UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into the Use of Cob and/or Straw Bale construction in non--residential buildings

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Abstract

The University of British Columbia (UBC) Farm regularly offers a variety of activities, learning experiences, and general community programs on its land and is therefore planning to construct a new “UBC Farm Centre” in order to meet the needs for additional space. The farm has decided to explore the possibility of building either a portion of the building, or the entire building, with cob and/or straw.

In addition to conducting a triple-bottom line assessment, an analysis of three separate case studies was done to examine the successes and failures of previous cob and straw bale construction projects, before outlining findings from primary and secondary research. Primary research was conducted in the form of a survey that polled the views of over 200 individuals regarding certain questions that arose in the social consideration of cob and/or straw bale construction, discussed in more detail in section 5.0 of this report. As for secondary research, a number of academic journals and scientific reports were consulted when researching the benefits and drawbacks of using these alternative construction materials in the UBC Farm’s construction project. It was assumed that the cob and straw materials would be coming from a source near UBC and that the Farm would not be seeking cob or straw from any location outside of British Columbia. Another constraint that arose was that two of the case studies are of lodges, rather than purely non-residential buildings. The building principles involved in designing the infrastructures described in the case study section are similar to those that will apply to the UBC Farm Centre, due to size and purpose of the buildings.

After the research was conducted and correlated, it became clear that both materials possessed a variety of environmental benefits versus traditional construction materials of wood and cement. They also proved to be more economically feasible, despite shorter life cycle than traditional construction materials, and provided positive social impact. Each material had its own strengths in terms of heat distribution, insulation, and other factors that will be mentioned in more detail throughout the report, but the final conclusion was to use straw bale for the exterior portion of the building while utilizing cob for the interior.

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Glossary

Embodied Energy or Embodied Carbon:

Embodied energy is the sum of all the energy required to produce a certain product or material. It can be considered as if the energy is embodied in the material or product itself. Since energy input usually implies greenhouse emissions, accounting for embodied energy can be useful in determining whether a building material contributes or mitigates climate change when compared to other materials. A similar concept would be "embodied carbon" in which the carbon emitted or absorbed through the construction, transportation, assembly, maintenance, and deconstruction of a building is accounted for. The two can be seen as functional equivalents for our purposes.

Operational Carbon:

Operational carbon is accounting for the carbon emission associated heating, cooling, lighting and other upkeep required by a building. Operational carbon is often evaluated using an assumed building usage lifetime of 60 years.

Insulation:

Thermal insulation is a way of reducing heat transfer between objects. In the case of housing, a wall that is a made of materials that are good insulators will decrease the amount of heat entering or escaping the house. Well-insulated buildings are more energy-efficient and reduce carbon-footprint.

Thermal mass:

Thermal mass is the amount of resistance buildings have against temperature change. High thermal mass is both a result of high specific heat capacity and high density of the building materials. A building with high thermal mass can smoothen out daily temperature fluctuations by releasing and absorbing heat that opposes changes to the surrounding temperature.

1.0 Introduction

As the University of British Columbia Farm undergoes the planning stages of its new Farm Centre construction, inquiries pertaining to the use of certain materials must be assessed before construction can begin. The UBC Farm, a 24-hectare piece of land that is managed by the UBC Centre for Sustainable Food Systems, is a dynamic place where individuals of all ages participate in activities that are interdisciplinary in nature. They include academic experiences as well as community and socially related ones, all revolving around the concept of sustainability. Because the farm holds such a large number of activities throughout the year and reaches thousands of individuals, the need for new, additional space has arisen.

Before this can be done, however, an assessment must be made regarding whether or not to use cob and/or straw bale to construct a portion, or all, of the new building. A triple-bottom line assessment of the benefits and drawbacks of using these materials rather than traditional materials (wood and cement) has been undertaken and will be presented in the pages to come. Ultimately, this report aims to provide a recommendation as to whether the UBC Farm should use cob and/or straw in their upcoming construction project, and if so, on what portion of their building.

2.0 Case Studies

2.1 Case Study #1 - Pilgrim Holiness Church

The Pilgrim Holiness Church (Figure 1), located in Arthur, Nebraska, was built in 1927. Congregationalists planned to build the church on the Sandhills covering about one-fourth of the state of Nebraska, but they met hardship in using traditional building materials (Spencer and Murphy, 1979). These Sandhills have a particularly sandy terrain, which makes the area unsuitable construction sod. Few trees were able to grow in the Sandhills, which made wood a scarce building material. Additionally, sod did not disintegrate during cutting and handling. This caused the sod to crumble after being laid up in walls. Because of this, Nebraskan settlers decide to do away with conventional building materials and instead turn to a rye straw bale.

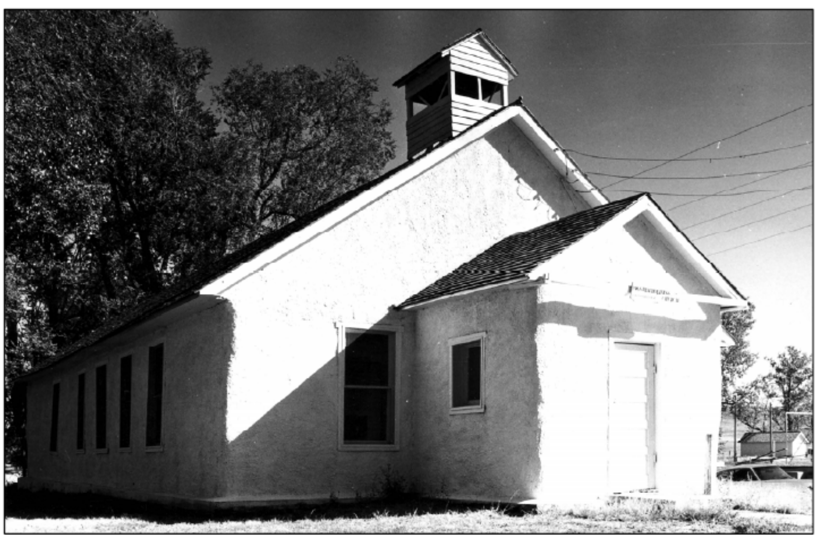

Figure 1: The Pilgrim Holiness Church located in Arthur, Nebraska (Spencer and Murphy, 1979)

The building, constructed in 1927, was made by stacking baled hay with walls 2 feet thick. The roof spans twenty-eight feet onto its load-bearing walls. As of 2012, the building has undergone many renovations but has maintained its straw built basis. In one particular renovation in 1976 this church was plastered on the sides to provide structural support by locally obtained "gumbo mud", an ideal soil material containing equal amounts of sand, silt, and clay (Carter, 2006) . Today, the Pilgrim Holiness Church stands as the only church built of the material anywhere. It exists as a landmark and as a structure significant to the folk architectural traditions of Nebraska.

2.1.0 Successes

Because of poor growing conditions, virtually no wood was available as building material. The people of Nebraska were forced to think creatively as the ecology was generally not ideal for building. Congregationalists were very resourceful in using readily available rye straw bale as a substitute for wood or sod. A local rancher and church member donated the straw, which significantly lowered material costs.

2.1.1. Failures

Congregationalists would likely have used wood or conventional building materials had they been readily available. The people of Nebraska who were eager to build a church turned to using rye straw bale because they had no other options. Sustainability was not a particular concern when building this church as the Congregationalists turned to straw because of it's low cost and lack of traditional building material.

<u>2.2 Case Study #2 - Five Star Didilama Lodge</u>

The Didimala Lodge (Figure 2) is located 30 miles north of Pretoria, South Africa. This is Africa's first straw as well as the world's largest building made primary out of straw bale. The owners required only two conditions to be met by the Dumani Architects when designing the building; they insisted that the building be audacious and green-friendly (Laylin, (n.d.)).

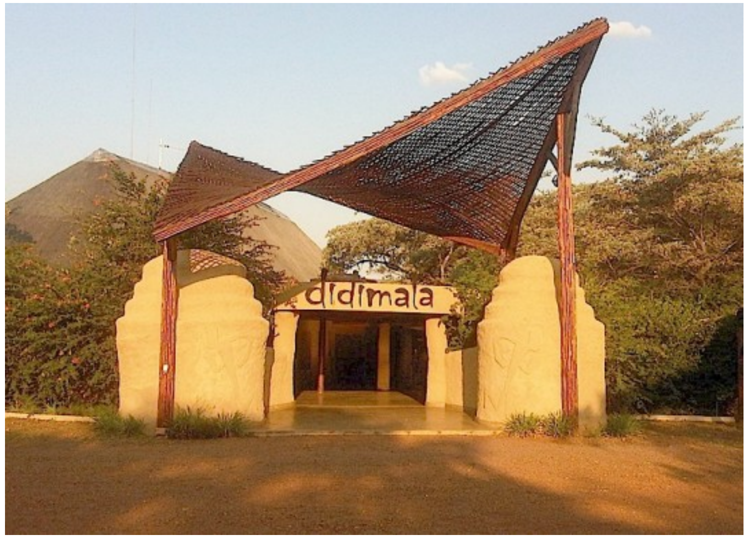

Figure 2: The Didilama Lodge located in Pretoria, South Africa (Laylin, (n.d.))

The Lodge was built from 10,000 wheat straw bales, which was readily available byproduct in the region. The wheat straw bales were wrapped in chicken wire and then covered in a layer of gunite, a concrete mixture that is sprayed from a special gun-like machine used in construction. The floors were designed and made with polished screed and inlaid with pebble borders.

The entirety of the Lodge, which includes 20 rooms, a massive boardroom seating up to 30, a function hall, and an underground soundproof theatre with 50 rotating seats, is built primary from straw bale. The interior seating and shelving is molded in a similar design to that of conventional buildings even with this straw composition as shown in Figure 3. The roof is constructed with post-beam thatch.

Figure 3: Interior design of a straw bale building (Laylin, (n.d.)).

2.2.0 Successes

The owners of the Didimala Lodge were successful in working with an architecture company, which suggests that other firms may also be willing to contribute to a similar project. This supports the idea that other companies may have similar sustainability views and put a particular focus on environmental ramifications in building design.

Owners of the Didimala Lodge also make note of the cellulose based straw material. As insects and critters cannot digest this material, it naturally makes the lodge an unfavorable region for these creatures. Keeping these insects and critters away from the lodge is fundamental in maintaining a focus on hospitality.

Taking all these factors into account, the Didimala Lodge deserves recognition simply as the world’s largest straw-based building.

2.2.1 Failures

Construction of the Didimala Lodge involves covering the straw bales with a layer of gunite. While this gunite provides structural support and ensures the building will last a long time, applying this concrete mixture is expensive and not very earth friendly.

Additionally, the lodge's main function as a hotel is to provide a hospital place for people to stay. Reviews from www.tripadvisor.ca suggest unfavorable reactions from guests who claim the building is dirty and not properly maintained (TripAdvisor). Having a straw based building requires a particular focus to maintenance and cleaning and should be of utmost precedence, especially for hotels and lodges.

2.3 Case Study #3 - Maya Guesthouse

The Maya Guesthouse (Figure 4) is the first hotel in Europe built entirely with straw bales located in Nax Mont-Noble in Val d'Hérens, Switzerland (Maya Guesthouse). The clean, natural earth finish is consistent with the location near the Maya Mountain. The defining selling point for the guesthouse is the stunning location and vivid mountaintop scenery to go along with the sustainable friendly building.

The walls are a meter thick, the depth of the straw bale, with purely natural rooms. Clay covers the walls with wooden sealing. The furniture is wooden and carved by local artists, to go along with wooden furnishes in all areas of the hotel. All eight rooms have private bathrooms and a large private terrace or balcony as shown in Figure 5.

Figure 4: The Maya Guesthouse located in Nax Mont-Noble in Val d'Hérens (Maya Guesthouse)

Energy is harnessed through nature for the Maya Guesthouse. The building recovers excess heat from wooden stoves to heat water in winter and uses solar energy for heating in the summer.

The owners describe the hotel as “our commitment to help you discover and appreciate the interdependence and need for respect between man and nature”.

Figure 5: Side view of entirely straw bale constructed building. (Maya Guesthouse)

2.3.0 Successes

Reviews of the Maya Guesthouse are very favorable according to www.tripadvisor.com. Using an eco-friendly building material in straw construction is an excellent complement to the natural feel the owners of the hotel are looking for in designing a building by the Maya Mountain. The building effectively utilizes different aspects of the building, like heat and water conservation, to maintain an initiative towards sustainability (Trip Advisor, (n.d.)).

2.3.1 Failures

As the hotel is relatively small and widely unknown due to the low population of the Nax Mont-Noble village, there has not been any research conducted on potential failures of the Maya Guesthouse. As the hotel is run primarily as a business, it would be to the owner’s best interest to highlight the features of the hotel rather than the downsides.

3.0 Environmental

In order to properly identify the environmental advantages of straw bale and cob construction versus traditional construction materials and techniques, we will examine several different factors that can be used to evaluate the environmental-friendliness of such building materials. These different factors include embodied energy/embodied carbon, operational carbon, and other performance indicators (which affect operational carbon) such as insulation and thermal mass, all of which are defined in the glossary. It should also be noted that straw bale is an excellent flame retardant, slowing the spread of fire in case of an unfortunate emergency.

3.1 Straw Bale

Embodied Energy of Straw Bale

Because straw bale can be grown naturally in a wide array of climates and environments, straw bale is easily and readily available in most places in the world. As a result, straw bale inherently has low embodied energy compared to most other construction materials because it is naturally grown, requires minimal processing, and low transportation cost. However, other materials typically used in straw bale walls must also be taken into consideration; these materials include sand, clay, and lime. A study (Pritchard & Pitts, 2006) comparing the embodied energy of wall sections made with similar insulation value made from different materials had the following result: it showed that the straw bale wall had about $1/10^{th}$ the embodied energy of a brick/concrete wall and $2/5^{th}$ the embodied energy of a timber panel wall. This result confirms another previous study which indicated that a straw bale wall section has $1/6^{th}$ the embodied energy of a wall made with wooden frame and brick sidings (Offin, 2004). Alternatively, if straw bale was used as insulation, it reduced the embodied energy by 5x and 11x when compared with foamed glass and mineral fiber insulation respectively.

Construction	Embodied energy (GJ)	CO_2 emissions resulting from construction (tonnes)
Clay- and lime-plastered strawbale wall: re-baling	0.35	0.03
sand	1.0	0.07
clay	0.15	0.01
lime	6.0s	0.36
transport	3.5	0.25
Total	**11.0 GJ**	**0.72 t CO_2**
Brick / lightweight concrete cavity wall: brick	63.7	13.38
cellulose insulation	10.5	1.60
lightweight concrete	7.2	2.30 *
plasterboard	3.6	0.55
transport	10.5	0.75
Total	**95.5**	**18.58 t CO_2**
Timber panel system: timber	2.4	0.36
cellulose insulation	12.5	1.90
plasterboard	3.6	0.55
transport	7.5	0.54
Total	**26.0**	**3.35 t CO_2**

** includes carbon dioxide emitted in cement production*

Table 1: Comparing Embodied Energy of 150m^2 of Wall Sections (Pritchard & Pitts, 2006)

Operational Carbon of Straw Bale

Straw Bale is interesting because the carbon required to produce straw is actually less than zero because straw “locks-up” some carbon inside the plant itself during its growth; this process is also known as carbon sequestration. Other considerations we also need to take into account are the fact that during the curing of lime, which is commonly used in straw bale walls, carbon is absorbed to mitigate some of the carbon released during the production of the lime. As a result, the net carbon cost of the lime is less than that of cement. The result of a study (Sodagar, Rai, Jones, Wihan, & Fieldson, 2011) compared the whole-life impact (60 years) of houses with different walling systems with equal insulation.

The result showed that carbon sequestration accounts for a 61% reduction in carbon output and that the straw bale wall system resulted in a reduction of 18%~29% in carbon output when compared to other wall systems.

Construction	Without sequestration		With sequestration	
	Total kg CO_2	kg CO_2/m^2 floor area	Total kg CO_2	kg CO_2/m^2 floor area
Straw bale	51 761	603.6	31 739	370.1
Engineering timber frame	53 022	618.3	38 493	448.9
Brick-clad timber frame	54 904	640.3	39 040	455.3
Rendered masonry	55 069	642.2	41 163	480
Brick-faced masonry	58 411	681.2	44 506	519

Table 2: Comparison of the whole-life impact of houses with different walling systems over 60 years (Sodagar et al., 2011)

Insulation

Straw Bale is inherently a very good insulator. Standard agricultural straw bales provide a level of insulation twice that required by current building regulations. This results in an immediate 50% energy savings (Atkinson, 2008). The result is high levels of insulation at low cost and therefore, low operational carbon.

Thermal mass

Straw Bale does not have high thermal mass due to its low density. Straw Bale is not used because of its thermal mass (or lack thereof) but instead is used because of its high insulating property as previously mentioned.

3.2 Cob

Embodied Carbon

Cob consists of clay, sand, straw, and earth, which means that it is readily available. Because all the constituents are naturally found and do not require processing, cob is low in embodied carbon. The information on embodied energy/embodied carbon of cob is not as abundant as that of straw bale. This may be because cob housing has already existed for centuries and is already generally understood as a sustainable and environmentally material. However, the “greenguide” published by BRE (Building Research Establishment) of UK has indicated that Cob has 50% the embodied carbon of traditional methods (THORPE, 2011).

Operational Carbon

Cob being a poor insulator (as will be discussed later) will result in higher heating costs when compared to other construction methods when used to be external walls. As a result, the operational carbon is higher than other construction methods. A study performed by Thorpe (2011) compares the heating demand and carbon footprint of different types of external walls with equal thickness over a 60-year period.

Structure Type	60 Year Heating Demand (KWh / year)	60 Year CO^2Foorprint (Kg/ 60year) (Gas)	60 Year CO^2Foorprint (Kg/60year) (Wood Chip)
Insulated Cavity	456960	84480	17820
Stone	1076340	199080	41940
Cob	690000	127620	26880

Table 3: Heating Demand and Carbon Footprint of Cob and other wall types (THORPE, 2011)

It is evident that cob required 50% more energy than an insulated cavity to heat when used as an external wall. The percent increase in carbon footprint is roughly equal regardless of whether the heat was generated using natural gas or woodchips.

Insulation

As previously mentioned, Cob is a poor insulator. This is partly a result of its high density when compared to other construction methods that employ different types of insulating material and/or air cavities (which are good insulators themselves). A 60 cm wall thickness is observed to have the following properties.

The U-value is a measure of amount of insulation where a lower U value indicates higher level of insulation. It is interesting to note that although the Insulated cavity has less than ½ the U value of Cob (i.e.: more than 2X higher level of insulation), two-layered walls of cob can theoretically and very possibly be built to improve the insulation level of cob walls because the trapped air in between also will act as an insulator; perhaps this will bring the two values closer. However, straw bale will still have much higher level of insulation because "insulated cavity" is considered to be a traditional building technique, which as previously discussed, are inferior to straw bale in terms of insulation.

Structure Type	U – Value (KW/m^2K)
Insulated Cavity	0.2
Stone	1.6
Cob	0.45[91]

Table 4: Insulation values of 60cm wall sections of different materials (THORPE, 2011).

<u>Thermal mass</u>

Cob, being high in density when compared to other building, has high thermal mass. This thermal mass is able to "flatten out" changes and fluctuations in temperature by absorbing and releasing heat that oppose the temperature change. A comparable material to cob in terms of thermal mass is concrete.

Material	SHC *(kcal/kg°C)*
Concrete	0.18 -0.22[74]
Cob	0.190[75] - 0.2[76]

Table 5: Specific Heat Capacity of cob vs. concrete (THORPE, 2011).

Material	Density (kg/m^3)
Concrete	2240-2400
Rammed earth	1600

Table 6: Density of rammed earth vs. concrete (self-constructed table).

Cob has a similar specific heat capacity when compared to concrete. Rammed earth (which is a building material/method similar to cob) has a density ~70% that of concrete (we were unable to find the density of cob). The result is that cob has thermal mass comparable to that of concrete.

4.0 Economical

Building with straw has many benefits as well as couple drawbacks. In one study, 27 straw bales houses were analyzed. 18 out of those 27 were built for under $40,000, which is much less expensive compared to the average of $75,000 – $120,000 cost for a regular stud-frame home. There are several aspects behind the lower cost of building using alternate construction, such as labor costs and obtaining the materials.

4.1 Straw Bale

The construction of straw buildings is much simpler than standard building construction, allowing most of the work to be done without the need to hire professionals. UBC students who want to participate can learn how to build using these materials, which saves a lot of labor costs.

The costs of building with straw are much cheaper than a stud-frame constructed building. Straw bales can be grown at UBC, or bought from another source. Even when bought, money can be saved because straw can obtained from local farmers rather than at retail costs.

A large drawback of dealing with straw is the moisture content. The straw bales will begin to rot if the building is not built properly and allows moisture to come into contact with the straw. To prevent this, it should be built on a plinth, and should carry a large overhang to protect from the rain. If the straw begins to rot, it presents the danger of wall failure and may need to be replaced. Using straw bale for walls in the North American climate is relatively new, and is still somewhat experimental, so the condition of the straw bale should be monitored.

In order to ensure the durability of straw bale walls in the building design, it is necessary to monitor the moisture content of the straw based on precipitation rates and water levels in the region. Moisture is a problem in all forms of construction; the particular concern in straw bale buildings is that the bale will decay when kept in a high moisture environment (Lawrence et al, 2009). Research from the Innovative Construction Materials Department of Civil Engineering notes that moisture content of less than 15% leaves the straw bale safe from degradation and suitable for construction. As moisture levels fluctuate on a seasonal basis and vary among different regions, moisture levels should be monitored to determine whether or not straw is durable with respects to climate.

4.2 Cob

Building with cob, just like straw, is easy to learn; the Cob Builder's Handbook is a great resource to learn the basics of building with cob. Obtaining the materials to build with cob is easy and cheap. The majority of the materials used are just clay and sand, which can be obtained for free from excavating the site, or taken from somewhere else on the UBC campus.

Cob does not have the danger of rotting, even in humid climates. There are cob buildings in Europe that are over 500 years old and still in use today, so we can see that if built properly, cob buildings can last for a long time.

When building with cob and straw, the design should be kept simple to minimize labour and use of materials. It should be designed in a manner that allows for sun to come in during the summer and to retain heat during the winter. This will lower the energy consumption of the building after it is built. It should be designed in a manner that allows for sun to come in during the summer and to retain heat during the winter, similar to what is shown in Figure 6 below.

Figure 6: Example of how to build an energy efficient building

To save costs on heating and to lower energy consumption, another aspect should be considered as well. Straw bale is a very strong insulator-type material, whereas cob provides thermal mass. This means straw will keep the heat inside efficiently and cob stores heat energy and then releases it over time.

Both cob and straw save money in the construction process, but both have drawbacks. Straw bales run the risk of rotting if not built properly, and cob is not very well suited to insulate the building in this climate. We recommend using straw bale on the outside, as it is more appropriate for the Vancouver climate, and using cob on the inside, preferably placed in a manner where it will receive sunlight in the winter in order to maximize efficiency.

5.0 Social

When considering using materials such as cob and straw for the construction of their new Farm Centre, social factors pertaining to the usage of these materials are an integral part of the decision process. The main points to consider when discussing the social analysis of using these materials are educational opportunities, community building, and general perception towards being in a building made of these materials.

5.1 Straw Bale

From an educational standpoint, there is an opportunity to use the fact that construction was done with alternative materials as a tool to engage younger audiences and get them thinking about sustainable practices. Younger generations aside, this is an opportunity to impact students here at UBC, showcasing an example of mixing in sustainable practices with problems and tasks in our lives. As for community building, Friends of the Farm, as well as others, could certainly get involved in the construction phase. Unlike construction with traditional materials such as wood and cement, straw bale construction involves a process that consists of attaching large quantities of straw bale together before doing any heavy-duty construction (Carter, 2006). This would be an ideal opportunity to get a community of individuals involved in the construction process. Finally, with regards to general perception, there have been a number of research studies that connect good health and increased happiness to materials such as straw bale. It's natural and allows for more airflow due to its lack of concrete thickness. Furthermore, because of the nature of the material, not as many toxins (such as paint) are utilized. In general, this leads to greater well being in the people who get to experience the space. Additionally, since straw walls don't give off harmful chemicals as profusely as traditional building material such as wood and concrete, the air inside the structure is more refreshing and enjoyable. Heat and sound are also well maintained and insulated by straw bale, making the overall experience for the individual that much better.

5.2 Cob

There exist many similarities to straw bale. In terms of educational opportunities as well as community building, the verdict is relatively similar. For community building, people would still be able to get involved in the construction phase of this project, but rather than attaching straw bales together, they would be helping in a manner that more resembles smashing up cob for the pre-construction phase. Overall, however, there would exist the opportunity to get involved in the process to some extent. As for general perception towards cob, as was the case with straw bale, having cob on a building would actually create a greater sense of calm and serenity (Laylin, (n.d.)), thus leading to more relaxation and happiness than would normally be experienced in a typical wooden building. In terms of safety, certain studies show a slight bit of unease at the idea of living in a building made entirely of cob or straw bale; however, when it comes to using a part of a building that is made of these sustainable, alternative materials, there has been no precedence of fearing for one's safety.

When surveying 233 UBC students on whether they would feel safe in a building made of cob or straw bale, and whether they would use the building's facilities, the majority reaction was that they would treat it as a regular building, using it as they would any other on campus (Appendix A). With regards to the use of cob and straw bale in the construction of this UBC Farm Centre, there are a number of positive social factors that should certainly come into play and affect the decision.

6.0 Conclusion and Recommendations

Based on the research, cob and straw have proved to be beneficial environmentally, socially and economically. The following key points summarize the analysis of cob and straw bale as potential building materials:

- Both cob and straw cost less to construct in comparison to the conventional building materials.
- The net carbon cost of building with straw and cob is less than wood, bricks, and concrete and other conventional building materials.
- Straw is a very good insulator resulting in energy savings and low operational carbon.
- Straw is a natural fire retardant, which slows down combustion reactions to resist the spread of fire.
- The relative simplicity of construction with cob and straw provides an opportunity for individuals in the community to take part in the building process.

Given the benefits of straw and cob usage on both the environmental and economical aspects, using both materials experimentally in construction becomes a reasonable plan. The opportunity for the community to come together in collective construction becomes an opportunity for learning as well. With particular focus of the UBC Farm building construction, it is suggested that the outside walls be built with straw because of straw bale's insulator-like properties. The interior walls should be designed with cob basis due to its high thermal mass and it's ability to release or absorb heat as needed.

It is further suggested that only a part of the UBC Farm building should be constructed using a combination of straw and cob rather than the entirety of the building. More straw and cob construction or expansion can be planned based on how well this part of the building performs throughout the years, as building with cob and straw is still experimental. Based on the environmental, economical, and social aspects pertaining to the study, cob and straw serve as viable alternatives to conventional building design for the new UBC Farm building.

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Appendix A – Survey Results