resulting in the deterioration of the building envelope.

In the proposed design, the temperature changes gradually avoiding peaks. Since the R-value of softwood is not high [1.2 to 1.5 per inch. See pg. 50], the transference occurs progressively over the thick wall [18 inches]. Additionally, the prototype proposes ventilation between each layer [see build prototype]. For example, the exterior layer has 45 degrees' angle channels of 4 mm deep open from the bottom and ventilated in the top. This channels naturally induce air currents to dry the material and reduce the surface area that is in contact with the following layer. The subsequent layers are ventilated through the middle [insulation] layer that is open from the bottom to the interior of the wall and is open in the top to the exterior of the building envelope [Fig 17 and built prototype].

5.5 Other **Prototypes**

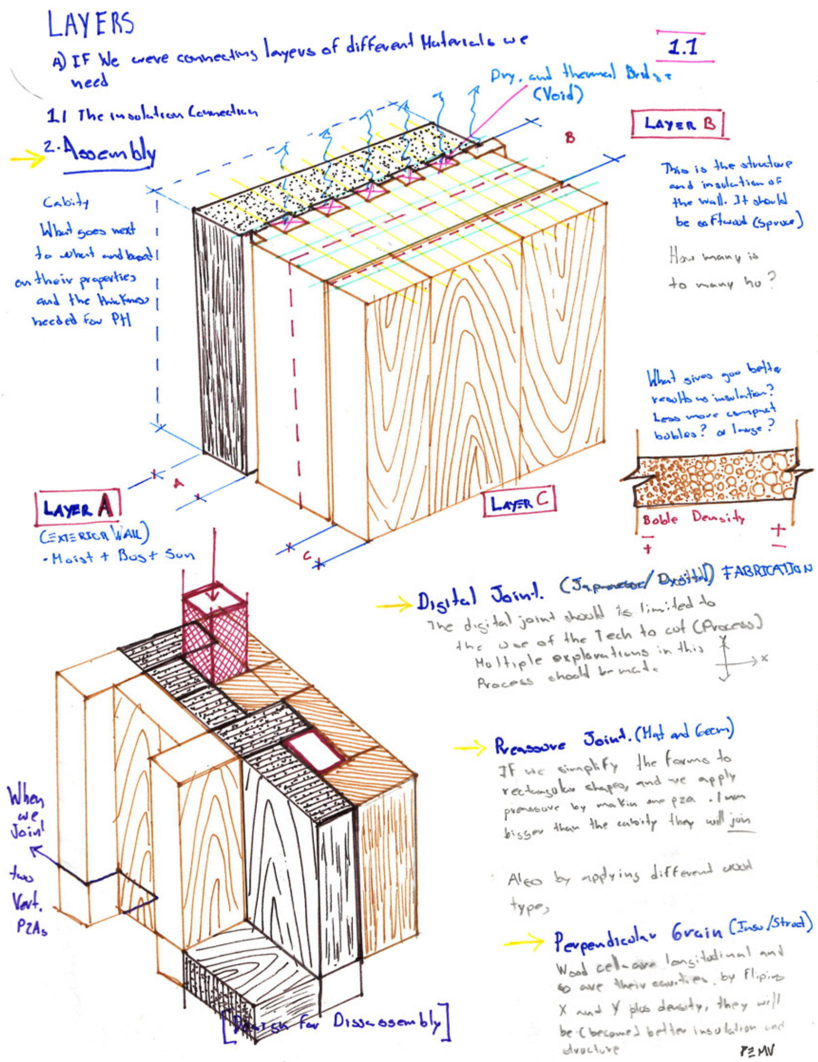
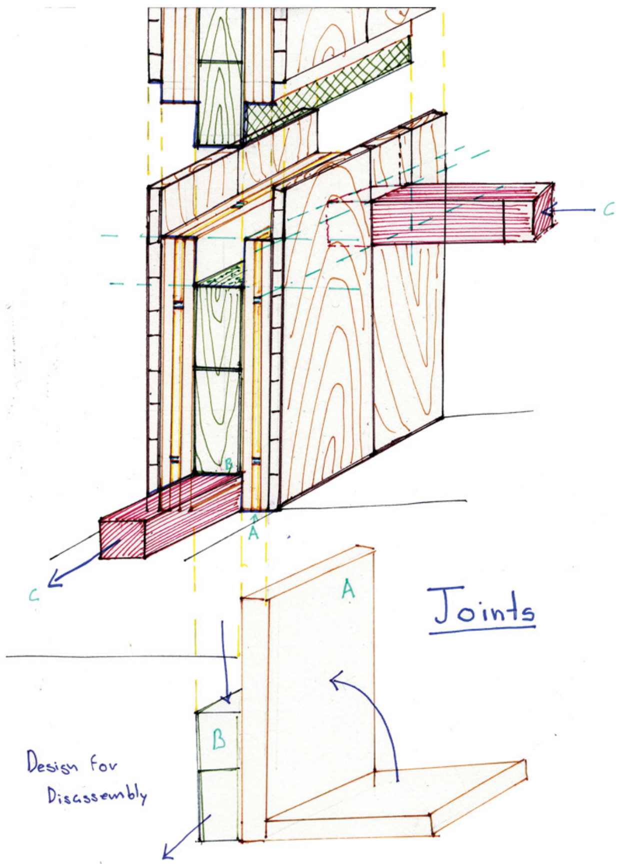


Fig [45] – **Prototype One**, Conceptual drawing (2018)
By Pablo Medina Villanueva

Prototype **One**

This option plans the arrangement of commercial wood geometries and to assemble the different layers. If the end corners of the wall are tight, the rest of the wall could be assembled from a single rectangular shape. The pressure joint would be then a slight ticker piece (red) of hardwood coming from the top and putting pressure on the secured corners of the wall. This system seems suitable for renovation purposes or interior walls. As a conceptual prototype, it requires in-depth research.



A

B

Fig [46] – **Prototype Two**, Conceptual drawing (2018)
Left – Conceptual drawing
Right – Built prototype.
By Pablo Medina Villanueva

Prototype **Two**

This prototype was composed of three layers, two (interior and exterior) built in the same manner. These layers are composed of tree sublayers of alternating spruce and pine rotating in angles from 90 (vertical), 45 (angular) and 180 (horizontal) angles working the lateral forces of torsion and bending. The second (middle) layer, slightly in density, has diagonal channels that allow the wood to dry. The middle layer is made of poplar, hardwood suitable to work in compression and low in cost because of its abundance. The purpose of this layer is to insulate and carry the compression loads. The system was design to be disassembled as panels.

Conclusion: Breathing Wall's, Performance by correspondence

This research began with the common assumption that a performative building envelope was related to what is known as a high-performance envelope. The starting questions were; what defines high-performance? Is it the capacity of the system to minimize energy consumption? Is it the insulation? Alternatively, the durability of the system? The answers found were continuously incomplete. For once, if the focus is on energy, is passive house always a better option to advanced generation systems? Would better generators justify poorly designed building envelopes? If insulation is what determines performance, does it mean that super-insulators (like aerogel for example) are better options? The path of synthetic materials, like plastics for example, had led to permanent global damage. Moreover, In the case of durability, does it make sense to fabricate synthetic walls that last longer than multiple generations all together? Is interrupting the cycle of material change a fit to our human temporal experience? From this perspective, performance seems more the result of an obsession to standardization than an improvement to the quality of life. What about more straightforward solutions like wearing a sweater when winter demands it?

On the other hand, what does it mean to design performance by correspondence? From the perspective of correspondence, the material world, as evident as it looks, is a performative world. In correspondence, materials, different from images, are not static but performative. From a practical sense, performance rather than standardization means to slow down and follow along, through intellectual and sensorial awareness, the direction and intention of these transformations. In making a wall, like a line from A to B, the material selection (material pallet) and material use, should intersect and follow along. The path of correspondence leads me to wooden walls. Wood, rather than only structural, is remarkably active and responsive.

Through this research, I was able to produce multiple drawings and prototypes. Drawing like researching and making, are forms of testing reality. The missing element of this work is measuring. My next goal is to test the capacity of wood to cleanse the air, the performance of multiple types of pressure joints, the insulating properties of the overall assembly, and the stability of the trapezoid over time.

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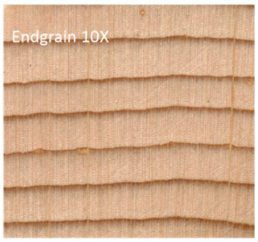
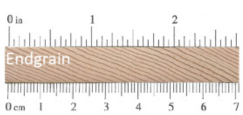
7.0 Material Index - Canadian Species and hygrothermal and mechanical properties

[Picea] Spruce



Stika Spruce
[S.G. 0.49 - 0.59]



Stika Spruce
Distribution: Northwestern North America
Tree Size: 130-160 ft (40-50 m) tall, 4-6 ft (1.2-1.8 m) trunk diameter
Average Dried Weight: 27 lbs/ft3 (425 kg/m3
Specific Gravity (Basic, 12% MC): .36, .42

Mechanical Properties
Janka Hardness: 510 lbf (2,270 N)
Modulus of Rupture: 10,150 lbf/in2 (70.0 MPa)
Elastic Modulus: 1,600,000 lbf/in2 (11.03 GPa)
Crushing Strength: 5,550 lbf/in2 (38.2 MPa)
Shrinkage: Radial: 4.3%, Tangential: 7.5%, Volumetric: 11.5%, T/R Ratio: 1.7

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

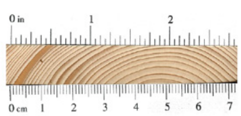
White Spruce
[S.G. 0.33 - 0.43]

White Spruce
Forest: Northern North America
Tree Size: 110 ft (34 m) tall, 2-3 ft (.6-1.0 m) trunk diameter
Average Dried Weight: 27 lbs/ft3 (425 kg/m3)
Specific Gravity (Basic, 12% MC): .33, .43

Mechanical Properties
Janka Hardness: 480 lbf (2,140 N)
Modulus of Rupture: 8,640 lbf/in2 (59.6 MPa)
Elastic Modulus: 1,315,000 lbf/in2 (9.07 GPa)
Crushing Strength: 4,730 lbf/in2 (32.6 MPa)
Shrinkage: Radial: 4.7%, Tangential: 8.2%, Volumetric: 13.7%, T/R Ratio: 1.7

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Red Spruce
[S.G. 0.37 - 0.43]

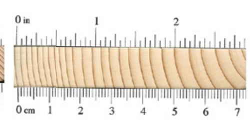


Red Spruce
Forest: Eastern North America
Tree Size: 80-110 ft (24-34 m) tall, 2-4.5 ft (.6-1.4 m) trunk diameter
Average Dried Weight: 27 lbs/ft3 (435 kg/m3)
Specific Gravity (Basic, 12% MC): .37, .43

Mechanical Properties
Janka Hardness: 490 lbf (2,180 N)
Modulus of Rupture: 9,580 lbf/in2 (66.0 MPa)
Elastic Modulus: 1,560,000 lbf/in2 (10.76 GPa)
Crushing Strength: 4,870 lbf/in2 (33.6 MPa)
Shrinkage: Radial: 3.8%, Tangential: 7.8%, Volumetric: 11.8%, T/R Ratio: 2.1

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Engelmann Spruce
[S.G. 0.33 - 0.39]

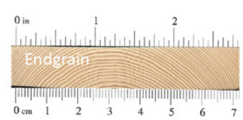


Engelmannii
Forest: Western North America
Tree Size: 130 ft (40 m) tall, 3 ft (1 m) trunk diameter
Average Dried Weight: 24 lbs/ft3 (385 kg/m3)
Specific Gravity (Basic, 12% MC): .33, .39

Mechanical Properties
Janka Hardness: 390 lbf (1,740 N)
Modulus of Rupture: 9,010 lbf/in2 (62.2 MPa)
Elastic Modulus: 1,369,000 lbf/in2 (9.44 GPa)
Crushing Strength: 4,560 lbf/in2 (31.5 MPa)
Shrinkage: Radial: 3.8%, Tangential: 7.1%, Volumetric: 11.0%, T/R Ratio: 1.9

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Black Spruce
[S.G. 0.38 - 0.45]



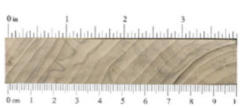
Black Spruce
Forest: **Boreal Forest**
Tree Size: 30-50 ft (10-15 m) tall, 1-1.5 ft (.3-.5 m) trunk diameter
Average Dried Weight: 28 lbs/ft3 (450 kg/m3)
Specific Gravity (Basic, 12% MC): .38, .45

Mechanical Properties
Janka Hardness: 520 lbf (2,320 N)
Modulus of Rupture: 10,100 lbf/in2 (69.7 MPa)
Elastic Modulus: 1,523,000 lbf/in2 (10.50 GPa)
Crushing Strength: 5,410 lbf/in2 (37.3 MPa)
Shrinkage: Radial: 4.1%, Tangential: 6.8%, Volumetric: 11.3%, T/R Ratio: 1.7

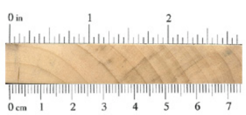
Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

[Populus] Poplar

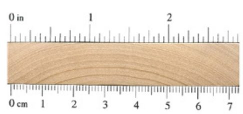
Balsam Poplar
[S.G. 0.31 - 0.37]



Bigtooth Aspen
[S.G. 0.36- 0.43]

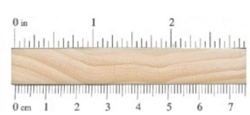


Black Cottonwood
[S.G. 0.31 - 0.38]



Eastern Cottonwood
[S.G. 0.37 - 0.45]

Quaking Aspen
[S.G. 0.35 - 0.42]



Balsam Poplar
Distribution: Canada and northern United States
Tree Size: 80-100 ft (25-30 m) tall, 3-5 ft (1.0-1.5 m) trunk diameter
Average Dried Weight: 23 lbs/ft3 (370 kg/m3)
Specific Gravity (Basic, 12% MC): .31, .37

Mechanical Properties
Janka Hardness: 300 lbf (1,330 N)
Modulus of Rupture: 6,800 lbf/in2 (46.9 MPa)
Elastic Modulus: 1,100,000 lbf/in2 (7.59 GPa)
Crushing Strength: 4,020 lbf/in2 (27.7 MPa)
Shrinkage: Radial: 3.0%, Tangential: 7.1%, Volumetric: 10.5%, T/R Ratio: 2.4

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Bigtooth Aspen
Distribution: Northeastern North America
Tree Size: 65-80 ft (20-25 m) tall, 1.5-2 ft (.6-.7 m) trunk diameter
Average Dried Weight: 27 lbs/ft3 (435 kg/m3)
Specific Gravity (Basic, 12% MC): .36, .43

Mechanical Properties
Janka Hardness: 420 lbf (1,870 N)
Modulus of Rupture: 9,100 lbf/in2 (62.8 MPa)
Elastic Modulus: 1,430,000 lbf/in2 (9.86 GPa)
Crushing Strength: 5,300 lbf/in2 (36.6 MPa)
Shrinkage: Radial: 3.3%, Tangential: 7.9%, Volumetric: 11.8%, T/R Ratio: 2.4

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Black Cottonwood
Distribution: Northwestern North America
Tree Size: 80-150 ft (25-45 m) tall, 5-6 ft (1.5-2.0 m) trunk diameter
Average Dried Weight: 24 lbs/ft3 (385 kg/m3)
Specific Gravity (Basic, 12% MC): .31, .38

Mechanical Properties
Janka Hardness: 350 lbf (1,560 N)
Modulus of Rupture: 8,500 lbf/in2 (58.6 MPa)
Elastic Modulus: 1,270,000 lbf/in2 (8.76 GPa)
Crushing Strength: 4,500 lbf/in2 (31.0 MPa)
Shrinkage: Radial: 3.6%, Tangential: 8.6%, Volumetric: 12.4%, T/R Ratio: 2.4

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Eastern Cottonwood
Distribution: Central and eastern United States
Tree Size: 100-165 ft (30-50 m) tall, 4-6 ft (1.2-2.0 m) trunk diameter
Average Dried Weight: 28 lbs/ft3 (450 kg/m3)
Specific Gravity (Basic, 12% MC): .37, .45

Mechanical Properties
Janka Hardness: 430 lbf (1,910 N)
Modulus of Rupture: 8,500 lbf/in2 (58.6 MPa)
Elastic Modulus: 1,370,000 lbf/in2 (9.45 GPa)
Crushing Strength: 4,910 lbf/in2 (33.9 MPa)
Shrinkage: Radial: 3.9 %, Tangential: 9.2%, Volumetric: 13.9%, T/R Ratio: 2.4

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

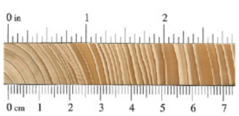
Quaking Aspen
Scientific Name: Populus tremuloides
Distribution: Canada and northern United States
Tree Size: 65-100 ft (20-30 m) tall, 2-3 ft (.6-1.0 m) trunk diameter
Average Dried Weight: 26 lbs/ft3 (415 kg/m3)
Specific Gravity (Basic, 12% MC): .35, .42

Mechanical Properties
Janka Hardness: 350 lbf (1,560 N)
Modulus of Rupture: 8,400 lbf/in2 (57.9 MPa)
Elastic Modulus: 1,180,000 lbf/in2 (8.14 GPa)
Crushing Strength: 4,250 lbf/in2 (29.3 MPa)
Shrinkage: Radial: 3.5%, Tangential: 6.7%, Volumetric: 11.5%, T/R Ratio: 1.9

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

[Abies] Fir

Balsam Fir
[S.G. 0.33 - 0.40]

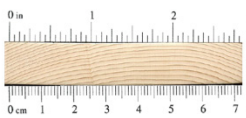


Balsam Fir
Distribution: Northeastern North America
Tree Size: 40-65 ft (12-20 m) tall, 1-2 ft (.3-.6 m) trunk diameter
Average Dried Weight: 25 lbs/ft3 (400 kg/m3)
Specific Gravity (Basic, 12% MC): .33, .40

Mechanical Properties
Janka Hardness: 400 lbf (1,780 N)
Modulus of Rupture: 8,800 lbf/in2 (60.7 MPa)
Elastic Modulus: 1,387,000 lbf/in2 (9.57 GPa)
Crushing Strength: 5,000 lbf/in2 (34.5 MPa)
Shrinkage: Radial: 2.9%, Tangential: 6.9%, Volumetric: 11.2%, T/R Ratio: 2.4

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Sulbapine Fir
[S.G. 0.31 - 0.53]



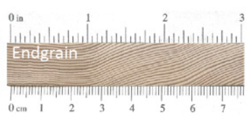
Subalpine Fir
Distribution: Mountainous regions of eastern North America
Tree Size: 65-100 ft (20-30 m) tall, 2-3 ft (.6-1 m) trunk diameter
Average Dried Weight: 33 lbs/ft3 (530 kg/m3)
Specific Gravity (Basic, 12% MC): .31, .53

Mechanical Properties
Janka Hardness: 350 lbf (1,560 N)
Modulus of Rupture: 8,420 lbf/in2 (58.0 MPa)
Elastic Modulus: 1,324,000 lbf/in2 (9.13 GPa)
Crushing Strength: 4,910 lbf/in2 (33.9 MPa)
Shrinkage: Radial: 2.6%, Tangential: 7.4%, Volumetric: 9.4%, T/R Ratio: 2.8

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

[Tsuga] Hemlock

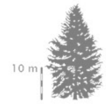
Western Hemlock
[S.G. 0.31 - 0.47]



Western Hemlock
Scientific Name: Tsuga heterophylla
Distribution: Northwest coast of North America
Tree Size: 165-200 ft (50-60 m) tall, 3-5 ft (1-1.5 m) trunk diameter
Average Dried Weight: 29 lbs/ft3 (465 kg/m3)
Specific Gravity (Basic, 12% MC): .37, .47

Mechanical Properties
Janka Hardness: 540 lbf (2,400 N)
Modulus of Rupture: 11,300 lbf/in2 (77.9 MPa)
Elastic Modulus: 1,630,000 lbf/in2 (11.24 GPa)
Crushing Strength: 7,200 lbf/in2 (37.3 MPa)
Shrinkage: Radial: 4.2%, Tangential: 7.8%, Volumetric: 12.4%, T/R Ratio: 1.9

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK



Eastern Hemlock
[S.G. 0.36 - 0.45]

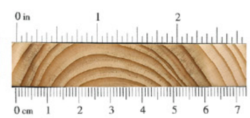
Eastern Hemlock, Canadian Hemlock
Scientific Name: Tsuga canadensis
Distribution: Eastern North America
Tree Size: 65-100 ft (30 m) tall, 2-3 ft (.6-1 m) trunk diameter
Average Dried Weight: 28 lbs/ft3 (450 kg/m3)
Specific Gravity (Basic, 12% MC): .36, .45

Mechanical Properties
Janka Hardness: 500 lbf (2,220 N)
Modulus of Rupture: 8,900 lbf/in2 (61.4 MPa)
Elastic Modulus: 1,200,000 lbf/in2 (8.28 GPa)
Crushing Strength: 5,410 lbf/in2 (37.3 MPa)
Shrinkage: Radial: 3.0%, Tangential: 6.8%, Volumetric: 9.7%, T/R Ratio: 2.3

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

[Larix] Larch

Eastern Larch
[S.G. 0.49 - 0.59]



Tamarack, Eastern Larch
Scientific Name: Larix larcina
Distribution: Canada and northeastern United States
Tree Size: 50-65 ft (15-20 m) tall, 1-2 ft (.3-.6 m) trunk diameter
Average Dried Weight: 37 lbs/ft3 (595 kg/m3)
Specific Gravity (Basic, 12% MC): .49, .59

Mechanical Properties
Janka Hardness: 590 lbf (2,620 N)
Modulus of Rupture: 11,600 lbf/in2 (80.0 MPa)
Elastic Modulus: 1,640,000 lbf/in2 (11.31 GPa)
Crushing Strength: 7,160 lbf/in2 (49.4 MPa)
Shrinkage: Radial: 3.7%, Tangential: 7.4%, Volumetric: 13.6%, T/R Ratio: 2.0

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Source: The Wood-Database
http://www.wood-database.com/about/

[Pinus] Pine

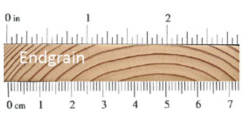
Jack Pine
[S.G. 0.4 - 0.5]

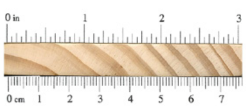
Lodgepole Pine
[S.G. 0.38 - 0.47]

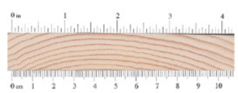
Ponderosa Pine
[S.G. 0.38 - 0.45]

Red Pine
[S.G. 0.41 - 0.55]

Eastern White Pine
[S.G. 0.34 - 0.4]







Jack Pine
Distribution: Canada and northern United States
Tree Size: 50-80 ft (15-24 m) tall, 1-2 ft (.3-.6m) trunk diameter
Average Dried Weight: 31 lbs/ft3 (500 kg/m3)
Specific Gravity (Basic, 12% MC): .40, .50

Mechanical Properties
Janka Hardness: 570 lbf (2,540 N)
Modulus of Rupture: 9,900 lbf/in2 (68.3 MPa)
Elastic Modulus: 1,350,000 lbf/in2 (9.31 GPa)
Crushing Strength: 5,660 lbf/in2 (39.0 MPa)
Shrinkage:Radial: 3.7%, Tangential: 6.6%, Volumetric: 10.3%, T/R Ratio: 1.8h

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Lodgepole Pine, Shore Pine
Distribution: Western North America
Tree Size: 65-100 ft (20-30 m) tall, 1-2 ft (.3-.6 m) trunk diameter; size varies widely depending upon subspecies
Average Dried Weight: 29 lbs/ft3 (465 kg/m3)
Specific Gravity (Basic, 12% MC): .38, .47

Mechanical Properties
Janka Hardness: 480 lbf (2,140 N)
Modulus of Rupture: 9,400 lbf/in2 (64.8 MPa)
Elastic Modulus: 1,340,000 lbf/in2 (9.24 GPa)
Crushing Strength: 5,370 lbf/in2 (37.0 MPa)
Shrinkage:Radial: 4.3%, Tangential: 6.7%, Volumetric: 11.1%, T/R Ratio: 1.6

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Ponderosa Pine
Scientific Name: Pinus ponderosa
Distribution: Western North America
Tree Size: 100-165 ft (30-50 m) tall, 2-4 ft (.6-1.2 m) trunk diameter
Average Dried Weight: 28 lbs/ft3 (450 kg/m3)
Specific Gravity (Basic, 12% MC): .38, .45

Mechanical Properties
Janka Hardness: 460 lbf (2,050 N)
Modulus of Rupture: 9,400 lbf/in2 (64.8 MPa)
Elastic Modulus: 1,290,000 lbf/in2 (8.90 GPa)
Crushing Strength: 5,320 lbf/in2 (36.7 MPa)
Shrinkage:Radial: 3.9%, Tangential: 6.2%, Volumetric: 9.7%, T/R Ratio: 1.6

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Red Pine, Norway Pine
Distribution: Northeastern North America
Tree Size: 65-100 ft (20-30 m) tall, 2-3 ft (.6-1 m) trunk diameter
Average Dried Weight: 34 lbs/ft3 (545 kg/m3)
Specific Gravity (Basic, 12% MC): .41, .55

Mechanical Properties
Janka Hardness: 560 lbf (2,490 N)
Modulus of Rupture: 11,000 lbf/in2 (75.9 MPa)
Elastic Modulus: 1,630,000 lbf/in2 (11.24 GPa)
Crushing Strength: 6,070 lbf/in2 (41.9 MPa)
Shrinkage: Radial: 3.8%, Tangential: 7.2%, Volumetric: 11.3%, T/R Ratio: 1.9

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Source: The Wood-Database
http://www.wood-database.com/about/

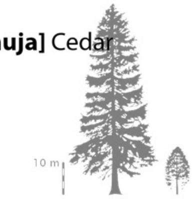
Eastern White Pine
Distribution: Eastern North America
Tree Size: 65-100 ft (20-30 m) tall, 2-4 ft (.6-1.2 m) trunk diameter (historically older-growth trees were much larger)
Average Dried Weight: 25 lbs/ft3 (400 kg/m3)
Specific Gravity (Basic, 12% MC): .34, .40

Mechanical Properties
Janka Hardness: 380 lbf (1,690 N)
Modulus of Rupture: 8,600 lbf/in2 (59.3 MPa)
Elastic Modulus: 1,240,000 lbf/in2 (8.55 GPa)
Crushing Strength: 4,800 lbf/in2 (33.1 MPa)
Shrinkage: Radial: 2.1%, Tangential: 6.1%, Volumetric: 8.2%, T/R Ratio: 2.9

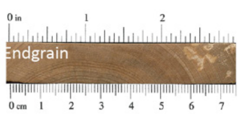
Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

[Acer] Maple

[Thuja] Cedar



Red Maple
[S.G. 0.49 - 0.61]



Red Maple
Distribution: Eastern North America
Tree Size: 65-100 ft (20-30 m) tall, 2-3 ft (.6-1.0 m) trunk diameter
Average Dried Weight: 38lbs/ft3 (610 kg/m3)
Specific Gravity (Basic, 12% MC): .49, .61

Mechanical Properties
Janka Hardness: 950 lbf (4,230 N)
Modulus of Rupture: 13,400 lbf/in2 (92.4 MPa)
Elastic Modulus: 1,640,000 lbf/in2 (11.31 GPa)
Crushing Strength: 6,540 lbf/in2 (45.1 MPa)
Shrinkage: Radial: 4.0%, Tangential: 8.2%, Volumetric: 12.6%, T/R Ratio: 2.1

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Silver Maple
[S.G. 0.44 - 0.53]

Silver Maple
Scientific Name: Acer saccharinum
Tree Size: 80-115 ft (25-35 m) tall, 2-3 ft (.6-1.0 m) trunk diameter
Average Dried Weight: 33 lbs/ft3 (530 kg/m3)
Specific Gravity (Basic, 12% MC): .44, .53

Mechanical Properties
Janka Hardness: 700 lbf (3,110 N)
Modulus of Rupture: 8,900 lbf/in2 (61.4 MPa)
Elastic Modulus: 1,140,000 lbf/in2 (7.86 GPa)
Crushing Strength: 5,220 lbf/in2 (36.0 MPa)
Shrinkage: Radial: 3.0%, Tangential: 7.2%, Volumetric: 12.0%, T/R Ratio: 2.4

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

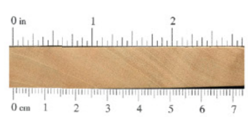
Black Maple
[S.G. 0.52 - 0.64]

Black Maple, Black Sugar Maple
Scientific Name: Acer nigrum
Tree Size: 80-115 ft (25-35 m) tall, 2-3 ft (.6-1.0 m) trunk diameter
Average Dried Weight: 40 lbs/ft3 (640 kg/m3)
Specific Gravity (Basic, 12% MC): .52, .64

Mechanical Properties
Janka Hardness: 1,180 lbf (5,250 N)
Modulus of Rupture: 13,300 lbf/in2 (91.7 MPa)
Elastic Modulus: 1,620,000 lbf/in2 (11.17 GPa)
Crushing Strength: 6,680 lbf/in2 (46.1 MPa)
Shrinkage: Radial: 4.8%, Tangential: 9.3%, Volumetric: 14.0%, T/R Ratio: 1.9

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Manitoba Maple
[S.G. 0.42 - 0.49]

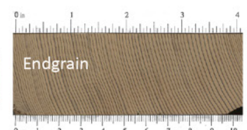


Box Elder, Manitoba Maple
Tree Size:35-80 ft (10-25 m) tall, 1-2 ft (.3-.6 m) trunk diameter
Average Dried Weight: 30 lbs/ft3 (485 kg/m3)
Specific Gravity (Basic, 12% MC): .42, .49

Mechanical Properties
Janka Hardness: 720 lbf (3,200 N)
Modulus of Rupture: 8,010 lbf/in2 (55.2 MPa)*
*Estimated bending strength from data of green wood at: 5,220 lbf/in2 (36.0 MPa)
Elastic Modulus: 1,050,000 lbf/in2 (7.24 GPa)*
*Estimated elasticity from data of green wood at: 870,000 lbf/in2 (6.00 GPa)
Crushing Strength: 4,950 lbf/in2 (34.1 MPa)
Shrinkage: Radial: 3.9%, Tangential: 7.4%, Volumetric: 14.8%, T/R Ratio: 1.9

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK

Western Red Cedar
[S.G. 0.31 - 0.37]



Western Red Cedar

Tree Size: 165-200 ft (50-60 m) tall, 7-13 ft (2-4 m) trunk diameter
Average Dried Weight: 23 lbs/ft3 (370 kg/m3)
Specific Gravity (Basic, 12% MC): .31, .37

Mechanical Properties
Janka Hardness: 350 lbf (1,560 N)
Modulus of Rupture: 7,500 lbf/in2 (51.7 MPa)
Elastic Modulus: 1,110,000 lbf/in2 (7.66 GPa)
Crushing Strength: 4,560 lbf/in2 (31.4 MPa)
Shrinkage: Radial: 2.4%, Tangential: 5.0%, Volumetric: 6.8%, T/R Ratio: 2.1

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Source: The Wood-Database
http://www.wood-database.com/about/

[Pseudosuga] Douglas fir

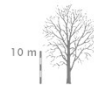
Douglas-fir
[S.G. 0.45 - 0.51]

Douglas-Fir
Distribution: Western North America
Tree Size: 200-250 ft (60-75 m) tall, 5-6 ft (1.5-2 m) trunk diameter
Average Dried Weight: 32 lbs/ft3 (510 kg/m3)
Specific Gravity (Basic, 12% MC): .45, .51

Mechanical Properties
Janka Hardness: 620 lbf (2,760 N)
Modulus of Rupture: 12,500 lbf/in2 (86.2 MPa)
Elastic Modulus: 1,765,000 lbf/in2 (12.17 GPa)
Crushing Strength: 6,950 lbf/in2 (47.9 MPa)
Shrinkage: Radial: 4.5%, Tangential: 7.3%, Volumetric: 11.6%, T/R Ratio: 1.6

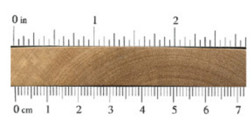
Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

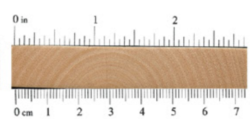
[Betula] Birch



Yellow Birch
[S.G. 0.55 - 0.69]

White (paper) Birch
[S.G. 0.48 - 0.61]





Yellow Birch
Distribution: Northeastern North America
Tree Size: 65-100 ft (20-30 m) tall, 2-3 ft (.6-1.0 m) trunk diameter
Average Dried Weight: 43 lbs/ft3 (690 kg/m3)
Specific Gravity (Basic, 12% MC): .55, .69

Mechanical Properties
Janka Hardness: 1,260 lbf (5,610 N)
Modulus of Rupture: 16,600 lbf/in2 (114.5 MPa)
Elastic Modulus: 2,010,000 lbf/in2 (13.86 GPa)
Crushing Strength: 8,170 lbf/in2 (56.3 MPa)
Shrinkage: Radial: 7.3%, Tangential: 9.5%, Volumetric: 16.8%, T/R Ratio: 1.3

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

White (Paper) Birch
Distribution: Northern and central North America
Tree Size: 65-100 ft (20-30 m) tall, 2-3 ft (.6-1.0 m) trunk diameter
Average Dried Weight: 38 lbs/ft3 (610 kg/m3)
Specific Gravity (Basic, 12% MC): .48, .61

Mechanical Properties
Janka Hardness: 910 lbf (4,050 N)
Modulus of Rupture: 12,300 lbf/in2 (84.8 MPa)
Elastic Modulus: 1,590,000 lbf/in2 (10.97 GPa)
Crushing Strength: 5,690 lbf/in2 (39.2 MPa)
Shrinkage: Radial: 6.3%, Tangential: 8.6%, Volumetric: 16.2%, T/R Ratio: 1.4

Hygrothermal Properties
Carbon Storage: 788 Kg Co2e/m3
Chemical Composition:
69% Cellulose
28% Lign
3% Extractives and minerals
Physical Properties
Density U0 430 kg/m3
Density U12 470 kg/m3
Hygrothermal Properties
Saturated Moisture: 30- 34 %
Vapour Resistance Factor: 40/80
Thermal Conductivity U12: 011 W/mK
Heat Capacity : 1.6 kJ/kgK

Source: The Wood-Database
http://www.wood-database.com/about/