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

James Li, Matthew Gray, Sam Coulter

University of British Columbia

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ABSTRACT

The effects of climate change and exhaustion of natural resources has triggered a movement towards “sustainable” or “green” construction (Offin, 2010). This trend has created a renewed interest in construction with natural building materials.

This study aims to examine the suitability of Cob and Straw Bale based construction for the UBC farm’s new building based on 3 primary factors; economic, social, and environmental.

Primary research was conducted through online, in-print, and professional resources. Existing examples of Straw Bale and Cob utilizing buildings were both the inspiration and the main target of research and information gathering efforts.

This study shows the suitability of Straw Bale based construction for a large scale building, and the complementing Cob based construction for a smaller building or new wing of an otherwise traditional building.

These conclusions should prove useful in all future infrastructure investments of the University of British Columbia.

TABLE OF CONTENT

LIST OF ILLUSTRATIONS

GLOSSARY

Composite:	A material made from constituent materials that act as one in the finished material
Fault:	A fracture or discontinuity in a body of rock, usually causing displacement of rock
Plaster:	Material similar to cement or mortar used to seal surfaces
Tensile:	To be in tension or pulling apart (opposing forces)
Vapour Pressure:	The pressure of a vapour in contact with its liquid or solid form

1. INTRODUCTION

The University of British Columbia (UBC) Farm strives to be a leader in sustainable innovation and design. The farm is currently working with campus planning to develop a new sustainable Farm Centre. The farm centre will serve as gathering place to educate and practice sustainability. The farm is situated on the UBC Vancouver campus and covers 24 hectares of forested and cultivated land. The purpose of this report is to investigate having one wing of the building or the entire building (2917.7 m2) constructed with cob or straw bales. The report uses a triple bottom line assessment to analyze the economic, environmental, and social factors associated with straw bale and cob construction of non-residential buildings. The research for the report was gathered through online journals, websites, and primary communication.

Cob is a construction material that consists of straw, water, clay and sand. Cob is effectively a concrete; it is mixed in appropriate proportions and then becomes stiff when cured. Straw bale construction utilizes straw bales stacked vertically for structural support or insulation. The bale walls are covered with plaster* to seal and protect the straw.

The first section of the report describes the similarities and differences between cob and straw bale. The next segment focuses on three case studies of straw bale and cob buildings and summarizes their successes and failures. The last section is a triple bottom line assessment comparing the economic, environmental, and social factors of straw bale and cob construction.

2. SIMILARITIES AND DIFFERENCES

Cob and straw bale both utilize very similar natural building materials. For straw bale construction straw is the main component and is used in bales typically 36”L x 20”W x 15”H. In cob buildings straw is added to the mix to work as a fibre to increase the tensile* strength. Sands and gravels make up the bulk of the cob mix and provide the structure or matrix to the mix giving it strength. Cob must contain 15-25% clay; the clay is an important and is used to bind and hold the mix together (Weismann & Bryce, 2007). In straw bale construction sand or earth is used to develop the plaster that protects the bales.

The construction methods of straw bale and cob are unique to the material. Straw bale buildings are either constructed as load bearing or as an infill around a structural frame (Ashour, Georg, & Wu, 2011). Hybrid designs of post and beam are popular for large structures. In hybrid designs the straw bales work primarily as insulation. The walls are constructed by stacking pre-compressed bales in an overlapping pattern or running bond (Offin, 2010). The bales are secured typically with nylon straps to aid with stability and strength. Cob construction is similar to construction using a standard(Portland Cement) concrete. The cob mixture is mixed in batches in poured into frames constructed from lumber or piled rocks (Lovegrove, 2012). The cob dries and becomes a high strength composite.

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3. CASE STUDIES

The following case studies are of real world examples of cob and straw bale construction. The cases were chosen based on their similar geographical setting to Vancouver. The successes and failures of each building project are described below.

3.1. SANTA CLARA TRANSIT FACILITY (SCTF)

In 2006 construction was completed on a straw bale transit maintenance facility for the city of Santa Clara, California. The 47,000 sq. ft. facility is rated Leadership in Energy and Environmental Design (LEED) Gold, and is recognized as one of the first LEED certified straw buildings in the world (Smith, 2007). The building utilizes a hybrid straw bale design. The main load bearing structure is constructed out of timber. The straw bales form the walls of the building and provide effective insulation.

Santa Clara is located near a desert environment and experiences an average annual rainfall of 20 inches (World Media Group, 2012). This is substantially less compared to the 50-60 inches of annual rainfall in Vancouver. Santa Clara is located in close proximity to the San Andreas Fault. The San Andreas Fault is active transform fault* with more seismic activity then experienced in Vancouver.

There SCTF experiences positive building attributes utilizing a straw bale design. The SCTF boasts excellent indoor air quality and ventilation; this is attributed to lack of toxic materials in straw bale construction (Smith, 2007). The straw bales work as an exceptional insulator to moderate outdoor temperature fluctuations and conserve energy. The building is able to conserve 44% more energy than required by the California Energy Code (Smith, 2007). The inside and outside surfaces of the straw bale walls are coated in a lime plaster (Smith, 2007). The plaster protects the bales from moisture and eliminates the need for conventional paint. A light colored plaster was used to increase reflectivity of sunlight and insulate the building (Smith, 2007).

Although the project was very successful, there were obstacles involved with implementing an innovative straw bale design. Initially wire was used to attach the straw bales to the footings but this method had to be replaced with straps because the bales became very unstable (Smith, 2007). There was also misalignment of the bales from workers climbing on the bales (Smith, 2007). This led to sections of the wall having to be rebuilt. The biggest construction set back of the project was made when a roof contractor did not properly cover the bales during a rain storm (Smith, 2007). The result was that 60% of the bales had to be replaced (Smith, 2007). The recommendations from the project were that with better communication and quality control these issues could have been prevented (Smith, 2007).

3.2. SALTSPRING ISLAND

Saltspring Island is host to a number of Cob constructed residences. Located south west of Vancouver, the island shares much of the same environmental and weather conditions ("Climate and weather"). The popularity of cob-constructed homes is primarily with 20-40 year old permanent residents of the island looking for a more economical approach to green and sustainable housing (Vancouver Sun, 2006).

Unfortunately cob construction of community centers or public spaces, as opposed to private residences, is not as common on the island and so no direct examples a 'target' building can be researched. In addition, much of the cob construction is done without adhering to BC construction permits (Vancouver Sun, 2006), and is done primarily by volunteers and other non-professional labourers (“Mudgirls: About”) and as such yields no reliable quantitative data.

However, the presence of both cob and straw bale houses is a good soft indicator that these materials are viable in the temperate climate of Vancouver.

3.3. THE STRAW BALE RESEARCH CENTER

A case study was done on the Straw Bale Research Center at the University of Manitoba. This building was constructed in 2004 as a model for alternative building design. The project was led by engineering professor Dr. Kris Dick. The building has one storey with a floor area of 4200 square feet. Due to its large area, approximately 2000 straw-bales was used for infill of the walls, as opposed to other building designs where straw-bales were used for load-bearing. The framework of the Straw Bale Research Center is supported by wooden beams. The straw-bales are covered with cement stucco for a plaster (Joshi, 2006).

With straw bale as construction material, the building has gained several advantages. In addition to the natural sustainable properties of straw, the walls have a higher insulation value than standard house walls that are filled with fiberglass, cellulose and rock wool. The building saves over 20 percent space heating energy compared to conventional houses according to Canada Mortgage and Housing Corporation. The straw bale walls worked well for sound isolation. They were tested to have twice as much fire resistance as frame walls. Each block was compacted to a predetermined size in tight strings. The moisture content was kept below 15 percent. In its rectangular shape, the building had its long side facing south and north. This orientation used solar radiation to induce a difference in vapour pressure* on both sides of the building. This difference prevents moisture accumulation inside the walls as the different pressures caused movement of moisture in one direction through the straw bale walls and their stucco layer. The waterproof roof of the building is made with timber battens and tarpaulin. The building can also survive high wind and snow loads (Joshi, 2006).

The Straw Bale Research Center has been successful in its design and provided research opportunities to various related fields. However, it was difficult to obtain building permits due to its uniqueness from conventional buildings. It was also hard to calculate an insurance premium for the building because insurance companies did not have enough data to perform risk assessment for such building. Another challenge was that its geographic location was distant from dense population. The building location was difficult to find for visitors (Joshi, 2006).

4. TRIPLE BOTTOM LINE ASSESSMENT

Section 4 discusses the triple bottom line assessment indications of cob and straw bale. The indicators are economic, environmental and social indicators.

4.1. ECONOMIC INDICATORS

Section 4.1 discusses the material costs, maintenance and lifespan, and disposal and recycling options of cob and straw bale.

4.1.1. Material Costs

The cost analysis for the both straw bale and cob construction accounts for the purchase cost of the materials. The transportation costs were not included in the analysis due to the variability. The transportation will be kept to a minimum by utilizing materials in the local Vancouver area. The labour costs are also not included into the analysis because are dependent on the project platform. Table 1 outlines the cost analysis of straw bale construction. The quantity of materials used for cost analysis is based on amounts given in assessments outlined in the embodied energy section of the report.

Cost Analysis of Straw Bale Building			
Material	**Price ($)**	**Quantity**	**Total Cost ($)**
33 x 88mm studs (2x4)	3.25 /10ft	8.748 board feet	2.84
Plywood	30.21 /15kg	7.573 kg	15.25
Straw Bales	6.00 /bale	92.46 kg (2 bales)	12.00
Cement	12.50 /40kg	22.59 kg	7.11
Lime	18.50 /23kg	18.105 kg	14.56
Sand	16.00 /tonne	144.18 kg	2.31
38 x 140 mm studs (2x6)	7.59 /16ft	26.73 board feet	12.68
		Total Cost for 2.4 m^2:	66.75
		Total Cost for 1 m^2:	27.81

Table 1: Cost Analysis of Straw Bale Building

Straw bales can be purchased form several farms in the local Fraser Valley area. The straw bales used for the cost analysis were a standard size of 45lb 36”L x 20”W x 15”. The lumber, cement, and lime used for the construction can be found in local hardware suppliers in the Vancouver area. The sand can also be purchased locally from an aggregate supplier.

The cost analysis utilizes material quantities outlined in Maria Offin’s report “Straw Bale Construction: Assessing and Minimizing Embodied Energy”. The cost analysis is for a hybrid post and beam (non load bearing) design and uses a lime based plaster (Offin, 2010). The design also utilizes a 2.4 meter squared section of wall

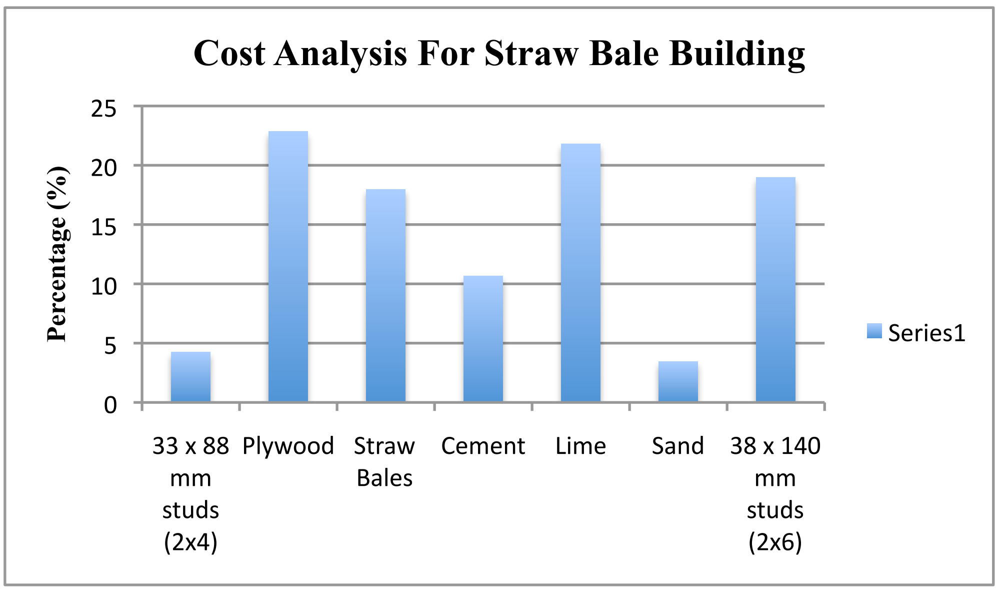

Figure 1: Cost Analysis For Straw Bale Building

Figure 1 shows the breakdown of the cost analysis for straw bale buildings. The bulk of the cost is attributed to both the lumber and the components of the plaster (cement, sand, lime). The costs for lumber could potentially be reduced by using recycled wood from other construction projects on the UBC campus. An alternative to using a lime plaster would be a clay or earthen plaster. Similar to the materials used in cob a plaster could be created from the soil on site reducing costs.

Cob construction utilizes similar materials to straw bale and can be found locally in the Vancouver area. Straw bales can be found on local farms in Fraser Valley. A major component for Cob is a suitable clayey soil. Ideally the soil from the excavation of the building footprint can be used to make the cob. Proportions of sand, clay and gravel can be added to meet the mix requirements. Sand and gravel are readily available for purchase from suppliers all over the mainland. The potential problem is that the native soil does not contain enough clay. After substantial research, suppliers of clayey soil in the Vancouver area could not be found. Dr. Dharma Wijewickreme of the UBC Civil Engineering department suggested that clayey can usually be purchased from construction sites with large excavations (Wijewickreme, 2012). Table 2 below shows the cost analysis of a cob building.

Cost Analysis of Cob Building			
Material	**Price ($)**	**Quantity**	**Total Cost ($)**
Gravel	20.50 /tonne	13 tonnes	266.50
Sand	16.00 /tonne	30 tonnes	480.00
Straw Bales	6.00/ bale	7 bales	42.00
		Total Cost for 55 m^2:	788.50
		Total Cost for 1 m^2:	14.34

Table 2: Cost Analysis of Cob Building

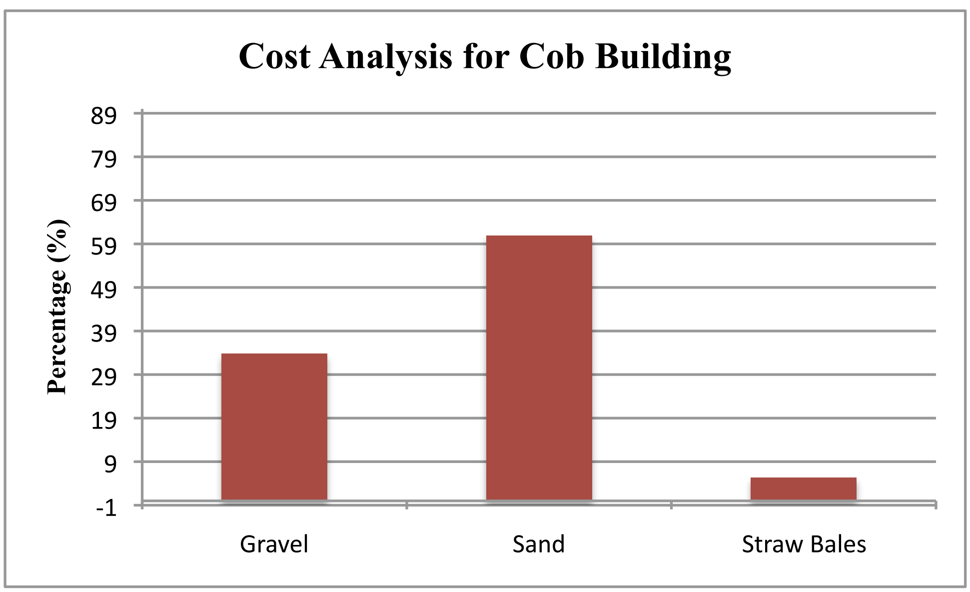

Figure 2: Cost Analysis for Cob Building

A graphical representation of the costs is shown in figure 2. The costs associated with cob construction are highly dependent on the soils used in for the mix. If a suitable quantity and composition of soil can be found on the UBC farm this can greatly reduce the costs for construction. However, if large amounts of soil are trucked in from construction sites the costs for transportation could become substantial in the total building costs.

The simplistic design of cob accounts for its lower construction costs compared to straw bale. Cob requires less money being spent on expensive lumber and plaster materials. Both the construction materials costs are heavily dependant on the availability of materials. The costs can be reduced if the materials can be harvested from the site or recycled from other construction sites.

4.1.2. Maintenance and Lifespan

Both Cob and Straw Bale construction pose their own maintenance and lifespan challenges, especially in temperate climates. Straw bale is particularly susceptible to difficulties, including but not limited to; mold, moisture, and insects (Times Colonist, 2009). Cob fares much better as it is susceptible to structural damage caused by moisture but can be both proofed against moister damage, and usually, very easily repaired (Geiger).

The weakness of Straw Bale is primarily because of the high moisture conditions of temperate climates. Straw bale must be given a foundation of 2-3 feet above the ground to prevent moisture seeping upwards (Times Colonist, 2009) as even a small amount of moisture can cause a catastrophic mould problem that is difficult, if not impossible to repair without rebuilding the affected areas. The other main problem is insect infestations, as insulated masses of straw provide perfect breeding grounds for large swaths of insects and rodents. This can be prevented with adequate sealing, and subsequent resealing of the straw bale exterior (Geiger).

Cob’s main adversaries are cracking/crumbling due to low moisture conditions and damping and structural failure due to excessively high moisture conditions. Low moisture cracks and other damage can be repaired at very low cost be reapplying cob mixture to the affected areas (Geiger). High moisture problems can be prevented with adequate exterior sealing with a lime mixture or similar material in combination with proper ventilation systems to keep the moisture from building to intolerable levels (Times Colonist, 2009).

4.1.3. Disposal and Recycling Options

Both Cob and Straw bale buildings are very easy to dispose of and recycle. As both are formed from bio-degradable materials, both the disposal and recycling of either material is trivial ("Cob strawbale hybrid").

However, sealants used to waterproof and for pest control in Straw Bale and Cob construction must also be chosen carefully if a purely bio-degradable structure is desired. Both lime and clay plasters are traditionally used as bio-degradable sealants (Smith).

4.2. SOCIAL INDICATORS

Section 4.2 discusses the social indicators of cob and straw bale, including safety, building codes, and community involvement.

4.2.1. Safety

One of the biggest concerns with earthen and straw bale buildings is their safety and comfort. In engineering design the safety and welfare of the public is paramount to all other concerns. In assessing the social impact of straw bale and cob buildings, the report investigates safety concerns associated with the structures.

Straw is very combustible material and the general perception is straw bale buildings are highly flammable. This has lead to an abundance of tests looking at straw bale buildings resistance to fire. Testing has concluded that straw bale walls have a higher resistance to fire then conventional (Theis, 2003). The fire resistance is attributed to the straw being compressed into blocks; this decreases the ability for oxygen to feed the fire (Theis, 2003). The plaster on the walls assists with the fire resistance by preventing the fire from reaching the straw bales and timber frames. Most of the fires associated with straw bale buildings occur during construction when the bales are not plastered and are exposed (Theis, 2003).

Fire safety is a lower concern for cob buildings. The buildings still contain straw but the majority of the wall is noncombustible earth. The biggest concern with cob and fire safety is the strength of the cob during exposure to high temperatures. The cob shrinks under heat and small cracks and fissures expand creating planes of weakness (Ley and Widgery, 1997).

Vancouver is located in close proximity to the tectonically active Cascadia seduction zone. The potential for a large earthquake is a consideration that must be accounted for when building in the area. Recent testing was completed at the University of Nevada to analyze straw bale buildings under earthquake loads. The testing was completed on a plastered 14’x14’x10’ load bearing straw building (Donovan and Elfass, 2009). The straw bale building was able to withstand shaking accelerations 200% greater then the 1994 6.7 magnitude earthquake in Canoga Park California (Donovan and Elfass, 2009). Their ability to withstand earthquakes is likely due the bales being able to absorb energy and the wide footprint of the walls.

The ability to with stand an earthquake is also an important safety concern for cob construction. The City of Vancouver Engineering Department and the UBC Civil Engineering Department completed testing analyzing the structural stability of cob buildings under seismic loading conditions. At the UBC Earthquake Engineering Research Facility, the cob structure was able to withstand a 9.0 magnitude earthquake without fully collapsing ("A Creative Impact").

Moisture content is an important safety concern, especially in load bearing straw bale designs. If the moisture content in the bales is too high they will begin to degrade. Their load capacity will be reduced and could lead to structural failure. These effects can be monitored the moisture content of the bales with a moisture probe (Goodhew, Griffiths and Woolley, 2004). Special care must be taken during construction to prevent excessive moisture in the bales. Straw bale buildings also need proper ventilation to reduce moisture and the development of mold (Lovegrove, 2012). Mold can have serious health effects to the occupants of the building.

Moisture is not big of a concern with cob construction as it is with straw bale. Cob design uses substantially less straw and the concern of straw degradation is very minimal. The clay in the cob can however be a target to erosion from rain (Lovegrove, 2012). The water can erode the clay and affect the stability of the wall. These effects can be minimized by using a plaster to seal the cob and a large roof overhang (Lovegrove, 2012).

Straw bale and Cob construction both have similar safety concerns because of their similar designs and building materials. For straw bale the largest safety concern is moisture infiltration and the degradation. The safety concerns associated with cob are minor and it holds up to elements well because it is a more resilient design.

4.2.2. Building Codes

Building codes, regulations and standards are established to protect the public. The recent increase in construction of straw bale and cob buildings has led to more testing being completed. The testing helps analyze safety concerns and develop codes, regulations and standards.

Straw bale construction was first incorporated into buildings codes in the South Western United States (Swan, Rteil and Lovegrove, 2011). In the last 25 years their inclusion into building codes has been growing around the world (Swan, Rteil and Lovegrove, 2011). The codes in place regulate the allowable dimensions for buildings; they also limit the amount of vertical load and require the building to be able to take a minimum lateral load (Swan, Rteil and Lovegrove, 2011). Specific codes for straw bale buildings fall under non-conventional buildings in British Columbia (BC). For straw bale construction permits the design would have to be approved by a structural engineer.

Cob construction has a more developed presence in building codes then straw bale. Similar to straw bale the South Western United States has made the most progression to including cob into their building codes (in North America)(Swan, Rteil and Lovegrove, 2011). The codes in place standardize the geology and particle size of the soil and require mix design similar to concrete (Swan, Rteil and Lovegrove, 2011). Most codes limit the construction to 2 storeys and invoke a minimum wall thickness to height ratio (Swan, Rteil and Lovegrove, 2011). The compressive strength of the cob is an important safety consideration to prevent structural failure. The codes and standards require that test specimens be cast and tested in laboratory; the specimen must reach a minimum compressive strength of 2000 kPa (Swan, Rteil and Lovegrove, 2011). Similar to straw bale, in BC building codes cob falls into the category of alternative housing. To receive permits to build a large cob structure in BC the design would have to be approved by a structural engineer.

Under the BC building codes the construction of straw bale and cob buildings are only provisional by the approval of an engineer. The area of sustainable building materials is becoming an increasingly popular research topic. When a substantial amount of research has been completed there is likely to be standards included into the BC building code.

4.2.3. Community Involvement

In this section of the report, social community involvement of cob and straw bale constructions are discussed. As both cob and straw bale housing are non-conventional construction, small communities have been formed to promote sustainability values of both options, sharing experience and exchange skills.

In British Columbia, several cob-housing communities exist. The Stanley Park has a cob house that was built by volunteers for fundraising and promoting environmentally sustainable community. The cob house is shown in Figure 3a. UBC Civil Engineering, the BCIT Green Roof Research Facility and other volunteers, all together 200 people, formed the construction team. Volunteers included children, teenagers, adults and elders.

Figure 3a: Cob house at Stanley Park

Figure 4b: Cob house project volunteers

Figure 3b shows volunteers who helped out in the construction process. The team constructed thousands of hours onto the project (Stanley Park Ecology Society, 2012). In Maine Island, a community initiated by Cobworks has also been actively involved in cob housing. They host workshops for people to gather together and learn how to build a building from cob (Cobworks, 2009).

Sustainable Works is another construction group based in British Columbia. They provide workshops for people who are interested in straw bale house building as well (Sustainable Works, 2012). Besides local community, international communities on sustainable housing are also providing social opportunities. StrawBale.com hosts an online blog. It shares tips and experience of straw bale house building on the Internet. It has a large user base from around the world (Strawbale Innovations, 2012).

Community involvement of cob and straw bale housing has not only created opportunities for people of the same interest to get together. It also increases people's consciousness on sustainability. Community involvement allows people to make their own decisions fro improving the environment.

4.3. ENVIRONMENTAL INDICATORS

Section 4.3 discusses embodied energy assessment, thermal efficiency, and carbon emission reduction that are environmental indicators of cob and straw bale.

4.3.1. Embodied Energy Assessment

The embodied energy looks at the energy associated with the production of the materials and the building construction. The models focus only on the construction of the straw bale and cob walls. The models do not account for energy used by construction machinery such as saws and cement mixers (Offin, 2010). These energy values are relatively low and can be even avoided by using hand tools. Transportation of the materials to site has also been neglected. The materials are assumed to be from the local Vancouver area to minimize the EE.

Straw is a renewable resource produced annually from stalks remaining after grains have been harvested. In the United States more 200 million tons of straw are wasted annually (United States Department of Energy, 1995). The straw is typically burned releasing harmful toxins into the atmosphere. Using straw for construction purposes is form of recycling the straw and preventing disposal. Straw is natural material that degrades over time. It can be recycled to be used as compost. Straw can purchased from farms in the Lower Mainland and Fraser Valley. This helps to support the local community and reduce the transportation footprint. Table 3 below shows the embodied energy (EE) of a straw bale building.

Embodied Energy Of Straw Bale Building			
Material	**EE per unit mass/volume**	**Quantity**	**Total EE (MJ)**
33 x 88 mm studs (2x4)	2.795 MJ/board foot	8.748 board feet	24.45
Plywood	10.397 MJ/kg	7.573 kg	78.74
Straw Bales	0.91 MJ/kg	92.46 kg	84.14
Cement	4.689 MJ/kg	22.59 kg	105.9
Lime	6.864 MJ/kg	18.105 kg	123.7
Sand	0.0948 MJ/kg	144.18 kg	13.67
38 x 140 mm studs (2x6)	2.795 MJ/board foot	26.73 board feet	74.71
		Total EE for 2.4 m^2:	505.3
		Total EE for 1 m^2:	210.5

Table 3: Embodied Energy Of Straw Bale Building

There have been numerous studies completed on the embodied energy of straw bale construction. This report uses research completed in Maria Offin's Report "Straw Bale Construction: Assessing and Minimizing Embodied Energy". The

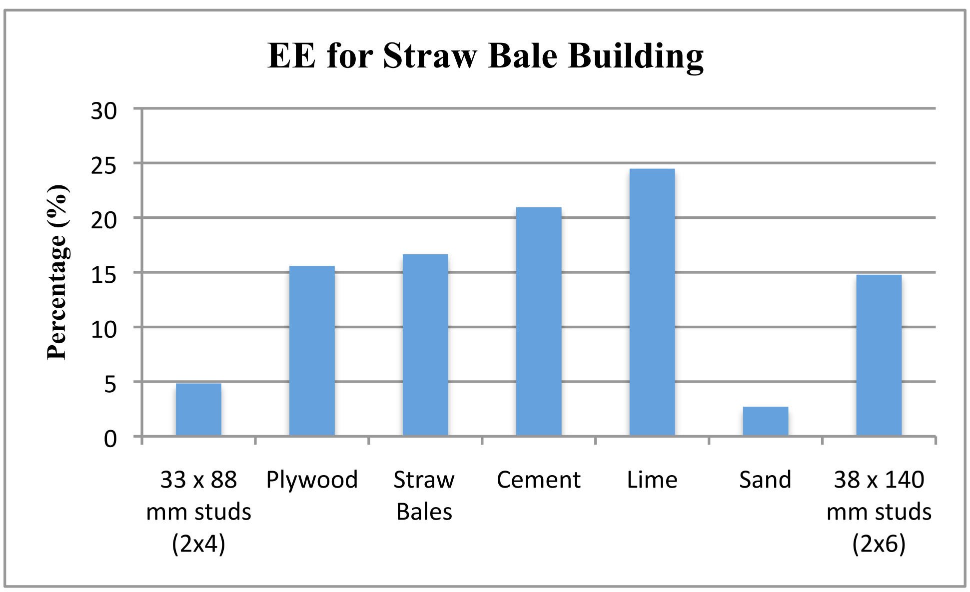

Figure 5: Embodied Energy for Straw Bale Building

model looks at a 1x2.4m section of wall constructing using a hybrid (non load bearing) post and beam method (Offin, 2010). The analysis considers the use a 6:1:1 plaster (6 parts sand, 1 part cement, 1 part lime) (Offin, 2010). This is the most common plaster used but it also has the highest embodied energy.

The above plot figure 5 shows that the plaster contributes to 48% of the total embodied energy. The plaster contains a high EE due to the volume needed to cover the walls and its high density (Offin, 2010). To reduce the EE of the plaster an alternative plaster such as lime based plaster or an earth or clay plaster can be used. Offin's report also looks at ways to effectively decrease the EE of the 6:1:1 plaster. The EE of the plaster can reduced by increasing the amount of sand added to the mixture (Offin, 2010). This must be done carefully because it decreases the plaster strength and can affect the buildings structural integrity. The construction of a straw bale building under these conditions has a value of EE 6 times lower then a conventional frame of wood and brick siding (Offin, 2010).

Cob construction consists of 4 materials: straw, water, clay and sand. The materials used in cob construction are very renewable and can be sourced in the local Vancouver area. As mentioned above straw can be purchased locally and is a very sustainable material. Clay and sand are found naturally in soils and can easily be recycled for other farm projects or sold. The soils needed for the cob could possibly be sourced from fill removed to make the proposed buildings foundation. Table 4 below shows the EE for a cob building.

Embodied Energy of Cob Building			
Material	**EE (MJ/kg)**	**Quantity (kg)**	**Total EE (MJ)**
Gravel	0.083	13000	1079
Earth/Sand	0.45	30000	13500
Straw Bale	0.91	320	291.2
Water	0.2	8000	1600
		Total EE for 55 m^2:	16470.2
		Total EE for 1 m^2:	299.5

Table 4: Embodied Energy of Cob Building

There have not been many scholarly studies completed on the embodied energy of cob construction. A simplified analysis of the embodied energy of cob construction was found on the "Cob Research Institute" website (Cob Research Institute, n.d.). This website uses values retrieved from a report completed by Prof. Geoff Hammond and Craig Jones of the University of Bath, UK called the "Inventory of Carbon & Energy"(Hammond and Jones, 2008).

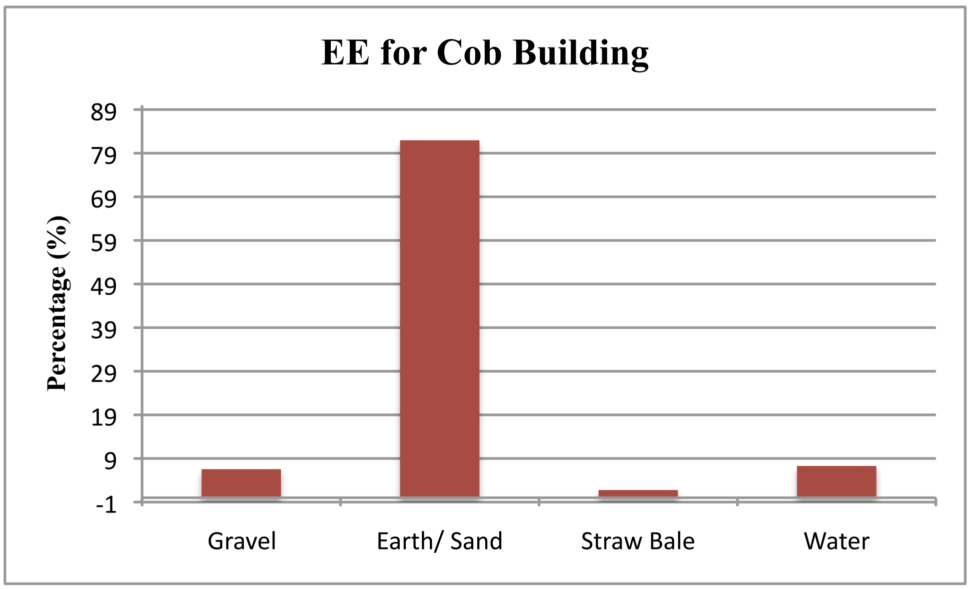

Figure 6: Embodied Energy for Cob Building

Straw bale construction has a lower value of embodied energy compared to cob construction. The straw bales used in straw bale construction make up the majority of the construction materials used; they have a very low embodied energy due to the little energy required to harvest them. This helps to keep the value of EE low for straw bale construction. The embodied energy for Cob construction is controlled by the energy associated with excavation of suitable soils.

4.3.2. Thermal Efficiency

This section of the report compares the thermal properties of cob and straw bale. To analyze thermal performance of cob and straw bale, insulation efficiency are considered. Insulation efficiency is determined by thermal resistance, which is also known as the R-value. The higher the R-value, the better insulation the material is (Straube, 2001).

Table 5: R-values of cob wall samples measured by KD-2 Pro Analyzer (Straube, 2001)

	# Samples	R/in	R of 22-inch wall	R of 12-inch wall
N.W Wall 1	24	0.39	8.66	4.72
N.W Wall 2	17	0.26	5.82	3.17
W. Wall 1	26	0.28	6.23	3.40
W. Wall 2	15	0.30	6.67	3.64
S. Wall outer	13	0.19	4.13	2.25
S. Wall inner	10	0.28	6.11	3.33
N. Wall	17	0.30	6.54	3.57
Average		0.287	6.309	3.441

Table 5 shows the R-values of a thermal conductance test on a group of wall samples using a commercial thermal properties analyzer KD-2 Pro. The tests were conducted on wall facing various directions. 12-inch and 22-inch walls were used to calculate the average R-value per inch. The average result was determined to be 0.287 per inch (Straube, 2001).

Insulation efficiency of straw bale depends on the density. According to a Danish research paper on straw bale walls, straw bale is more insulation effective than cob (Baird, 2011).

Table 6 lists test results of the research. Due to the orientation of straw, perpendicular and parallel directions of heat flow were both considered in the test. Straw bale wall samples had considerably low density ranging from 4.8 to 5.9 pcf.

R-value was also calculated for compacted straw bale wall. It was determined to be 1.31 per inch (Baird, 2011).

Heat flow relative to straw direction	Density (pcf)	R-value/inch	R-value/18 inch
Perpendicular	4.8	2.77	50
Perpendicular	5.9	2.58	46
Parallel	4.8	2.53	46
Parallel	5.7	2.40	43
Compacted	37.4	1.31	

Table 6: R-values of straw bale wall samples from a Danish research (Baird, 2011)

The research results from the KD-2 Pro analyzer on cob and Danish research on straw bale showed evidence that straw bale has significantly better insulation than cob (Baird, 2011).

4.3.3. Carbon Emission Reduction

While cob does not contribute to carbon emission, straw bale is a construction material with lower carbon emission compared to conventional building materials for wall construction. This report is based on a research completed by the School of Architecture at the University of Lincoln in the UK. The research analyzed both embodied carbon emission and operational emission. Embodied carbon emission refers to carbon emitted during the construction process, while operational emission refers to carbon emitted throughout the lifecycle of a building after it was built. Carbon emission was calculated based on a 60-year life span of a standard UK semi-detached house. The house contains two storey, three bedrooms, with internal gross area of 86.75 m2. The design of the house uses straw bale as load bearing, plastered with lime. Clay tiles were used for the roof. The effect of variable materials such as interior finishes was not considered as they could vary by choice of house owner (Sodagar, 2011).

First, embodied carbon emission was analyzed using embodied carbon assessment. Cellulose, hemicellulose and lignin are the three main substances in wheat straw. The amount of carbon within cellulose and lignin were calculated to be 44.4% and 66.6% respectively. The moisture content was assumed to be 10%. The carbon content of straw was calculated to be 0.367. Using this value, the total CO2 sequestered within the straw bale was estimated to be 1.35 CO2/kg of bale. A benefit of straw bale was CO2 lock-up, also known as CO2 sequestration that was an ability to store CO2, preventing it to be released to the atmosphere. Even without considering this benefit of straw bale, the embodied emissions rate for the house was 151 CO2/kg. It was significantly lower than the rate of 475 CO2/kg from conventional houses in UK. 82.5 kg of CO2 would be stored in every square meter of floor area if sequestration were taken into account (Sodagar, 2011).

Next, operational carbon emission was analyzed by using the approach of life cycle assessment to take into account the impact of integrated material and energy flow throughout all the stages of the building's entire life. Table X shows the whole-life operational CO2 emissions for a wall of the house over 60 years (Sodagar, 2011).

Stages	Without Sequestration		With Sequestration
	Kg CO2	Relative CO2 (%)	Kg CO2
Materials	12952	25.02	-7070
Construction process	647.6	1.25	647.6
Materials waste	647.6	1.25	647.6
In-use	37378.2	72.2	37378.2
Deconstruction process	136	0.26	136
Total	51761.4	100	31739.4
Total kg CO2/m2	603.6		370.1
Kg CO2/year	862.7		529

Table 7: Whole-life operational CO2 emissions for UK semi-attached house wall over 60 years (Sodagar, 2011)

According to Table 7, the semi-detached house emitted 51761.4 kg CO_2 throughout all stages of its life without sequestration. With sequestration, the carbon-storage property has a negative value of -7070 kg CO_2 on the impacts of other stages. 61% of emission was reduced with sequestration. This reduction is significantly beneficial to the environment in terms of climate change (Sodagar, 2011).

5. CONCLUSIONS AND RECOMMANDATIONS

In summary, the three case studies provide evidence for successful implementation of straw bale and cob construction in a geographical location similar to Vancouver. Straw bale and cob buildings use similar natural materials for their construction. Their main differences are to do with their construction methods and performance as building material. The triple bottom line assessment showcases that both cob and straw bale are excellent methods of sustainable construction.

The proposed size for the new UBC Farm Centre building is 2917.7 m2. Both Cob and straw bale materials can potentially be used for the construction of the entire building. This can be accomplished by using a hybrid design combining post and beams with either cob or straw bale (Lovegrove, 2012). The post and beam method uses a traditional building skeleton with straw bales or cob acting as non-load bearing walls. This takes out the uncertainty involved with the supporting loads on the straw bale or cob walls. This hybrid design would be less design intensive and more likely to be approved by building regulations.

The decision between cob and straw bale for a large-scale building such as the new UBC Farm Centre ultimately comes down to the availability of materials. An immense amount of soil would be needed to build a cob building of 2917.7 m2. The soil at the farm would not be enough and soil would have to be located from other sources. This could lead to high costs and embodied energy with the transportation and excavation. Large-scale cob construction would have to involve machinery to move and mix the cob. This also increases costs and increases the environmental footprint of construction. Straw bale would be a better choice for a large-scale building. The materials in their required quantities could all be found locally. Straw bale is generally an easier to work with and does not require as much pre planning. Cob is effectively dries as a concrete so it requires lots of preplanning to incorporate utility ducting into the walls. The Santa Clara Transit Facility is an example where a large-scale hybrid straw bale building was successful.

If the UBC farm decides to limit the design to a wing or smaller section of the building Cob would be the best option. Cob has a greater social impact on the community then straw bale. Cob allows for the community to come together and contribute to the construction. The community is able to help out and gain a sense of belonging to UBC Farm. Construction methods are very simple and would allow contribution from a wide variety of workers including children and the elderly.

Dr. Lovegrove, an UBC Okanogan Engineering Professor, was contacted regarding his expertise in sustainable building materials. He was interested in the details of the Farm Centre project and possibly being involved with the design. The UBC Farm and UBC Engineering could both benefit from working together on the project. The UBC Engineering department will be able to complete research on the sustainable design and monitor the success of the project. The UBC farm will benefit from the input from the design experts and the social context of involving the University in the project. It may be a great opportunity for the UBC Engineering graduate students to become involved with the project. Dr. Lovegrove has a PhD graduate student working on Compressed Earth Blocks a form of sustainable construction. This could be another form of earthen design that could be considered for the UBC Farm Centre. The UBC Farm should present their project to both the UBC Okanogan and UBC Vancouver Civil Engineering Departments in an attempt to include professional expertise.

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Appendix

Questions asked during a telephone conversation with Dr. Gordon Lovegrove of the UBC Okanagan Faculty of Applied Science. The conversation took place on Friday November 16th, 2012. The answers to these questions were used as a source for the report.

1. For the Cob and Straw Bales we were wondering whether you knew of any companies that supply the materials for construction applications? Or are the materials usually just found locally from farms and businesses?

2. For our report we are trying to investigate examples of non-residential straw bale/cob buildings. We have had great success finding residential houses but are having difficulties with non-residential. Would you happen to know of any non-residential straw bale or cob buildings that have been researched or documented?

3. The UBC farm is looking into either having the whole building cob or straw bale or just a smaller wing of the building. The building will be used as a farm center/community center. The designs are very preliminary; the only information we know is that the building is going to be around 2900 sq. meters or 30000 sq. ft. From your experience would straw bale or cob be a suitable building material for this size of building? Is it even possible to entirely use these materials or would suggest a small building be designed using cob and or straw bale?

4. We were also looking into how the straw bale and cob buildings hold up to Vancouver's climate. What would estimate the life span of these materials to be? Would there be lots of maintenance involved with their structure?

5. We are investigating the social implications of designing with straw bales or cob. In your personal experience do people generally feel safe in these buildings? Do you feel that the building codes for these straw and earthen materials are adequate? Does more research need to be completed in this area to improve safety? How do they buildings react to seismic activity?