UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation Into The Use of Glue Laminated Wood in Construction

Regina Lok Yun So James Wilkie Thai Nguyen Szymon Brykajlo

University of British Columbia

APSC261

November 30, 2010

An Investigation Into The Use of Glue Laminated Wood in Construction

by

Regina Lok Yun So
James Wilkie
Thai Nguyen
Szymon Brykajlo

APSC 261

Instructor: Christina Gyenge

November 30, 2010

ABSTRACT

This report is a triple bottom line assessment off use of glued laminated wood (glulam) in construction. Its purpose is to evaluate the use of glulam for structural elements against conventional reinforced concrete construction. In particular this report considers the social, environmental, and economic impacts of using glued laminated wood over steel and concrete.

One of the advantages of glued laminated wood is that it can be built out of pine beetle infested wood without losing its strength properties. If glulam was more widely used as a construction material, many hectares of BC pine forests previously regarded as non-merchantable would become useful. This could potentially bring back thousands of jobs to people in forestry industry. Studies have shown that people prefer wooden interiors over concrete or steel for their warm and relaxing feel. To evaluate glulam from the environmental perspective the Life Cycle Assessment method was used. It was found that total energy use, greenhouse gas index, air pollution index, solid waste and ecological resource impact use where all the lowest for wood. When considering the use of glulam one should keep in mind that formaldehyde is still the most common glue used to bond individual parts of a glulam beam. Formaldehyde is toxic and at concentrations above 0.1 ppm has adverse effects to human health. More expensive non-toxic resin alternatives are available. From an economic standpoint, using wood for structural elements of multi-story buildings costs the same or less comparing to a traditional concrete and steel construction. Using wood could be made cheaper by increasing prefabrication, increasing logistics, and improving construction process.

Considering that the new sub is designed with sustainability as its primary objective, wood would be a good material to use for at least some of its structural elements. The key points to support this idea are the lowest negative environmental impact according to LCA method, lower costs of construction, and ability to use pine beetle infested timber.

TABLE OF CONTENTS

TABLE OF FIGURES

GLOSSARY

Life Cycle assessment (LCA): a technique to assess each and every impact associated with all the stages of a process from cradle-to-grave (i.e., from raw materials through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).

Photosynthesis: a process that converts carbon dioxide into organic compounds, especially sugars, using the energy from sunlight occurring in plants, algae, and many species of bacteria, but not in archaea.

Carbon Cycle: the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth.

Formaldehyde: an organic compound with the formula CH_2O used in many different chemical compounds. Exposure to formaldehyde is a significant consideration for human health.

1.0 INTRODUCTION

Glued laminated wood (glulam) is a type of structural timber composed of multiple dimensioned layers of wood glued together. Each dimensional piece is usually not thicker 3 inches and its length varies. Glulam is typically used for roof and floor beams as well as joists. Individual glulam beams are typically joined by plates, bolts and dawels. Some of the primary advantages of glulam over concrete are lower embodied energy and greenhouse gas balance. Some of the primary glulam advantages over solid wood are longevity, strength, ability to make long and complex shapes.

2.0 SOCIAL IMPACTS OF USING LAMINATED WOOD IN CONSTRUCTION

One of the most important factors to decide whether laminate wood is a suitable choice as a construction material is to look at the various impacts it has on the welfare of human beings in society –our personal well being as well as for our general community. The following sections will discuss various aspects concerning the social impacts due to the use of laminate wood.

2.1 USE OF PINE BEETLE INFECTED WOOD

The primary factor in considering using wood for construction is due to our location where the lumber industry is one of the largest industries in British Columbia. Pine beetle infection is known to be one of the greatest dangers to lodgepole pine forests, with an enormous impact both socially and economically.

The largest outbreak of mountain pine beetle as of 2007 was recorded at over 10.1 million hectares out of only 14.9 million hectares of lodgepole pine forests being affected just in British Columbia alone. While mature pine contributes to approximately 29% of total provincial timber, 40% of merchantable pine has been affected by pine beetles. [1] Figure 1 shows a photo of the aerial view of the infected forest in British Columbia, and Figure 2 shows the approximate areas in British Columbia that was infected in the past few years, and the prediction for the next few years. The beetles mass-murder mature healthy trees and leave the dead trees stained with a tint of blue. Due to the blue stain,

Figure 1 - Pine beetle affected forests in British Columbia

(http://www.treehugger.com/files/2009/01/time-to-grow-cut-use-wood.php)

these pine beetled affected pine wood was regarded as non-profitable and useless on the market. However, the structural properties of blue-stained lodgepole pine do not differ much from non-stained healthy pine wood.

2.2 PINE BEETLE INFESTED WOOD APPLICATION

Due to the increased volume of attacked pine lumber, more studies have been done to test the properties of post laminated wood with pine beetle transmitted lodgepole pine. Bending, toughness, and trust connector tests conducted by Forintek Canada Corp in 2003 shows that there are no significant differences between beetle infected wood and non-infected wood in terms of mechanical properties. [2] In fact, stained laminate posts

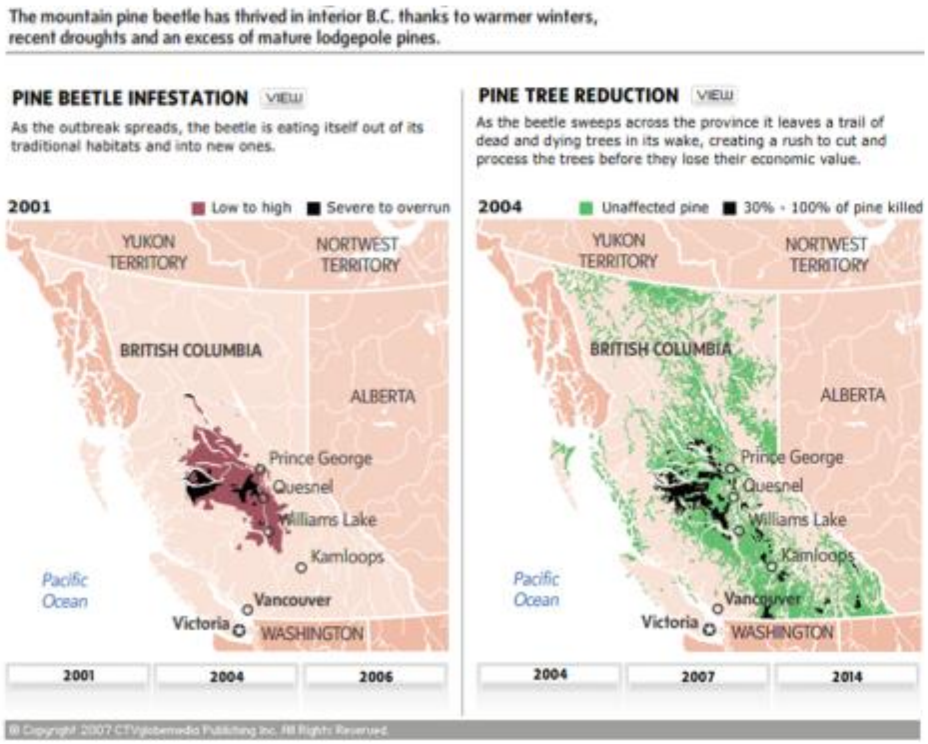

Figure 2 - Pine beetle infestation and pine tree reduction in British Columbia

(http://www.treehugger.com/files/2007/09/the_pine_beetle.php)

exhibited good performance compared to 140mm x 140mm Select Structural Douglas-fir posts.

Due to the increasing volume of affected areas, it is much more sustainable to use the stained pine wood. If the blue tint may be an issue, there are methods to cover the blue-tint during the process of lamination. The extra cost to cover the color can be balanced by the significantly lower cost of pine beetle infected wood as compared to healthy timbers.

As an example, the Richmond Oval, speed skating rink built for Vancouver Winter Olympics 2010, used one million board feet of B.C. pine beetle-infected wood to construct one of the longest clear span roofs in North America. It was constructed by undulating linked sections and has received an award for the use of the infected wood in the ceiling construction. The blue tint in the roof during construction (Figure 3) is much more evident as compared to the finished rink (Figure 4). With the Richmond Oval demonstrating the use of laminated pine beetle infected wood, it is not hard to implement the same concepts for the new SUB project utilizing the abundance of the infected wood.

2.3 JOBS AFFECTED BY PINE BEETLE

A report from the Central 1 Credit Union predicts over 11, 250 forestry jobs will be lost due to the pine beetle infestation. 9500 indirect jobs will also be lost in the BC Interior region. Just like with the mining boom, many forestry-supported populations have moved elsewhere and it is expected around 11, 500 homes will become vacant. [3] This is caused by the amount of jobs due to the lack of market value for pine beetle infected timber. If there is an increased interest to use the blue stained pine wood, a lot more jobs can be made available again and less people will have to relocate due to infestation.

Figure 3 - Roof of Richmond Oval during construction

(http://www.treehugger.com/files/2009/01/time-to-grow-cut-use-wood.php)

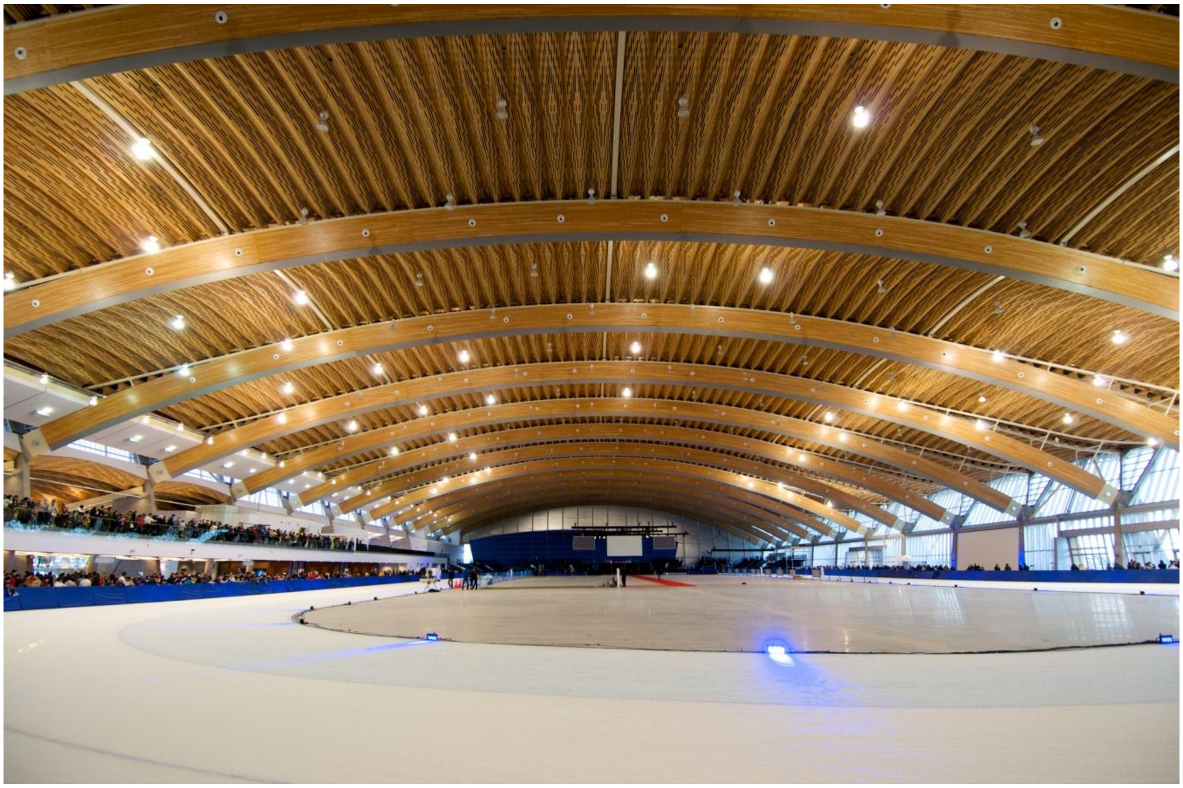

Figure 4 - Finished roof of Richmond Oval

(**http://en.wikipedia.org/wiki/File:Richmond_Olympic_Oval_intern_View.jpg**)

2.4 SOCIAL SPACE

Environments with strong wood presence are often connected to words such as "warm", "comfortable", "relaxing", "natural", and "inviting". In a study by a group of professors at University of British Columbia, 119 people partake in a three-part experimental study to try to understand whether wood have an effect on the overall psychological well being of humans. [4] Mentioned in their paper was another study done by Broman in 2000, which found that different features of wood would evoke feelings such as "harmony", "simplicity", and "balance" in the participants asked. In another study in Japan in the early 1990s also showed people find interiors with higher proportion of wood to be more "warm" and "calming".

In their main study, where they showed the 119 participates photos over various photos of interiors with different layouts, there were several factors that seem to contribute to higher scores. They tend to have larger windows, with a nature view visible outside the window. The two highest rated living rooms have a heavy wood presence and with very little synthetic materials. Most of the top rated (photos of) rooms also had wooden floors.

Figure 5 outlines the importance of various factors in a room the participants prefer to spend time in. Although wood, explicitly listed, isn't ranked very high, it definitely contributes the top few factors.

Factor	% of responses[1]
Color	49.6%
Lighting	42.0%
Comfort	27.7%
Natural lighting	27.7%
Furniture	25.2%
Warmth	21.0%
Windows	18.5%
Space	16.0%
Wood	15.1%
Plants/flowers	13.4%
Efficient/functional layout	13.4%
Not cluttered/crowded	12.6%
Clean/tidy	10.9%
Openness	10.1%

[1] Total exceeds 100% because multiple responses were provided by some subjects.

Figure 5 - Importance of various factors that subjects would want to spend time in

It is important to note that since "color" is important, if pine beetle infected wood is to be used, the blue tint may become a big factor to consumer's preference. Lighter colored wood would likely cause a room looking "brighter", which will contribute to the 2^{nd} ranked "lighting" and 4^{th} ranked "natural lighting" factor. Although this report focuses on the use of laminate wood in construction and not interior design, it is likely beams and the ceiling or roof would be visible in the finished building. In figure 6, it is evident most think of wood as the warmest, most natural, homey, and relaxing as compared to ceramic, stone and leather materials. A similar response when comparing wood with plastic and glass as well as comparing wood with painted surface and wallpaper. Over 75.6% of the 119 respondents have positive feedback about a room containing a lot of wood details and furnishings.

This study being done locally helps us put in perspective the amount of people who would likely find an environment with more wood presence to be more “homey”, “warm” and “relaxing”. This is important because the new SUB is to be a central space for students, staffs, and visitors and what they feel about the building will be one of the priorities in deciding the building design.

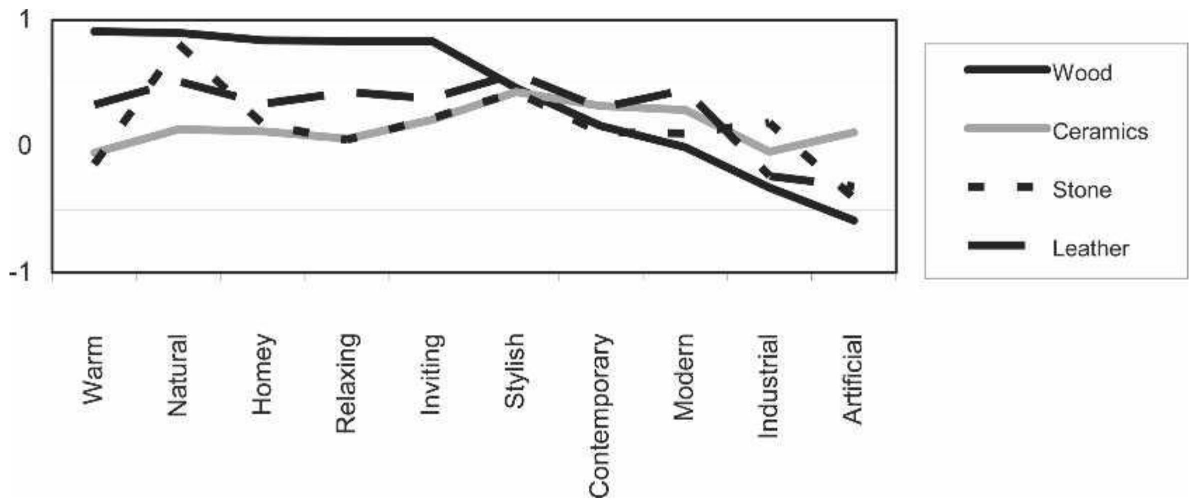

Figure 6 - Perceived attributes of wood versus other natural furnishing materials (1 = material possesses attribute, -1 = material lacks attribute)

3.0 EVIRONMENTAL IMPACTS OF USING LAMINATED WOOD IN CONSTRUCTION

3.1 ENERGY CONSUMPTION

Total energy consumption is the first factor to consider when evaluating the environmental aspects of a product. A systematic way to do this is to use Life Cycle Assessment (LCA). LCA gives a scientific measurement of environmental impacts of a product throughout its entire life span from production stage to in-use stage and eventually end of life stage including disposal, reuse or recycling [5]. Comparing LCA of common construction materials such as steel, concrete and wood helps determine the friendliness of a material to the environment. As a result, wood surpasses steel and concrete at all criteria. In particular, wood consumes less total energy meaning that solid waste and ecological impact are reduced. Less impacts on environment essentially allows the achievement of lower greenhouse gas index and air pollution index. See Figure 7 below:

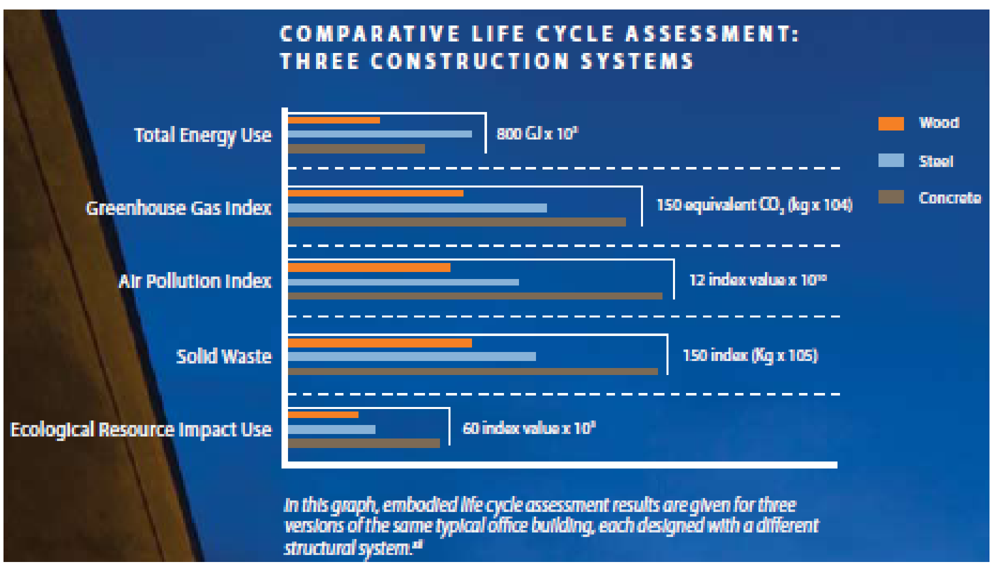

Figure 7 - LCA of wood, steel and concrete

(**http://www.cwc.ca/NR/rdonlyres/4749BE13-2089-4A49-87C8-55E40257EDD7/0/Canadian_Wood.pdf**)

3.2 CARBON DIOXIDE (CO2) EMISSION

One of the most significant and distinctive advantages of using constructional wood over other materials is the reduction of CO2 emission. As mentioned in previous section, LCA is again used for CO2 emission of wood in three main phases: production phase, in-use phase and end of life phase. At production phase, wood generally requires less energy for extraction, production and transportation than that of other materials. Therefore, less CO2 is emitted. In addition, the sink effect [6] of wood gives negative net emission. The in-use phase considers how much energy is needed to operate and maintenance the product. Fortunately, wood can be a really good thermal, acoustic and moisture insulator [7]. Because the majority of energy is spent on the operating period, a good design can significantly reduce energy consumption and at the same time give a comfortable living condition. The less energy is required, the less CO2 is emitted. Finally at the end of life phase, wood can be used as a carbon neutral energy source meaning that it simply returns the CO2 originally removed from the atmosphere. The net CO2 emissions of wood and other building materials are shown in Figure 8 below.

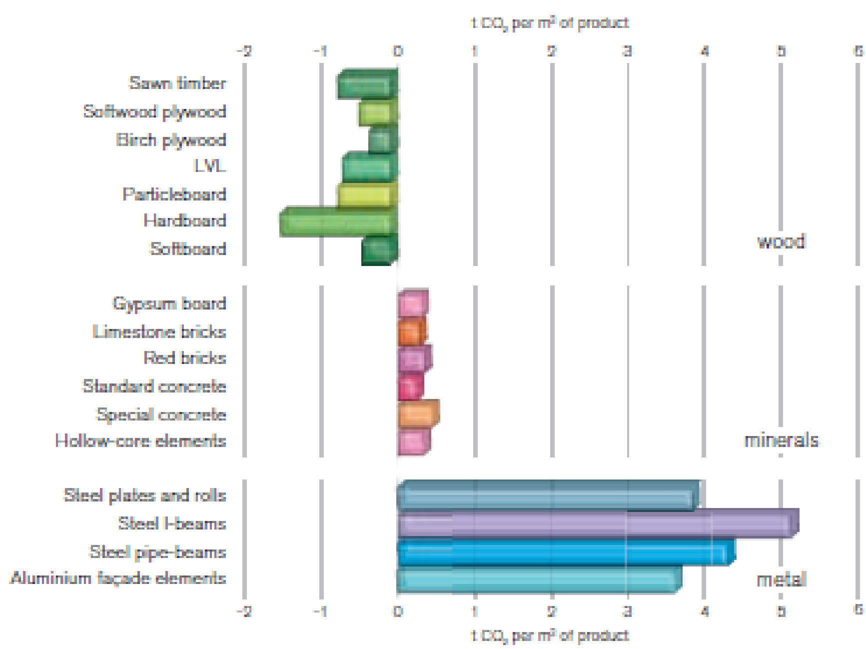

Figure 8 - Net CO2 emissions of selected building materials during whole lifecycle

(http://www.roadmap2010.eu/wisd/pdfs/30-45.pdf)

Wood and wood based products play an important role in attempting to slow down global warming. In nature, trees take in CO_2 and release oxygen during photosynthesis process. When trees are made into wood, they still hold on to the CO_2 absorbed previously and trap it inside for a long time. In contrast, other building materials require a large amount of energy for production which adds more CO_2 to the environment. A question would be asked is how much CO_2 can be saved using wood. The answer is quite impressive: 0.75 to 1 tonne of CO_2 is saved from substituting a cubic metre of wood for concrete blocks or bricks [8]. Therefore, using wood and wood based products does help tackle climate change.

3.3 CARBON CYCLE OF WOOD BASED PRODUCT

One crucial factor to determine if a material is environmental friendly is its recyclability. Wood, in fact, is much easier to recycle compared to other building materials. Depending on the conditions, wood can be re-used, recycled or used as carbon neutral energy source. Figure 9 below summarizes life cycle of wood based products.

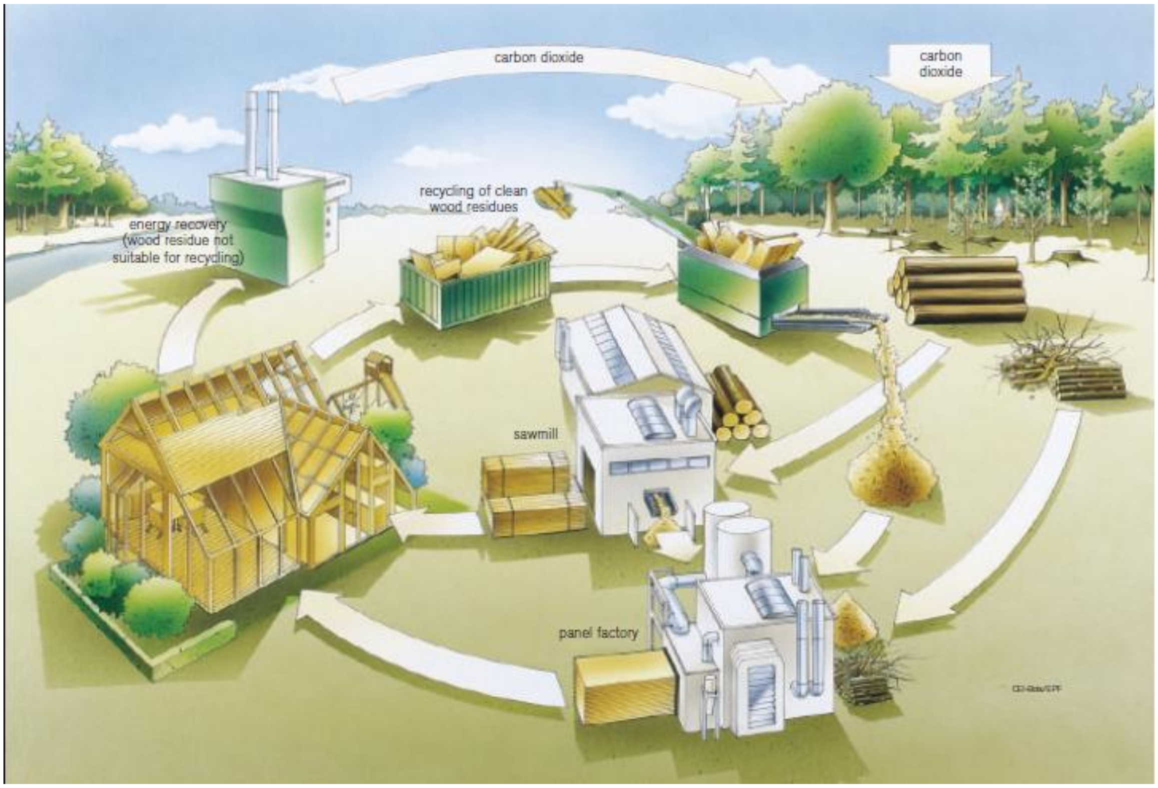

Figure 9 - Carbon cycle of wood and wood based product

(http://www.roadmap2010.eu/wisd/pdfs/46-57.pdf)

During its closed-cycle life, wood minimizes CO2 emission and maximizes usage with little energy consumption. For example, a wooden structure after many years of use can be re-used in a new building, either intact or resized. Generally, the portion of re-usable wood with or without repairs in existing structure is significant. A recent study in Europe shows that over half of 44000 tonne of building and demolition wood could be re-used, 6700 tonne as sawn timber and 16000 recycled into wood based panels [9]. In case the wood structures are not good enough to re-use, they can be recycled into other products. The recycled content from manufactured products has increased over time. Nowadays, numerous products are made from recovered wood including wood-plastic composites, animal bedding, surfacing etc [9]. Nevertheless, only high quality recovered wood can be used because of health concerns for all customers. Lastly, if those wood based products can be neither re-used nor recycled, they are then used as a substitute for fossil fuel. The energy coming out from this source is actually clean and does not produce additional CO2 other than the CO2 inside the wood originally.

3.4 ADHESIVES USED IN LAMINATED WOOD

In order to maximize the use of wood in construction, laminated wood has been introduced. Laminated wood is engineered wood which provides a much higher degree of dimension and quality controllability as compared to natural wood. It consists of multiple layers glued together by some adhesives and is designed to meet application specific requirements [10]. Several types of adhesives have been used to strengthen wood bonding. The most common ones are all derived from formaldehyde which is known to be toxic. Studies show that laminated veneer lumbers with Urea-formaldehyde has the best performance on bonding strength and dimensional stability [11]. However, there have been many health concerns with exposure to formaldehyde. Formaldehyde emission from formaldehyde based resins used for production of laminated wood is a real thread for both workers and consumers. At concentration above 0.1 ppm in air formaldehyde can irritate eyes and mucous membranes, resulting in watery eyes and when inhaled it cause headaches, difficulty breathing and asthma symptoms [12]. Therefore, this issue should be taken into account seriously when designing for the new SUB.

3.5 AVAILABLE RESOURCES IN CANADA

Another reason to support the use of wood in construction is the availability of natural resources. In fact, Canada has 10% of total forest cover in the world, more than any other country [8]. Abundant supply means no need for importing which retains affordable prices. With enhanced laws and regulations, only less than one percent of managed forest is harvested every year and those areas that are logged must be promptly regenerated. Overall, deforestation rate has been virtually zero for more than 20 years [8]. Breakdown of Canada's forest cover is shown in Figure 10 below.

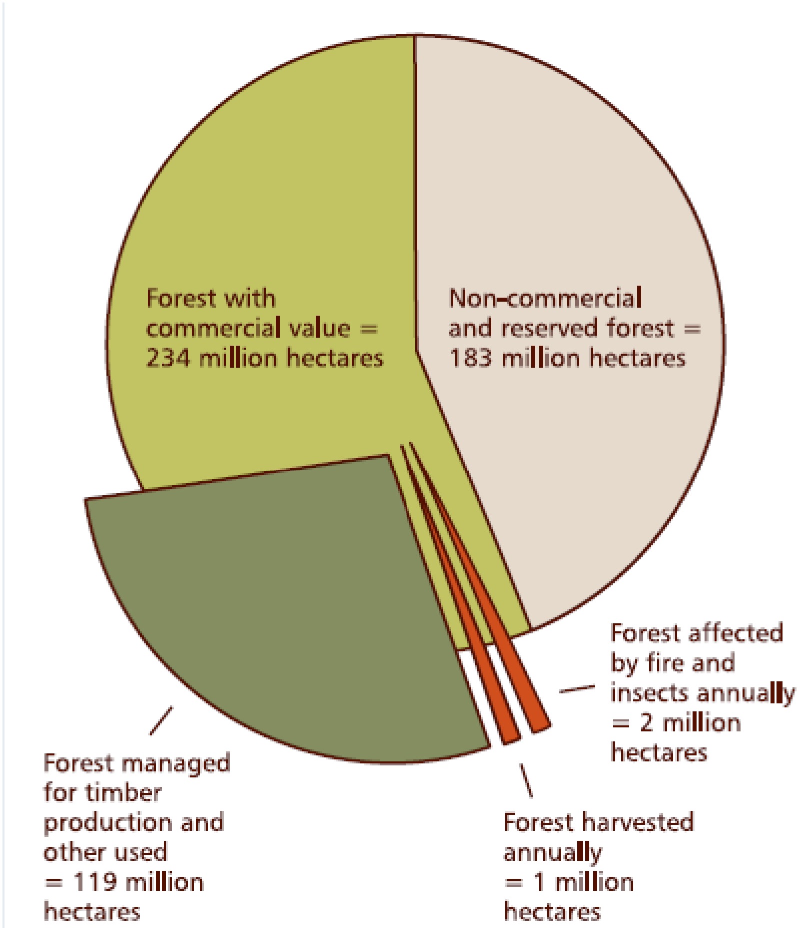

Figure 10 - Canada's 401 million hectares of forest

(http://www.bcforestinformation.com/assets/pdf/tackle-climate-change.pdf)

3.6 NEW SUB

The selection of building material for the new SUB is an intensive work of combining all social, environmental and economical factors. In terms of environmental aspect, laminated wood seems to be a very promising candidate. However, there are some disadvantages of using laminated wood in construction. Because it does not have a strong mechanical performance as concrete and steel, it is obvious that the new SUB can not be built with 100% laminated wood. Only a certain parts of the new SUB should laminated wood. Another concern is the public health when students and staffs are potentially exposed to formaldehyde emission. The possible solution is to use a non formaldehyde based resin. For example, Methylene diphenyl diisocyanate (MDI) or polyurethane (PU) resins are expensive, generally waterproof, and do not contain formaldehyde [10]. In addition, there have been recent developments of eco-efficient bio-based adhesives such as tannin, lignin, protein, carbohydrate and unsaturated oil adhesives [13]. In conclusion, laminated wood is an environmentally friendly building material for the new SUB.

4.0 ECONOMIC FACTORS OF USING LAMINATED WOOD IN CONSTRUCTION

Laminated wood is analogous to engineered wood. It uses wood and adhesive to create a structural material superior in strength and durability to plain timber.It is cheaper to build using laminated wood products than it is to use timber due to the following factors.

It is comprised of multiple smaller pieces, as opposed to a single slab, allowing more of a log to be used in the production, as well as small logs or slightly bent logs. As the supply of raw material capable of producing a product increases, the price of the material drops, as does the price of the product.

It is stronger. Using the volume of material in a solid beam, a much stronger glulam beam can be produced. In solid timber, the grain direction, knots and flaws in the wood cannot be controlled, so more wood must be used to create a structure of sufficient strength. Laminated wood is comprised of layers of wood that has the grain oriented along the direction in which the beam is loaded. Even if there are knots or weak points, they are only present in the defective layer. This comparison is analogous to solid glass to fibreglass. A crack in a pane of glass will spread and shatter the glass, whereas if a single strand in fibreglass breaks, the rest of the fibres bear the load and preventing failure. If a single laminar layer fails due to an impurity in the wood, only that layer is compromised.

The shape of the laminated structure is more flexible in design. Wooden I-beams can maximise the moment of area for the amount of wood used, reducing the amount of wood needed, and reducing cost. The strength of the wood can also be distributed throughout the shape: high quality wood is used for the outside layers that are under tension or compression, and lower quality (and thus cheaper) wood is used in the center [14].

The other economic factors for using glulam in construction are based on the input energy towards producing a comparable product to that of concrete or steel. The use of wood in construction instead of steel costs less due to labour savings and energy savings during construction. From the processes where raw material is extracted from the earth, wood uses between 44% and 85% less energy than steel, and 70-87% less than concrete [15]. According to a study performed by [16], a house made with steel used $14,895 worth of steel framing and fasteners, and $12,100 worth of labour, whereas a house made of wood uses $16,675 worth of wood and fasteners, and $9062 worth of labour for the framing. The framing of the steel house cost $1,258 or 4.9% more than that of the wood house.

In terms of heat conducted through the metal vs. through the wood, the wood house had a heat index (UAthermal) of 282BTU/hr/degF, whereas the steel house had an index of 293BTU/hr/DegF. This 11 BTU/Hr/DegF translates to 28.2kWh/degF. At $0.08 per kWh, and an average temperature difference of 15 deg F (indoor temperature: 65, outdoor: 50) the annual energy saving of a wood house would be $33.85 compared to living in a steel framed house.

From an economic standpoint, using wood has very few drawbacks. It uses less energy compared to other building materials, it requires less labour to construct an equivalent building, and it provides better insulation than steel construction.

5.0 CONCLUSION

Considering that the new sub is designed with sustainability as its primary objective, wood would be a good material to use for at least some of its structural elements. The key points to support this idea are the lowest negative environmental impact according to LCA method, lower costs of construction, and ability to use pine beetle infested timber.

REFERENCES

[1] J. Axelson, "Influence of fire and mountain pine beetle on the dynamics of lodgepole pine stands in British Columbia, Canada", Forest Ecology and Management, vol. 257, no. 9, April 16 , pp. 1874-1882, 2009.

[2] F. Lam, J. Gu, and I. Zaturecky, "Performance of posts laminated with mountain pine beetle transmitted blue-stained lodgepole pine", Forest Products Journal, vol. 56, no. 9, Sep., pp. 60-64, 2006.

[3] *Pine beetle to consume B.C. jobs: report*. Retrieved Nov 20th 2010 at: http://news.ca.msn.com/money/article.aspx?cp-documentid=24945726

[4] J. Rice, R. A. Kozak, M. J. Meitner, D. H. Cohen, "Appearance Wood Products and Psychological Well-Being", Journal Wood and Fiber Science, vol. 38, no. 4, Oct., pp. 644-659, 2006.

[5] Canadian Wood Council (2009), Canadian Wood. *Renewable by Nature. Sustainable by Design*. Retrieved Oct 20th 2010 at: http://www.cwc.ca/NR/rdonlyres/4749BE13-2089-4A49-87C8-55E40257EDD7/0/Canadian_Wood.pdf

[6] *How wood products help slow Global Warming*. Retrieved Oct 20th 2010 at: http://www.roadmap2010.eu/wisd/pdfs/30-45.pdf

[7] *The benefit of using wood*. Retrieved Oct 20th 2010 at: http://www.roadmap2010.eu/wisd/pdfs/58-67.pdf

[8] Canadian Wood Council (2009), Canadian Wood. *Tackle Climate Change, Use Wood*. Retrieved Oct 20th 2010 at: http://www.bcforestinformation.com/assets/pdf/tackle-climate-change.pdf

[9] *The eco-cycle of wood and wood based-products*. Retrieved Oct 20th 2010 at: http://www.roadmap2010.eu/wisd/pdfs/46-57.pdf

[10] *Engineered Wood*. Retrieved Nov 24th 2010 at: http://en.wikipedia.org/wiki/Engineered_wood

[11] B. Uysal, "Bonding strength and dimensional stability of laminated veneer lumbers manufactured using different adhesives after the steam test," International Journal of Adhesion and Adhesives, vol. 25, no. 5, Oct., pp. 395-403, 2005.

[12] Formaldehyde. Retrieved Nov 24th 2010 at: http://en.wikipedia.org/wiki/Formaldehyde

[13] A. Pizzi, "Recent developments in eco-efficient bio-based adhesives for wood bonding: opportunities and issues," J. Adhesion Sci. Technol., vol. 20, no. 8, pp. 829-846, 2006.

[14] Camille A. Issa, Ziad Kmeid, "Advanced Wood Engineering: Glulam Beams", Construction and Building Materials, Vol. 19, 2005 pp.100-102

[15] Ann Kristin Petersen, Birger Solberg, "Environmental and Economic Impacts of Substitution Between Wood Products and Alternative Materials: A Review of Micro-level Analyses from Norway and Sweden," Forset Policy and Economics, Vol. 7, No. 3, 2005

[16] NAHB Research Center, inc. "Steel vs. Wood: Cost and Short Term Energy Comparison" Prepared for The U.S Department of Housing and Urban Development Offce of Policy Development and Research, Washington, DC, 2001.