

Investigation of Rapidly Renewable Materials (RRM):

Natural Rubber & Straw

Ho-Hsiang(Henry) Chang

James Chou

Shu-Kai Chen

Sara Moayedinia

University of British Columbia

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Investigation of Rapidly Renewable Materials (RRM): Natural Rubber & Straw

The University of British Columbia



Faculty of Applied Science

APSC 261 Project Report

Prof: Dr. Carla Paterson

Ho-Hsiang(Henry) Chang
James Chou

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1.0 INTRODUCTION

University of British Columbia (UBC) is currently researching and designing a new Student Union Building. UBC strives to be sustainable friendly and therefore, the design process and research is thoroughly considered in every aspect to produce a highly sustainable building. This includes the consideration of social, environmental, and economic impacts of the building that is been designed.

The use of rapidly renewable materials can help the New SUB achieve its goal of attaining the LEED Platinum certification. RRM are plant based materials that can be renewed every ten years. Some examples of RRM include bamboo, natural rubber, linoleum, cork, cotton, straw and wool. This report focuses on Natural Rubber and Straw and discusses the various aspects of determining the benefits as well as discussing the sustainability of designing the New SUB achieve through a triple-bottom line analysis.

2.0 NATURAL RUBBER

Natural rubber is an elastomer that was originally derived from latex which is a milky colloid that is produced by plants. The plants would be tapped which means that an incision made into the bark of the tree and the latex sap is collected and refined into usable rubber. This section aims to do a triple bottom line analysis on natural rubber to determine the feasibility of using natural rubber as a RRM material for designing the new SUB building.

2.1 Application

Natural rubber is used in many different types of applications. Close to 21 million tons of rubber were produced in the world during 2005. Asia is the main source of natural rubber which accounts for around 94% of output in 2005. Thailand, Indonesia, and Malaysia are the three largest producing countries of natural rubber and together, account for around 72% of its production.

Natural Rubbers are especially good for Tires and Tubes which makes up their biggest consumers. Other significant uses of rubber include door and window profiles, hoses, belts, matting, flooring and dampeners for the automotive industry. Gloves and toy balloons are also large consumers of rubber. Rubber is also used as adhesives in many manufacturing industries and products. Two of the most noticeable ones include paper and carpet industries.

When designing the new SUB building, natural rubber can be considered into making the rubber mats as well as the carpet tiles. Such natural rubber mats or carpet tiles can be included in the New SUB building for the flooring of work stations, food processing station, and walkways. Figure 1 below shows an example of natural rubber mats.



Figure 1 BUBBLE MAT

Natural Rubber mats are designed to withstand harsh chemicals while creating a slip resistant surface. Rubber mats is a simple, economical solution to almost any industrial or food service application. Some of the recommended uses for natural rubber mats which are considered into designing the new SUB building include cooking areas, meat departments, bakery departments, and bar areas. The process of making rubber mats and carpet tiles is by recycling tires into crumb rubber and the steps to it are included below.

1. Mechanical Shredding – the tires are shredded by machines.
2. Cryogenic – the tires are frozen in liquid nitrogen then shattered into small pieces.

The mechanical Shredding process is described as follows. At the tire recycling facility, the scrap tires are fed into a splitter which cuts them into two half's. They are passed onto a shredder which shreds them into 2 square pieces of rubber. These pieces are put through a grinder which reduces them into tiny granules known as crumb rubber which passes through magnets to remove the steel wire. The next step is to filter and screen to remove dust and pieces of fabric after which it is ready for dispatch.

Rubber has a very unique mechanical property that makes it suitable for flooring mats or carpet tiles. The only other choice that can match the properties of natural rubber is the synthetic runner alternative. Synthetic rubbers are made from polymerization of variety of monomers that includes isoprene, chloroprene, and isobutylene with a small percentage of isoprene for cross-linking. These can be mixed in various desirable proportions to be copolymerized for a wide range of physical, mechanical, and chemical properties.

The table below shows a comparison of the Material Properties of Natural Rubber and Synthetic Rubber

Table 1 Material Properties of Natural Rubber and Synthetic Rubber

	Natural Rubber	Synthetic Rubber
Elastic Modulus	1.33 MPa	1.78 MPa
Tensile Strength	11.3 MPa	10.7 MPa
Fracture Elongation	1020%	962%
Density	0.9415 g/cm ³	1.2108 g/cm ³

Glass Transition	221.5K	250.15
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As noticed in Table 1, Synthetic Rubber is more resistant to both temperature and degradation. Natural Rubber is stronger and more ductile. Therefore, from this, we can conclude that Natural Rubber is generally better for accessories that last longer which include commercial vehicles, buses, and trailers. For the new UBC SUB building, natural rubber is better for making carpet tiles and mats that is more durable.

2.2 Production

Natural rubber comes from the *Hevea brasiliensis* tree which is only grown in the tropical regions of the world. They can reach up to 20-30 meters in height and are able to produce commercial quantities of latex at about 7 years of age depending on the climate and location (Azom.com, 2006). The economic life span of a rubber tree is between 10 to 20 years but it can extend past 25 years in the hands of a skilled tapper and bark consumption (Azom.com, 2006).

A tapper uses a knife that is shaped like a hook to shave off the thin layer of the fresh bark from the tree. This exposes the latex vesicles. The cut is done at 25-30 degrees to the horizontal because this exposes the maximum number of vesicles (Azom.com, 2006). The same incision is reopened the next time by shaving off the small amount of bark.



Figure 2 Tapping a rubber tree using angular, semi-spiral incisions.

Thickness of the layer is extremely important because too thick of a slice will damage the tree which reduces its productivity and life. On the other hand, if the slice is too thin, there will not be sufficient latex been produced (Azom.com, 2006). The bark is removed in a localized area for a period of time and then a new area is tapped allowing the tree to repair itself.

Processing of natural rubber involves the addition of a dilute acid such as formic acid. The coagulated rubber is rolled to remove excess water.



Figure 3 Rolling the latex into thin sheets.

The final rolling is performed using a textured roller and the resultant rubber sheet is dried. After this, the rubber is ready to be export for further processing.

2.3 Disposal/Recycling

Natural rubber is a biodegradable material. When disposed in landfill, it will decompose in short period of time. However, recycling or reuse natural rubber will conserve energy and natural resources. Recovering Rubber can be a difficult process however; there are many reasons why rubber should be recovered.

- Recovered rubber can cost half of that of natural or synthetic rubber
- Excellent way to dispose of unwanted rubber products which is often difficult
- Conserves non-renewable petroleum products which are used to produce synthetic rubbers
- Recovered rubber has properties that are better than those of virgin rubber
- Producing rubber from reclaim requires less energy in the total production process than does virgin material

There are enormous potential for reuse of rubber in developing countries. This is due to a large wastage of rubber tires. Whether the rubber tires are reused, reprocessed, or hand crafted into new products, the end results shows that there is less waste and less environmental degradation.

The use of retread tires saves valuable energy and resources. A brand new tire requires 23 litres of crude oil equivalent for raw materials and 9 litres for process energy compared with 7 litres and 2 litres respectively for retreading (Recycling Rubber). This saves up a total of 14 litres of Crude oil and 7 litres of process energy. This process involves the removal of the remaining tread and the application and vulcanisation of a new tread onto the remaining carcass. When you add up all the tires been saved and reused, the amount saved adds up. For example, in Nairobi, approximately 10,000 tires are received for retreading (Recycling Rubber). Reuses of whole tires are often used because of their shape, weight, form, and volume. Some examples such as erosion control, fences and garden decoration.

The next step involves the materials been broken down and reused as a new product. Rubber that is used for tires are extremely easy to reform by hand (Recycling Rubber). The tools required for making such products includes shears, knives, hammers and all the common tools found in the recycler's workshop (Recycling Rubber). Another way to reuse the material is by reducing the tires into granular form and

then reprocesses it. This method is used for low-grade automobile floor mats, shoe soles, and can be added to asphalt for road construction where it improves the material property (Recycling Rubber).

Rubber can be recycled into other things typically as crumb rubber modifier. Pyrolysis is a recycling process that can be used to reprocess the rubber into fuel gas, oils, solid residue, and low-grade carbon black. In the pyrolysis recycling method, a special mechanism of heat is used on the natural rubber in a closed, oxygen-free environment. This typically oxygen-free environment is used in a stove to melt down the rubber into materials that they were made of. There are many different ways to achieve the melting procedure. Recently, an electromagnetic field technology was developed and by using this method, it produces carbon, metal, gas and artificial oil as by-products of the recycling process.

2.4 Economic Analysis

The field production of Natural Rubber is a labour-intensive sector which involves millions of farmers. The standard method is tapping where for one person; they tap between 200-300 trees in 3-4 hours. The same person then collects the tapped latex. Below is a table that shows the private records of production and marketing enterprises, management and labour represented over half total direct expenditure on estates and smallholdings in Malaysia, Indonesia, and Thailand.

Table 2 Cost of Natural Rubber

Costs of Making Natural Rubber (cents per kg)	Malaysia		Indonesia		Thailand
	Estates	Smallholdings	Estates	Smallholdings	Smallholdings
Direct Costs					
Management and labour:	40.8	44.9	29	28.4	18.5
Materials:					

<i>Tapping and collection</i>	0.6	3.7	1	1	2.5
<i>Fertilizers</i>	1.7	-	2.2	-	
<i>Weedicides</i>	1.8	6.3	0.9	-	6.5
<i>Pest control</i>	0.9	-	1.1	-	
<i>Other</i>	0.3	1.8	2.9	2	3.3
Transportation:	1.8	2	0.4	2.5	2.3
<i>Capital costs</i>					
Planting investments	11.7	14.6	18.3	2.4	20.6
Total Cost	59.6	73.3	55.8	36.3	53.7

As seen from Table 2, the rubber cost in Malaysia is \$59.6 cents per kg for estates and \$73.3 cents per kg for small holdings. Indonesia has a roughly the same price compared to Malaysia for estates at \$55.8 cents per kg but their small holdings is much lower at \$36.3 cents per kg. Thailand only has smallholdings for natural rubber and its cost is \$53.7 cents per kg. The average cost of making rubber in Thailand, Indonesia, and Malaysia is \$55.7 cents per kg. The cost of natural rubber in Canada is \$2.50 per pound (around \$ per kg). We notice that natural rubber is much cheaper in developing countries. This is due to that natural rubber is produced in vast quantity in Thailand, Indonesia, and Malaysia. Another reason is that Canada has much more expensive labour. The cost and energy for transporting natural rubber to Canada must also be considered.

Dinoflex Group LP is a local supplier for natural rubber that is within 500 miles from Vancouver. Dinoflex Group LP has been committed to delivering high quality, recycled rubber products in an environmentally sustainable manner for over 20 years. Dinoflex Group LP supplies include custom designed resilient rubber flooring to unique acoustic underlay. Located at Salmon Arms, BC, Dinoflex Group LP is approximately 287 miles from Vancouver.

2.5 Social Impact

To the Producers

There are some social impacts associated with natural rubber to the producer of natural rubber. First, natural rubber production is very labour intensive as mentioned above. It provides a lot of working opportunities for the people that live in rubber tree growing area. Most of the countries that produce natural rubber are developing countries and many people make their life depending on producing natural

rubber products. However, based on the cost analysis above, natural rubber is very cheap if produced from the developing countries. This implies that natural rubber is not a fair-trade product.

Another social impact associated with natural rubber is that natural rubber trees bring pests and diseases. The most severe disease caused by natural rubber is the South American Leaf Blight. This disease is endemic throughout the rubber growing areas in America. South American Leaf Blight is caused by fungal attack and it is capable of causing very serious damage.

To the Users

Another concern about natural rubber products is that some people are allergic to the protein inside it. Research shows that 17% of the people gain allergy to natural rubber gloves when wearing them for an extended period of time. Many people believe the claim of allergy is a lie or is a commercial strategy because none of the natural rubber producer is allergic to natural rubber latex. A lot of arguments are based on the real cause of the allergy but this problem does exist.

3.0 STRAW

Straw, the agricultural by-product of the hay, is the dry stalk of cereal plants after removing the grains and the chaffs. Straw makes up about half of the yield of cereal crops such as barley, oats, rice, rye and wheat. Straw has many uses including animal feed, bio-fuel, rope, paper, and construction material. It is usually gathered and stored in a straw bale which is a bundle of straw tightly bound with twine or wire. Bales may be square, rectangular, or round depending on the type of baler used. This section suggests a more exact and scientific basis for designing straw bale walls to carry gravity loads of the new SUB is building.

3.1 Application

The first straw bale building were constructed by European settlers in the Sand Hills region of western Nebraska, USA. At that time, they had very few lumber to build the roof framing so the straw bale walls were made to support the roof without added structure. Several dozen buildings survive from that period, roughly 1880 - 1930 and the oldest extant survivor reached its 100th birthday in 2003. Nowadays, more and more buildings or parts of buildings especially roofs frames, walls, and window seals are erected by straw bales reinforced plasters. There are several reasons to explain why the increment of straw bale reinforced plaster buildings recently:

- Buildings that are constructed by straw bales reinforced materials are very close to green buildings which means as environmentally friendly as possible.
- Straw bale buildings are sustainable. These buildings can ensure the minimum use of wood, concrete, and steel.
- Straw bale reinforced buildings are often simpler and faster to be constructed.
- Straw bale reinforced buildings are much lighter than wood or concrete buildings which reduce to stress to their foundations.
- Straw bale reinforcement are easily repaired and replaced if any damage occurs on the structure.
- Straw bale reinforcement can be easily recycled.

Builders often pack the straws in two different sequences for constructing building walls.

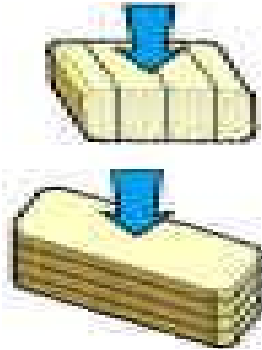


Figure 4 Straw bales “flat” and “on edge”

The upper bale is called a “flat”. Flat is loaded perpendicular to their largest face parallel to the plane of the tie hoops and generally perpendicular to the straw fibres. The lower bale is called an “on edge”. On edge is loaded parallel to their largest face perpendicular to the plane of the tie hoops and generally parallel to the straw fibres.

3.2 Production

At first, the oversized gravels and organic matter are needed to remove from the cohesive soil. The soil is then oven dried at the temperature of 105 °C to obtain a constant mass. After the drying process, the hard soil lumps were broken up with a hammer. The straw bales are also oven dried at 105 °C to constant mass. Afterwards, 2 Liter water was sprayed over the materials and the materials were mixed by hand for about 15 minutes until a homogenous mixture was obtained.



Figure 5 Production of straw bale reinforcement

Comparison of material properties between traditional concrete and straw bales are listed in table below.

Table 3 Comparison of Concrete to Straw Bale

	Concrete	Straw bale
Density	2240 - 2400 kg/m ³	110-125 kg/m ³
Tensile strength	2 - 5 MPa	5.2-6.2Mpa
Compressive strength	20 - 40 MPa	3.0-3.2Mpa
Modulus of elasticity	14000 - 41000 MPa	9.5-10.5Mpa
Thermal conductivity	0.29W/(mK)	1.1W/(mK)
Specific Heat Capacity	1000J/kgK	1200J/kgK
Insulation Value	0.13W/m ² K	0.39-0.42W/m ² k

From the table above, it is easy to observe that straw bales are much lighter than concrete. This gives straw bale houses less pressure to their fundamentals. Light materials as straw does not require complex tools to operate during the construction process. Even though straw bales' compressive strength and modulus of elasticity are much lower than concrete, straw bales have higher tensile strength. This indicates that straw bales houses can withstand more axial loads. Straw provides super-insulation at an affordable cost. The K value of straw in a straw bale is 0.09W/mK; this combined with walls typically over 450mm thick gives a U value of 0.13W/m²K which is two or three times lower than concrete materials and is much lower than current building regulations that require walls to have a U-value of 0.45 or less. The higher thermal conductivity suggests that heat from the outside flows easier into straw bale buildings than traditional concrete buildings. With the higher specific heat capacity, straw bale houses can store more energy than concrete buildings.

Straw houses have furthermore advantages over traditional concrete buildings.

- Straw is an annually renewable natural product that is grown by photosynthesis and fuelled from the sun. Using straw means less pressure to use other more environmentally damaging materials such as concrete and steel. If that building is no longer required, it could be broken down and then composted afterwards.
- Since straw bales are light, it does not require heavy trucks and cranes to transport which greatly reduce the greenhouse gas emissions.
- Plastered straw bale walls are less likely to create a potential fire risk than traditional timber-framed walls. ASTM tests for fire-resistance and the results of these tests suggested that a straw bale infill wall assembly is a greater fire resistive assembly than a wood frame wall

3.3 Environmental Evaluation

Straw is a renewable plant requiring only small amount of energy to process by the sun. There has been an increased interest in the use of straw in construction over the past decade.

The role of straw bale as construction materials for reducing the whole life impacts of the house has been studied by different researchers. In a study done by Sodagar et al the potential effect of using straw bale on CO₂ emission over a 60 year life span of a building in UK was studied. In their study, the main construction materials used in the shell construction was taken into consideration for the purpose of their study. The house model was based on traditional UK social housing design that has standard semi-detached three-bedroomed houses each with an internal gross area of 85.75m². In addition, materials were locally sourced in order to minimize transportation to the site. A standard straw bale is 450 mm wide which determines the foundation width. By using a 100 mm brick outer skin with a 140 mm recycled glass rigid insulation inner skin and 200 mm of shredded lightweight recycled insulation aggregate in the center, a U-value of 0.17 W/m² K was achieved. U-value is called the overall heat transfer coefficient which describes how well a building element conducts heat.

Knowing that wheat straw consists of hemicellulose and lignin, the carbon content of straw bale can be calculated. Table below shows the percentage of carbon within cellulose and lignin.

Table 4 Percentage of carbon within cellulose and lignin

	Atomic mass	Percentage Carbon
Cellulose	162	44.4
Lignin	540	66.6

Assuming the moisture content of straw at the time of construction is 10% the carbon content can be calculate:

$$[0.444 \times (0.365 + 0.286) + 0.666 \times 0.178] \times 0.9 = 0.367$$

This gives a total CO₂ sequestered in the bale around 1.35 CO₂/kg of bale (Sodagar et al)

A plastered straw wall of approximately 450 mm thick also has good thermal storage capacity of the order of 200 340 J/m² K that balance temperature fluctuations and allows the building to benefit from passive heating from solar gain(Sodagar et al). The operational life of a house should be taken into consideration when analyzing the carbon content. Their paper estimates that the overall emissions of building elements per dwelling are of the order of 13 tonnes of CO₂ with no sequestration. After considering the carbon lock-up potential of straw each dwelling will act as a carbon sink negating the influences of non-renewable materials resulting in locking up around 7 tonnes of CO₂. This is a significant difference which once again supports the potential usage of straw for construction.

It is known that more than 50% of all greenhouse gases are produced by the construction industry and the transportation associated with it. Assuming 4 million tonnes of straw in the UK is produced and used for local building (no cost of transportation); 450,000houses of 150m² could be made per year. Taking into consideration reduced heating requirements, further reducing carbon dioxide emission (greenhouse gas) from the burning of fossil fuels; straw made buildings can actually cause a net decrease in greenhouse gas emissions.

To compare the effectiveness of biomaterials (straw) with CO₂-minimizing technologies (solar hot water, photovoltaics, efficient appliances, efficient lighting, and wind generation) the life cycle analysis of different construction should be done. In a study by Alcorn and Donn, different construction methods for floors, walls, roofs, insulations, windows, and operating energy sources were compared to show their contribution to reduce emissions. Materials quantities were calculated from overall house dimensions, window areas, insulation thickness, painted area, and life expectancy of individual materials. Based on their study, a conventional 3 bedroom house uses approximately 46.5 GJ annually including embodied

energy of construction and maintenance. The total CO₂ emission is about 2,287 kg. These values can be compared to that of straw house. A table below shows the total CO₂ emissions for a highly insulated straw house:

Table 5 Total Annual CO₂-e Reductions: Selected Technologies, Courtesy of Alcorn and Donn

	Annual CO ₂ -e emissions (kg)	CO ₂ -e reduction (kg)	CO ₂ -e reduction (%)
Suspended timber floor, all polystyrene insulation	2,200	0	0.0
SB <i>ceiling</i> insulation, floor and walls polystyrene	2,060	135	6.5
SB <i>wall</i> insulation, floor and ceiling polystyrene	1,990	213	11
SB <i>floor</i> insulation, walls and ceiling polystyrene	2,060	143	7.0
All strawbale insulation	1,710	491	29

Total CO₂-e reductions from straw bale insulation may be as high as 560kg if a lower carbon loss rate from landfill demolition straw is assumed. Table below is also a comparison of different CO₂ minimizing methods and straw bale insulation. Wind generation has the greatest potential to reduce total net emissions but has a major disadvantage of not being suitable for all sites. After wind, timber and straw bale construction offer the greatest potential to reduce total net CO₂-e.

Table 6 Total Annual CO₂-e Reductions: All Strategies , Courtesy of Alcorn and Donn

	CO ₂ -e reduction (kg)	CO ₂ -e reduction (%)
Wind generator	1,031	47
<i>Aggregate of timber strategies</i>	739	34
Strawbale insulation	491	29
Solar hot water heater	472	22
PV panels	435	20
Lightweight timber wall v concrete masonry	350	16
Efficient refrigeration	170	7.8
Timber window frames	139	6.3
Efficient lighting	110	5.0
Roof shingles	110	5.0
Efficient appliances	90	4.1
Timber linings	77	3.5
Unpainted materials v painted	69	3.1
Timber suspended floor v concrete slab	54	2.5
Wider eaves and verges (1 m)	9	0.4

The second most important individual strategy after wind generation to reduce CO₂ emission is using straw bale insulation with a net reduction of 500kg. It has been known to public that Super insulation using conventional insulation materials is often assumed to reduce total energy use, but this is incorrect in most of the cases. Straw bale insulation provides increased CO₂ benefits as more is used. Straw bale buildings therefore represent a major opportunity to reduce annual CO₂-e emissions from housing construction and operation. Hence the use of straw house is considered as sustainable materials at the forefront of attempts to reduce construction and maintenance CO₂-e emissions and is at least on par with strategies to reduce operating emissions.

3.4 Economical Calculation

Literature review shows huge saving when using straw in construction industry. Below is a simplified cost estimation of straw bale construction in British Pounds. Assuming each bale cost £1.50 including the cost of transportation and assuming a 3 bedroom house uses 400 bales, the overall cost of bales will be £600. This value can be compared to materials cost for a conventional brick and block house. A typical house is made of approximately 1521 blocks and 81,053 bricks each cost 35p and £120 per thousand. Hence the cost of material can be approximated to:

$$(1521 \times 0.35) + (81,053/1000 \times 120) = \text{£}10,258.71$$

So the first financial saving in the case of 2storey, 3 bedroom houses is:

$$£10,258.71 - £600 = £9658.71$$

In the above analysis the cost of labour is ignored to emphasis on the cost difference of materials rather than overall cost which is quite substantial.

3.5 Socio-economic Aspect

There has been ongoing research on how the use of straw affects individuals in terms of health and wellness issues. Straw is a natural material that allows air exchange through the volume. This offers an alternative to the use of paint, glue, chemicals and toxins embedded in the construction materials. In the long run this can affect the mainstream culture towards using more natural products for construction. Straw walls can enhance the quality of air inside the building since it does not give off harmful fumes such as formaldehydes. Another health benefit is the ambience inside a straw bale house due to high level of sound insulation and heat insulation.

Using straw bale also has huge economic impact due to energy efficiency. An example of this is the straw bale housing in the rural parts of Chile where a study is done by Whitman and Holloway. Based on their study in the rural areas of Chile where straw is the by-product of the agricultural operations, construction cost of straw wall is considerably lower than that of conventional materials. This saving will introduce an alternative housing to low income families in the rural areas. In addition to being thermally efficient, straw bale construction is also considered sustainable and economical because straw is renewable and abundant. Straw can be grown in less than six months needs huge amount of energy to produce (solar energy). The low energy to manufacture straw compared to conventional construction materials is substantial. For example, it costs 6.15 million kJ of energy to manufacture one ton of concrete where it only costs 119,250 kJ of energy to produce one tone of straw. This substantial difference means more sustainable housing and eventually low carbon sustainable communities. The straw bale building enhances the interest among public to develop low cost, energy efficient from natural, local materials. At the same time, using straw bale can help locally available materials, as a result more local development and employment. In addition, new methods for mixtures of mud and straw can be developed to better suit the skills and tools available in different situations and locations. Straw building techniques imply a substantially reduced ecological footprint, principally through using natural biodegradable carbon-neutra materials which avoids highly polluting materials such as cement and reduces energy requirements for heating and cooling throughout its life.

4.0 Conclusion

Based on the information presented in the paragraph above, we recommend using natural rubber and straw bale for the construction of new Student Union Building (SUB) in UBC. Natural rubber is a perfect material for mats and flooring area such as work stations, food processing station, and walkways. It provides good wear and slip resistance. Straw bale on the other hand, is a good alternative to replace concrete blocks for building the new SUB.

Both natural rubber and straw are recyclable and count as rapid renewable material. The new SUB will get points toward obtaining the LEED platinum certificate by using both materials and are also available within 500 miles from Vancouver which makes them eligible for Regional Material credit in the LEED standard.

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