University of Cincinnati

Date: 5/2/2011

I, Sean P McIntosh , hereby submit this original work as part of the requirements for the degree of Master of Science in Civil Engineering.

It is entitled:

Factors Impeding the Advancement of Straw Bale As a Feasible and Sustainable Construction Building Material in North America

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1682

Factors Impeding the Advancement of Straw Bale As a Feasible and Sustainable Construction Building Material in North America

A thesis submitted to the

School of Advanced Structures of the

University of Cincinnati

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in the Department of Civil Engineering

within the College of Engineering and Applied Science

May 2011

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ABSTRACT

Building systems may achieve an integration of affordability, green construction, and sustainability through the utilization of straw-bale construction. This building method may be particularly beneficial to countries that are characterized by developing economies or are enduring a recovery from a natural disaster. Employed as a means to replace or complement traditional building materials, straw-bale construction provides easy installation and energy efficiency.

Conventional and prescriptive building regulations create a barrier to the widespread advancement of straw-bale construction. Specifically, common and standardized materials exist in capital intensive industries that compete against each other in a market that can support testing. These factors provide difficulty in introducing and establishing new and competitive building materials. Similarly, preconceived notions of straw-bale construction methodology, design limitations, and supposed deficiencies in straw bales as a feasible building material must be overcome. The exploratory study undertaken herein developed an evaluation of those factors that are impeding the development of this construction methodology in North America. The goal of the study is to provide an analysis of what is the general consensus from builders, contractors, engineers, and architects regarding straw-bale construction. The primary research methods included surveying building professionals throughout North America to gauge their perceptions and experiences. Furthermore, a Life Cycle Assessment (LCA) was conducted to measure the environmental impact of a straw-bale home as compared to a home utilizing common building techniques. Such results may be utilized to facilitate the advancement of this affordable and sustainable construction material.

ACKNOWLEDGEMENTS

The work herein is the culmination of research and learning that has been affected by the direct and indirect encouragement, support, instruction and guidance of many individuals. Through this collaboration, I have been able to fulfill my pursuit of further investigating many of the issues currently plaguing today's building sector. The educators and professionals involved within this project are comprised within several departments at the University of Cincinnati, as well dozens of experts involved with the design and construction of residential buildings throughout the United States and Canada.

With regards to the University of Cincinnati, this project involved the collaboration between the faculty of the Department of Construction Management, Department of Civil Engineering, and the Department of Environmental Engineering. As this project required efforts beyond a single discipline, I am grateful to have earned the support of the individuals within these three departments.

I would especially like to thank my graduate advisor, Dr. Hazem Elzarka, as well as Dr. Margaret Kupferle and Dr. Lilit Yeghiazarian for serving on my graduate committee. These professors allowed me the opportunity to research a topic that is not typically associated with the traditional curriculum, as they were able to see the potential benefits that the project could provide. Dr. Elzarka was an ideal candidate to serve as my academic advisor, as we shared a passion for sustainable construction practices. Additionally, courses taught by Dr. Kupferle and Dr. Yeghiazarian in which I was enrolled at the beginning of my graduate studies, allowed for a foundation of sustainability issues. The individuals who served on my committee were very supportive, and provided an integral aspect in my pursuits throughout my graduate studies. I wish express how grateful I have been to experience their support.

In addition to the faculty members who have served on my committee, Dr. McAvoy and Dr. Shahrooz have been a tremendous help throughout my graduate tenure. Dr. McAvoy has become an invaluable resource throughout my research and development of the Life Cycle Assessment portion of my project. Without his guidance, I am not sure I would have had the ability to accurately complete this portion of my project. Dr. Shahrooz, who serves as the Civil Engineering Department Director of Graduate Studies, provided a constant guidance throughout my graduate studies and served as the chair of my committee. I entered the Civil Engineering Master's program within the construction engineering discipline during a time of transition, and without his help and understanding of my goals, it is uncertain that I would have had an opportunity with the University of Cincinnati.

Beyond the support garnered by the University of Cincinnati, a great deal of gratitude may be extended to all of the building professionals who offered their valuable time and experience towards the survey portion of this project. I am appreciative of the honest and open views expressed by those professionals who have not had any prior experience with straw-bale construction. Similarly, it is quite evident that those who are involved with the straw-bale construction industry are ready and willing to expand upon and share their knowledge with great zeal. Through the achievement of this project I feel that I have become a member of this group and have been welcomed with open arms. In particular, I would like to express my thanks to Dmitry Ozeryanksy, who is a structural engineer currently addressing the need to add agricultural fibers to ASTM standards. Dmitry recognized the similar goals of this project and was a great help in many aspects of the completion of this report. It is individuals such as he that are necessary to help propel straw-bale construction into a mainstream construction practice.

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LIST OF ABBREVIATIONS AND SYMBOLS

LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
TRACI	(EPA) Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
US DOE	United States Department of Energy
HH	Human Health (refer to LCA portion)
GDP	Gross Domestic Product
sq. ft.	Square feet
CO_2	Carbon Dioxide
G8	The Group of Eight Forum
$W/(m^2 \cdot K)$	Watts per square meter per kelvin
US EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
ASTM	American Society for Testing and Materials
CID	Construction Industries Division of the New Mexico Regulation & Licensing Department
°F	Degrees Fahrenheit
CASBA	California Straw Bale Association
2x4	Two inch by Four inch, common construction material measurement
R-Value	Measure of thermal resistance
U-Value	Overall heat transfer coefficient
kN/m^2	Kilonewton per meter squared
psf	Pounds per square foot
psi	Pounds per square inch
lbs.	Pounds
in.	Inch
m^2	Meter squared
ft^2	Foot squared
USGBC	United States Green Building Council
MR	Materials and Resources (LEED category)
EQ	Indoor Environmental Quality (LEED category)
EA	Energy and Atmosphere (LEED category)
DCAT	Development Center for Appropriate Technology
HUD	United States Department of Housing and Urban Development
NAHB	National Association of Home Builders
CGP	Certified Green Professional
CHBA	Canadian Home Builder's Association
BILD GTHBA	Greater Toronto Home Builder's Association
GWHBA	Greater Windsor Home Builder's Association
GOHBA	Greater Ottawa Home Builder's Association
MHBA	Manitoba Home Builder's Association
SHBA	Saskatoon Home Builder's Association
RHBA	Regina and Region Home Builder's Association
ASE	Alliance to Save Energy
AIA	American Institute of Architects
CaGBC	Canada Green Building Council
GBI	Green Building Initiative
NIBS	National Institute of Building Sciences
NRCan	Natural Resources Canada

RAIC	Royal Architectural Institute of Canada
SIBC	Sustainable Buildings Industry Council
NREL	National Renewable Energy Laboratory
LCI	United States Life Cycle Inventory
o.c.	On center
OSB	Oriented Strand Board
LVL	Laminated Veneer Lumber
cyd.	Cubic Yards
H+	Hydrogen Ion
CFC	Chlorofluorocarbons
MJ	MegaJoules
Kg	Kilogram
bu.	Bushel
btu.	British thermal unit
GWP	Global Warming Potential
PM2.5	Air pollutants with a diameter of 2.5 micrometers or less
N	Nitrogen
NOx	Mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide)

Chapter 1

INTRODUCTION

1.1 General Introduction

Straw-bale construction represents a sustainable and widely underutilized building technique. With its foundation based upon a grassroots movement of self-building, it can provide an affordable green building practice for third world economies as well as those countries attempting to recover from a natural disaster. Beyond the economic implications, straw-bale construction provides incentives to builders with energy efficiency and environmental stewardship.

Based upon a block system of building, the simplicity of designs provide for an increase in adaptability from one project to another. Adding further benefit is the accessible nature of straw as an agricultural waste product. The coupling of these two factors can allow for participation from those not typically associated with the building process, and may be inclusive of charitable organizations.

The primary benefits associated with straw-bale construction include cost-effectiveness and energy efficiency. When compared to a typical two story 3-bedroom home of approximately 2150 ft^2 comprised of a traditional brick building system, a straw-bale building can yield a savings of nearly 15% (Amazon Nails, 2001). Furthermore, the use of this material provides enhanced insulation properties, which is associated with reduced heating and cooling costs. Once again considering the typical home, potential savings in energy costs reach as high as 75% (Amazon Nails, 2001). Straw bales as a building material are unique as they provide a combination of high thermal insulation features with sufficient load-bearing potential, allowing it to be both an appropriate building block and insulation material at the same time.

Despite the myriad of economic and environmental benefits correlating to the utilization of this material, the industry appears to have reached a stagnant level of development. Some consider that straw-bale construction may have become lost amongst the advancement of the "green movement". Whatever the case may be, it is necessary to determine what barriers exist that are preventing a further widespread utilization of this sustainable material.

This document will commence with a detailed description of the numerous benefits available to builders who select straw bale as a building material. Furthermore, potential issues that may appear to be a hindrance to the selection of this material will be addressed. Following an establishment of these matters, the study methods utilized throughout this research project will be detailed. Building professionals throughout North America were surveyed to gauge their experiences and preconceived notions of straw-bale construction in order to determine the current state of the industry. Finally, this document will culminate in the Life Cycle Assessment of various residential building options as compared to a straw-bale residence.

1.2 Issues Plaguing the Building Sector

Prior to any evaluation of straw-bale construction, an understanding of the impact that the building sector has on the environment must be established. Buildings in today's world display the juxtaposition of great accomplishment with many unforeseen consequences. While achieving necessary adaptations to appease modern comforts, they are at the same time presenting detrimental impacts to the environment at an alarming rate that has the potential to endanger the world's habitability for future generations. As the negative consequences of modern development and technological advancements have shed a scrutinizing light on manufacturing plants and the automobile industry in recent decades, the building industry has tended not to weather the same level of examination. Factors such as the depletion of natural resources, greenhouse gas emissions, and excessive waste sent to landfills are parallel issues that plague the building industry, in spite of the fact that these obstacles have solutions that may be more easily achieved. With a focus on innovation and alternative building materials, measures may be taken that are cost-effective to building owners, secure and comfortable to building inhabitants, and ecologically responsible to the environment.

Sustainable development may necessitate a transition from its current status as a responsible option towards a dire necessity in upcoming decades if certain statistics are not acknowledged and overcome. With the knowledge that the building sector accounts for around one-tenth of the world's GDP and at least 7% of its jobs, it should come as no surprise that it is responsible for half of all resource use, and up to 40% of energy use and greenhouse gas emissions (Bruelisauer, 2007). In the United States, buildings impact 36% of total primary energy use, 12% of water use, and 70% of electricity consumption (Elzarka, 2010). Natural resources are in a state of depletion as buildings induce one-sixth of the world's fresh water withdrawals, meanwhile exhausting one-quarter of its wood harvest, and two-fifths of its material and energy flows (Roodman, 1995). As a result, the occurrence of deforestation, air and water pollution, stratospheric ozone depletion, and global warming risks are forming dangerous trends spiraling in the wrong direction. Aside from environmental implications, the conservative estimate that 30% of new and recently renovated buildings place inhabitants at risk of suffering from “sick building syndrome” displays the necessity to reassess the ways we are designing our buildings (Roodman, 1995).

The primary impact that straw-bale construction could provoke upon current building methods would be its diminishment on the need for timber. From 1949 to the 1990s, homes in the United States have increased their average square footage from 1100 sq. ft. to 2000 sq. ft. Considering that 90% of these homes are wood-framed, and floor space per person has nearly doubled, the housing industry clearly has a severe accountability towards deforestation (Marks, 2005). Over the course of the last century, 20% of the world’s global forest cover has decreased, impacting the extinction of thousands of plant and animal species (Roodman, 1995). It is staggering to discover that Americans use more wood than any other single material, which includes the combined utilization of steel, plastic, and concrete (Marks, 2005).

Laurence Doxsey from the Excellence for Sustainable Development estimated in 2000 that in the United States there exists over 76 million buildings of residential use, and these have required nearly 836 billion board feet of wood. Extending his predictions into 2010, construction on 38 million more buildings would occur. Should building trends continue, this development would demand an additional 418 billion board feet of wood and deplete 38 million acres of forest. If 10% of these timber-framed homes could have been replaced with construction utilizing straw bales, then over 1 million tons of waste and 3 million acres of forests could have been conserved (Marks, 2005).

Additional concerns regard the fact that 65% of waste output generated by society can be traced back to the building sector (Elzarka, 2010). Again considering a typical home consisting of a timber frame, construction waste averages 3-7 tons per home (Marks, 2005). Similarly, the energy required to manufacture common building materials is associated with a 27% increase in atmospheric CO_2 levels during the last 100 years. Furthermore, 25% of the carbon dioxide increase corresponds to the emissions from burning fossil fuels as a means to provide energy to buildings (Roodman, 1995). During construction phases, the building industry makes the following contributions to global emissions: 49% of sulfur dioxide emissions, 25% of nitrate oxide emissions, 10% of particulate matter emissions, and 35% of carbon dioxide emissions (Marks, 2005).

The intention of stating these statistics is not to alarm, but rather initiate the understanding that innovation and utilization of alternative materials may provide solutions to many of the issues currently plaguing the building industry. Currently, 2 billion people now live and work in resource-intensive buildings, and in 50 years the number may reach 8 billion (Roodman, 1995). With the acceptance that these consequences are not going to relinquish, and in fact will only continue to compound themselves in the coming decades, it is now more than ever necessary to engage in modern solutions to past problems.

1.3 Sustainable Development

In spite of the developing acknowledgment that global resources are finite, economic growth and social welfare continue to often take precedent over environmental consideration and responsibility. The matter of sustainable development is established upon the core principles of satisfying the essential worldwide needs of today, while following development patterns which preserve the limited natural resources for future generations (Bruelisauer, 2007). Currently, the world's engineers and scientists are placed in a crucial position with the ability to redirect the future of our planet. As evidence for climate change mounts, as substantiated by the Intergovernmental Panel on Climate Change and the 2007 G8 Summit held in Heiligendamm, the scientific community must respond.

As overall environmental stewardship and awareness has increased, an unfortunate side effect has developed. While no company, manufacturer, or process wishes to appear neglectful regarding the importance of sustainability, it is often times difficult to see past fashionable "greenwashing". The most commonly accepted definition of sustainability culminated from the 1987 Brundtland Report of the World Commission on Environment and Development, which summarized that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This statement regarding the needs of future generations possesses a particular relevance towards buildings and infrastructure, considering that they are typically designed to last upwards of 50 to 100 years (Bruelisauer, 2007). Furthermore, buildings are in a constant state of evolution. U.K. architect Francis Duffy is reputed as an expert on buildings and the changes they endure throughout their lifetimes. His determinations are that most commonly building exteriors tend to change every 20 years or so, while new wiring, plumbing, and climate control systems require maintenance or replacement every 7-15 years, and floor plans may be modified as frequently as every 3 years. Under further inspection it is evident that buildings essentially consist of layers that are evolving at different rates (Roodman, 1995). In summary, the designs of today will most certainly have an impact on tomorrow.

The triple bottom line is a phrase that has grown to encompass the equivalent importance that must be placed on economic, social, and ecological issues, when making a sustainable decision or design. The phrase was established in John Elkington's book *Cannibals with Forks: the Triple Bottom Line of 21st Century Business,* which was published in 1998 and since has become widely regarded throughout the scientific community. When considering the design and construction of a building, the owners, financiers and developers, future building inhabitants and neighbors, along with the overall environmental impact prior to breaking ground to the future demolition all must be evaluated in order to consider the project to truly be sustainable. To satisfy all of these requirements, these buildings must be adapted to ensure that everything from indoor air quality and thermal comfort, to energy and water efficiency are accounted for.

Chapter 2

STRAW-BALE CONSTRUCTION INTRODUCTON

2.1 Origins of Straw-Bale Construction

Initial variations of homes using straw bales as a building material can be traced back to Africa during Paleolithic times. Native Americans utilized the advantage of straw's insulative properties by lining their teepees during winter months. More recently, Europeans began to build with straw bales several hundred years ago. There still exists straw built houses throughout Europe that have been standing for over 200 years (Marks, 2005).

The first structures in North America to utilize straw-bale building originated in Nebraska during the late 1800's, coinciding with the advent of the steam and horse-powered baling machines (King, 1998). Hay balers were an agricultural invention that was conceived in the 1850s, which lead to hay presses becoming common by the 1890s (Marks, 2005). Settlers of the northwestern "Sandhills" region of the Nebraska plains were farming crops of grain in an area, which lacked suitable stones or timber to use as building materials (US DOE, 1995). A common building practice at this time in history was to use sod to form housing. However, unlike much of the rest of the Great Plains, the thin sod located over top of the sand dunes in this area was too fragile and insufficient for building sod cabins (Marks, 2005). Originally these settlers built shelters out of straw as a means of temporary means of protection until shipments of timber arrived. These buildings most commonly utilized the abundant local agricultural materials of baled meadow or prairie grass (Marks, 2005).

At the time, straw stalk bales were considered a waste material, and used simply as building blocks supporting the loads of the structure. This style of straw building later became known as the Nebraska or load bearing style. This building method has continued to be utilized through the years, as the settlers were pleased with the material's ability to provide warmth in the harsh winters, yet remain cool during the summers. An additional benefit was found with the resistance to disturbance from the loud winds blowing across the plains as provided by the straw-bale's soundproofing qualities (Bruelisauer, 2007).

Resiliency and durability may be the most unexpected of benefits associated with straw-bale homes, but these structures clearly stand the test of time. The oldest existing straw-bale building in America, known as the Burke Homestead, is found in Alliance, Nebraska, and was constructed in 1903. Even in spite of the fact that the home was abandoned in 1956, the unmaintained building has continued to endure the region's extreme temperature fluctuations, as well as blizzard force winds (US DOE, 1995). During the timeframe of 1896 to 1945 when straw-bale building became a common practice in this region of Nebraska, nearly 70 straw-bale structures were constructed. These were built to serve a variety of purposes, which included homes, farm buildings, churches, schools, offices and grocery stores (Marks, 2005). The Pilgrim Holiness Church, built of baled rye straw in 1928 in the town of Arthur, was the first American straw-bale church (Marks, 2005).

Figure 2.1 The Pilgrim Holiness Church (Marks, 2005)

The Nebraskan towns of Alliance, Arthur, and Dannbrog, were the primary locations where the initial success stories of American straw-bale construction took place. Several of the first homes built in these towns are still standing to this day. In the contrasting climate of Huntsville, Alabama another extraordinary example of a straw-bale structure exists. The Burritt Museum, originally built as a mansion in 1938 is insulated with 2,200 bales and has remained in superb condition despite the average 50 inches of annual rainfall and average humidity exceeding 50% (Marks, 2005).

A similar testament to the durability of straw-bale structures came from Chuck Bruner, a Wyoming resident of a straw home. Straw-bale homes in the state have survived many severe weather storms and even earthquakes. Bruner has the following recollection of one particular event: "the earthquake was in the 1970s and it was either 5.3 or 5.8. There wasn't a single crack in the house." He goes on to state that: "You can live in this house comfortably during the summer. It stays nice and cool. We have never needed any air conditioning, and in summer we get days up in the 90s. Also, last winter, I only turned our small bedroom heater on twice. If I had to guess how our utility bills compare to those of our neighbors, I'd have to say our bill is about half" (US DOE, 1995).

Though the history of straw-bale building originated in the late 1800's, and many of these structures proved to be so durable that they are still occupied today, the building method did not endure a successful transition into the 20th century. The advent and increased popularity of cement caused the straw-bale building methods to diminish around the 1950s.

2.2 The Revival of Straw-Bale Construction

For reasons of environmental, aesthetic, and economic appeal a revival of the straw-bale construction industry was set in motion in the American West during the 1980s and has since extended across the world (King, 1998). In particular, it was the simplicity of the Nebraska-style home constructed of stacked and plastered straw bales that had instigated much of the rekindled interest. Aiding the revival was the fact that straw was readily available as a waste product. Farmers burn 180 million tons of straw each year in the United States alone, which is sufficient enough to create bales that can be utilized for the construction of 5 million homes (Roodman, 1995). This revival is illustrated below in Figure 2.2, detailing the participation in straw-bale building per state. It should be noted that the states of Nebraska, South Dakota, and Alabama possess straw-bale structures built prior to 1940. This exemplifies the durability and adaptability of straw bale to suit and endure various climates.

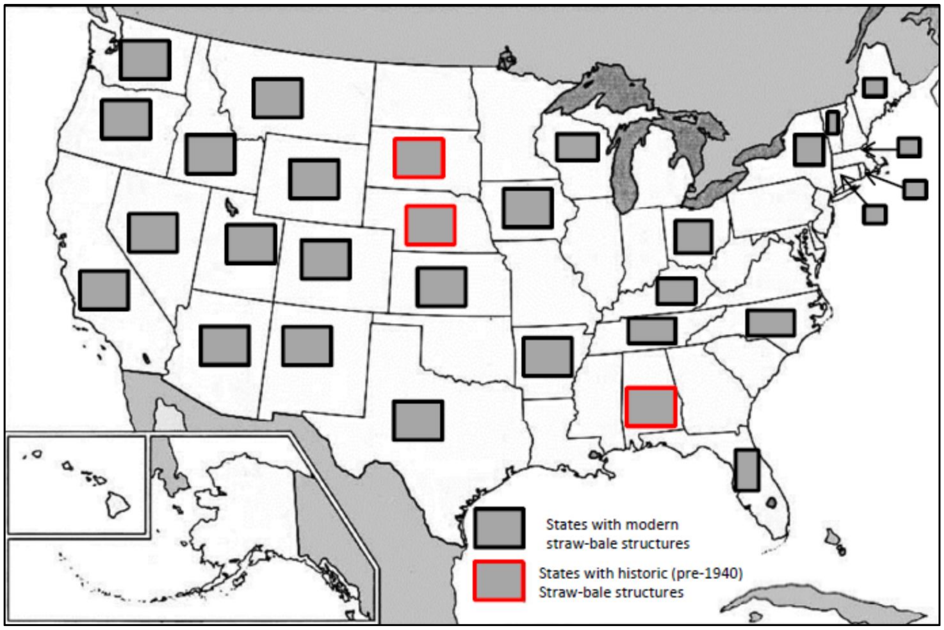


Figure 2.2 State Breakdown of Straw-Bale Revival
(Adapted from "The straw-bale building revival at a Glance" US DOE, 1995)

Though the phrase "any publicity is good publicity" may seem applicable to the revival of the industry, a certain experimental and "hippie" reputation does exist among this unconventional building method. Legitimacy is a concern that straw-bale construction has been striving for in recent years, and the creation of building and trade organizations has been beneficial.

Additionally, the straw-bale building process differs from the strict standardization of other building materials, such as steel and timber. Unlike those other materials, which profit from the building industry's ability to make money off of the testing and utilization of the materials, the structure of the current industry regarding the manufacturing of straw bales is not in a position to earn considerable revenue (Bruelisauer, 2007).

Chapter 3

BENEFITS OF STRAW BALE AS A BUILDING MATERIAL

3.1 Overview of Benefits

Straw-bale construction is an affordable and sustainable building option that is widely overlooked and underutilized. If proper precautions and measures are taken during construction phases, the straw bale walls will provide homeowners with a myriad of long-term benefits, while concerns regarding fire safety, waterproofing and strength can be mitigated with the historical knowledge that plastered straw-bale buildings commonly last 50-100 years (Seyfang, 2008).

Offering an inventive building technique with its foundation based upon a grassroots movement of self-building, its benefits have been noticed in recent years as it has become employed with more frequency among established engineering and architectural firms as a sustainable building material. The primary advantages of the building material are detailed throughout the following sections.

3.2 Energy

Beyond the economic implications, straw-bale construction provides incentives to builders with energy efficiency and environmental stewardship. In comparison to a common building constructed with traditional materials, a building of equivalent size designed with straw will yield a 25% reduction in carbon-based greenhouse gas emissions (Rajgor, 2005). Furthermore, the added insulation of straw bale reduces energy consumption and the associated greenhouse gas emissions. Due to enhanced insulation of straw bales, nearly 75% of heating and cooling costs may be reduced on an annual basis (Amazon Nails, 2001). Straw bales as a building material are unique as they provide a combination of high thermal insulation features with sufficient load-bearing potential, allowing it to be both an appropriate building block and insulation material at the same time.

The primary consideration for thermal insulation measurement is known as the U-Value, or overall heat transfer coefficient. As is the case when comparing U-Values, the lower value is considered to be the better option. Currently building regulations consider an allowable U-value for domestic external walls of 0.25 to 0.35 W/ ($m^2 \cdot K$). Straw bales provide a significant improvement, as they possess a typical U-value of 0.13 W/ ($m^2 \cdot K$) (Amazon Nails, 2001).

3.3 Sick Building Syndrome

Currently the adverse effects associated with modern building materials that emit toxins leading to the "sick building syndrome" should be of legitimate concern to builders. This statement is justified as the US EPA has ranked Indoor Air Quality as the most critical environmental problem due to the fact that 30% of new or renovated buildings have significant indoor air quality problems (Marks, 2005).

The "sick building syndrome" exists in a building that creates a dangerous indoor environment for its occupants. This could occur in a scenario where ventilation systems hinder rather than help the air quality, and the building inhabitants are subjected to stale air for long enough durations that unhealthy molds may be generated (Roodman, 1995). Consequently, the building inhabitants may suffer headaches and nausea. Further concerns are present in sealed buildings where volatile organic compounds, VOCs, are trapped and proper ventilation is unable to facilitate the necessary flow to offset these chemicals. VOCs most commonly escape from composite materials, furniture, carpets, and paint, and accumulate at concentrations hundreds of times higher than those just outside. Aside from the temporary inconvenience of nausea, long-term exposure to certain volatile organic compounds have been associated with increased risks of cancer and immune disorders (Roodman, 1995).

Inhabitants of a straw building do not need to be alarmed by such factors, as the primary material is both natural and breathable. Those who may suffer from hay fever or asthma are not susceptible when exposed to straw buildings, due to the lack of associated pollens. These issues can be further enhanced when a consideration of natural plasters and paints are utilized. Typically foundations and plastering materials for straw-bale houses lack the use of cement or gypsum plasters, in exchange for traditional lime or natural clay renderings. Considering local conditions and available materials may further enhance these decisions.

3.4 Fire Resistance

Throughout my experience researching straw-bale construction and engaging in discussions with professionals unfamiliar with the building technique, it is evident that there is a widespread trepidation regarding the fire resistivity of straw. However, contrary to common belief, walls composed of plastered straw bales present a lessened fire risk as compared to traditional timber framed walls. Reports have stated that due to the dense nature of tightly compacted straw bales, they possess an increased fire resistance. According to a report by Manuel A. Fernandez, State Architect and Head of Permitting and Plan Approval, CID, for the state of New Mexico, "ASTM tests for fire-resistance have been completed…the results of these tests have proven that a straw-bale infill wall assembly is a far greater fire resistive assembly than a wood frame wall assembly using the same finishes" (Amazon Nails, 2001).

This fire resistance is displayed as the bales simply smolder, and the wall of exposed bales remains intact. In addition, plastered straw-bale buildings have been recorded as surviving wildfires, which have destroyed nearby structures composed of wood and steel (King, 1998). This may be validated by the high silica content found in straw causing a hindrance in the progression of a fire, as a layer of char develops on the outer edges of the bales. Specifically, when the silica content is in the range of 3-14% fire penetration is impeded. (Marks, 2005)

Fire resistance of straw bales has become the subject of a significant amount of professional testing in recent decades. As mentioned, this attention and testing performed by accredited processionals and organizations is most certainly beneficial to the development and legitimization of the industry. The most respected testing agency, the American Society for Testing and Materials (ASTM), has conducted fire tests on plastered straw-bale wall assemblies in Albuquerque and California. Testing results provided that each wall assembly displayed considerable resistance to the spreading of flames, as well as increases in temperature. The report sustained the confirmation that the bales are typically very dense and lack the necessary amount of oxygen to support combustion (King, 1998).

SHB Agra Engineering and Environmental Services in Albuquerque performed further testing in the same region and climate in 1993. Their results provided that a two string bale of unplastered wheat straw survived 34 minutes of fire at 1691 degrees Fahrenheit (Marks, 2005). The firm also considered the impact that plastering may have on straw bale's fire resistance. A second test heated a gypsum-plastered wall, with cement stucco rendering on the interior unheated side. The heated side of this wall was able to withstand temperatures of 1942 degrees for two hours, and the cement stucco side remained at 21 degrees Fahrenheit throughout the testing. The total damage produced by the two hours of intense heat was simply that cracks in the gypsum formed where the fire penetrated the bales, which were charred no deeper than 2 inches (Marks, 2005). Similar results were achieved by The National Research Council of Canada as their tests on a plastered straw-bale wall withstood temperatures as high as 1850 degrees Fahrenheit for a duration of two hours before cracking (Marks, 2005).

With fire testing data displayed by these experiments, straw bales may be categorized as at least one-hour fire assemblies (King, 1998). It must be noted, however, that though fire may not be of concern to inhabitants of the final structure, the bales must be safeguarded from fire during construction. Throughout the construction phases, loose debris of straw will likely cover the jobsite, which is an extreme fire hazard.

3.5 Moisture

The most threatening factor to straw-bale construction may be considered moisture. If straw bales are exposed to a moist and aerobic environment there is a potential for mold growth, which may incite the straw's decay. Additionally, mites are known to live in wet straw, so it is ideal to purchase and store bales in a dry environment. The conditions where this may be of particular concern would include when the moisture content is greater than 20% coupled with a temperature exceeding 50°F (King, 1998). Even in building methods where the straw is utilized simply for its insulative properties, and not providing structural support, moisture can still be a danger. In such a case, moisture may cause a breakdown of the straw while damaging the plaster from a lack of support (King, 1998). Furthermore, mold spores may be released through the cracked plaster and provide a health hazard, which clearly creates a counterproductive effect when considering all of the benefits straw bales provide against the "sick building syndrome". With proper precautions taken during construction phases, moisture should not become an issue, though it certainly must be accounted for.

Whatever selection of plastering material is determined, the rendering must account for straw's property as a breathable material. The straw must be allowed to provide a passageway for moisture and air through proper ventilation. For this to occur, both surfaces of the straw bale must be vapor permeable. Bruce King is a licensed structural engineer in the State of California, an advisory board member of California Straw Bale Association (CASBA), and has literally "written the book" on the design of straw-bale structures. King has commented that from his experiences, though leaks and degradation failures have occurred, the source of most problems are derived from moisture intrusion as opposed to vapor intrusion (King, 1998).

In summary, it is acceptable for water vapor to flow freely within wall assemblies, whereas it is essential to provide a means to prevent liquid water from entering in the first place. Areas vulnerable to moisture intrusions, such as windowsills, joints with wood frames and tops of walls, must be covered in a sealant capable of shedding water (King, 1998). As it has been mentioned, fire is exposed to an increased risk during construction phases and moisture too is susceptible. Necessary precautions must be taken to ensure bales are covered from rainfall. Even though bales will dry out and appear unharmed after exposure to rain, long-term problems can develop after wall construction has been finalized.

As it relates to a straw-bale wall's location to the ground, specific moisture considerations must be taken. Even if the straw has been rendered, a necessary separation of at least 6 inches must exist between the bottom of the straw-bale wall system and whatever foundation is selected (US DOE, 1995). This factor is one of the few waterproofing barriers that need to exist on a straw-bale structure. At a minimum, the bottom of the bale wall system must be separated from the foundation by a barrier laid on top of a concrete surface to hinder any wicking moisture from the ground surface. In order for this to be achieved, many builders apply a 1 inch layer of pea gravel between 2x4 plates along the inside and outside faces of the walls to provide a means of security that the bales will never be sitting directly in any water (King, 1998).

King's most significant suggestion, which as he comments may be counterintuitive, states that no moisture or vapor barriers should be used, except for those mentioned above. Though many building permits require bale walls to be covered by a common moisture barrier such as Tyvek, or Grade D paper, King is in disagreement (King, 1998). This speaks to the fact that these considerations are used in common building techniques, such as stud wall construction, but are not transferable to straw-bale construction. The creation of a straw-bale building code could account for such measures.

Throughout his personal experiences and vast research within straw-bale construction, King concludes that no barrier should separate the plaster and straw due to straw's natural need to breathe and transmit water vapor (King, 1998). Furthermore, plastering considerations must not trap moisture against the straw and rendering interface, and structural integrity may be enhanced through a thorough bonding of plastering onto the straw (King, 1998).

3.6 Wall Coverings

Another particularly relevant consideration correlated to moisture involves the particular selection of wall coverings or renderings. The major function of a wall system, regardless of the material selection, is to provide a division from the varying interior and exterior conditions. Walls must control the thermal environment, as well as moisture and air flow. In standard building methods, the utilization of specialized layers and materials control these factors. Moisture in all of its forms, vapor, rain, and groundwater, must be inhibited. These measures are prescribed in building codes as Moisture Barriers-proposed to block liquid moisture, Vapor Diffusion Retarders-those that restrain moisture vapor and humidity in the interior trying to seep out, and lastly Air Barrier Systems-used to stop air leakage (Marks, 2005).

Many of the common plastering materials utilized to render the interior and exterior of straw-bale structures are primarily composed of natural materials. These materials are among some of the strongest, most economical, and sufficiently weatherproofing materials available for builders. These plastering materials are often stucco, plaster, and mortar. Buildings plastered by these materials have been known to last centuries.

It is necessary to detail a brief explanation of each rendering material, as they are similar, but contain unique intricacies. Stucco is commonly used to render the outside of a building, as it possesses a rougher surface. Plaster then serves the same purpose, but is utilized for interior walls, due to its smooth lime based mixture (US DOE, 1995). Both natural mixtures are combinations of crushed rock and sand, held together by Portland cement. Crushed limestone, simply referred to as Lime, adds flexibility to the mixture, while sand serves as the aggregate to give the mix a varying substance (US DOE, 1995). Ideally the aggregate sizes will differ and possess a blend of clean and sharp edge materials. Mortar, which also possesses a cement, lime and sand mixture, is used commonly for masonry purposes, but may also be chosen for plastering. Lastly, adobe, which possesses the most minimal environmental detriment, is simply compressed earth. An ideal adobe mixture contains a high content of clay, which enhances its cohesion. Adobe is rammed into forms or blocks while the mixture is damp, and is later dried in the sun to become ready to use for plastering purposes (US DOE, 1995)

Straw-bale construction frequently makes use of gypsum plasters for interior walls, lime and earthen plasters for exterior walls, and the most common material of cement stuccoes for both interior and exterior purposes. The primary benefits of stuccoes include the ability to act as a strengthener in addition to a sealant able to offer a vital air barrier (Marks, 2005). After straw bales have been rendered, they commonly possess a uniform permeability. Additionally, their properties tend to release moisture rather than that collect it, as opposed to plywood sheathing, which causes moisture to become trapped (Marks, 2005).

As evident in the *House of Straw* document published by the US Department of Energy, a frequently asked question regarding straw-bale construction relates to concerns of pests and vermin infiltrating straw bales and causing serious damage. Despite the natural suspicion, this is actually not of concern to straw-bale construction. Straw bales provide less opportunity for insects and vermin than a building composed of wood framing (US DOE, 1995). Additionally, once the bales have been plastered, all access to the bales has been eliminated.

The properties of straw as a building material may be enhanced when used in combination with other non-toxic and organic finishes. These decisions however, are optional and depend on local conditions and available materials.

3.7 Insulative Properties

As it has been addressed, one of the primary benefits of straw bale as a building material would include its insulative properties. Straw-bale's thermal efficiency relates to lessened energy requirements concerning heating and cooling loads. Environmental advantages are achieved through a decreased demand on natural resources, and monetary savings support the economic desires of the owner. In comparison to conventional homes, many of the straw-bale structures in North America utilize less than one-third of the typical amount of energy necessary for heating and cooling (Marks, 2005). The United States Department of Energy has estimated that 11% of the nation's total energy use goes towards heating and cooling measures (Marks, 2005).

A primary manner that allows for straw bale to possess such positive insulating properties is due to its large thermal mass. Thermal mass is a concept in building design that states a building's ability to equalize temperature fluctuations. As exterior temperatures fluctuate, as they clearly do in a Southwestern desert climate, a large thermal mass may absorb the thermal energy during higher temperatures and then distribute this energy during cooler periods. Since many bales can be up to two feet thick, this is associated with a large thermal mass. ASTM testing provided R-values in straw bales to be between R-2.4 and R-3.0 per inch. The fluctuation in values is due to variations in moisture and density of the bales (US DOE, 1995). R-values can be understood as the reciprocal of U-values and measure thermal resistance.

Matts Myhrman, a highly regarded straw-bale expert, believes an R-value of 2.4 per inch is more conducive to actual field conditions of bale's thermal resistance. Overall, straw-bales have been established to possess an R-value of 50. With such a value, it is evident that a home composed of straw bales would have associated lower utility costs involving heating and cooling, when compared to a conventional home (US DOE, 1995).

3.8 Structural Properties

Though it may be astonishing to discover, straw bales provide for a more than adequate building material option regarding structural integrity. As provided by the dimensions of straw bales, specifically with their great width, bales serves as a sturdy wall material. Building codes which address straw bales for load bearing purposes determine their appropriate design limits based upon height (h) to thickness (t) ratios, as well as the length (l) of unsupported walls (King, 1998). According to the *California Health and Safety Code* Section 18944, the defined height to thickness ratio is limited to an h/t of 5.6 to 1. This may be correlated to wall that exhibits the dimensions of 10 feet 8 inches high and 23-inches wide. Similarly it provides an l/t ratio of 15.7 to 1. Also, the code states that the bales may designed for a top-imposed dead + live loads up to 400 psf (19.2 kN/m^2) (King, 1998). Through the construction and design practices, which Bruce King has experienced throughout his career, he has published that the limits provided by the aforementioned mentioned code are actually conservative guidelines.

Though some may view straw-bale construction as an innovative and recently developed technology, it is a practice that has endured well over a century of experiences and accumulated empirical data. This is of particular benefit when considering how the structures behave regarding natural hazards and inclement weather. Due to the unrigid nature of the material, straw-bale structures have successfully withstood many seismic occurrences throughout history. Straw-bale construction can be designed to allow in-plane earthquake and wind loads to be transmitted through the plaster skins. Evidence has shown that in many cases straw structures employing the plastered sandwich panel behavior may even resist out-of-plane loads in Seismic Zone 4. A seismic zone is based on a statistical compilation of the number and the magnitude of past earthquakes, and Seismic Zone 4 is among the most dangerous in North America. To utilize this strength however, it is essential to secure edges and transmit loads to the frame (King, 1998). Furthermore, it has yet to occur that any wind forces have caused considerable damage to a straw-bale structure.

It has been established throughout testing in recent years that straw bales possess a modulus of elasticity around 200 psi as well as sustainable compressive forces over 70 psi (King, 1998). Additional, testing has occurred on plastered bales. The term "plastered bales" is considered to be widely encompassing and may include any of the following: traditional mud-based plasters, lime and gypsum plasters, shotcrete, gunite, cement stucco, and any combination thereof (King, 1998). The selection of plaster has not been proven to drastically affect the strength conditions so long as the buildings are in a Seismic Zone of 2B or lower (King, 1998). Despite these established determinations, the only plaster types that are considered to possess structural properties according to the Uniform Building Code are gypsum and cement stucco. Whatever the case may be, one must realize that once straw bales are rendered on either or both sides of the bales, it now encompasses the hybrid properties of straw and plaster. Due to the variation in moduli of elasticity between the two materials, any further loading on the structure will primarily be attracted to the plaster skins (King, 1998). Regardless of the plaster selection, the material is going to become stiffer than straw, and the loading will be directed to the stiffer material. The coupling of straw and plastering materials are known to supplement each other in a positive manner. Laboratory testing throughout the last decade has displayed that unplastered straw-bale walls are capable of carrying a significant amount of vertical loading, as well as can handle minor in-plane and out-of-plane shear forces. Consequently, straw would be able to provide the necessary supporting strength to the plaster skin in order to prevent failure of the wall system (King, 1998). Based upon data from the aforementioned Albuquerque testing, it can be inferred that a plastered straw-bale wall possesses a stiffness 20 times greater than that of an unplastered wall. One critical consideration is to ensure that the plastering material is thoroughly applied well into the straw. A significant strength increase is correlated to the plaster skins that are bonded to the straw substrate (King, 1998).

3.9 Precompression

It may be noted that long-term creep deflection could present an issue on straw-bale walls. In certain cases it has been discovered that an 8 foot wall may drop 0.5 to 4 inches in height within the initial weeks after the loading of its own weight and the weight of the roof has settled (King, 1998). One method to alleviate such creep deflection and its associated stresses and potential plaster cracking is to increase the compression of the bales by various means.

Another method is to increase the compression of the bales by simply allowing the loaded walls to settle for the maximum allowable amount of time prior to applying a rendering. However, simply waiting may not always be feasible under budget and time constraints. Recent more proactive techniques make use of precompressing the straw-bale walls mechanically. A simple approach is to utilize elastic polyester package strapping or fencing wire to compress and secure the wall down through the footing (King, 1998). In a method developed in Canada, stucco mesh sheets on the interior and exterior faces of the walls are fastened with oak bars at the top, and then tightened with car jacks or inflatable bags (King, 1998). The use of this method serves the same purpose of internal pinning.

Historically, the precompression of straw-bale walls has not been a concern. Those early load bearing homes of Nebraska have proven to be a durable housing solution surviving the elements while lacking reinforcement, pinning, and precompressed bales. Nonetheless, as all construction methodologies have evolved, straw-bale construction must continue to reflect such changes in order to increase its feasibility and reliability.

3.10 Agricultural Properties

It is necessary to establish an understanding of the distinction between straw and hay or grasses. Straw exists as rectangular bales of dead plant stems that are wastes of a grain crop and is difficult to decompose. Furthermore, straw does not contain any seed heads, nor any leaves or flowers. Conversely, hay consists of baled green grass, which contains decomposable organic matter deliberately left inside. Early homes utilized hay for bales, however due to the leafy nature of the material it is not recommended. Furthermore, straw is far more fibrous, and has a longer lifespan (US DOE, 1995). In comparison to hay, straw has minimal nutritional value, and is therefore less attractive to pests and biological activity (Marks, 2005).

On more specific biological terms, straw consists of the plant structure found between the root crown and the grain head (whereas hay contains the grain head), and is a composition of cellulose, hemi-cellulose, lignin, and silica. Essentially, the chemical basis of straw is very near that of wood, with the exception of a higher silica content (Marks, 2005). Exact ratios of chemical compositions and their associated strength properties vary between types of grain straw. For straw-bale building, rice straw is considered the most durable due to the fact that is possesses the highest silica content (King, 1998).

Qualifying as a renewable resource, straw is plentiful throughout the world, and may be regrown within 6 months. Comparatively, this impact is much less than the 25 years that is required for timber to be grown (Marks, 2005). Matts Myhrman, one of the most notable straw-bale experts has determined that harvested straw from the United States' major grains could be utilized to construct five million, 2,000 square-foot houses every year (US DOE, 1995). The US Department of Agriculture indicates slightly more conservative figures that each year farmers in the United States harvest enough straw to build 4 million homes of the same size. Even considering the US Department of Agriculture's figures, this is nearly four times the number of houses currently constructed. A 2000 square-foot home would require approximately 300 standard size three-wire straw bales, and would only cost the owner $1,000 (US DOE, 1995).

As a waste product, straw must be dealt with one way or another. According to the US Department of Energy, in the United States alone, 200 million tons of straw are underutilized or wasted on an annual basis. Most commonly, straw is simply burned, though this obviously has associated environmental impacts. During the early 1990s, California burned more than one million tons of rice straw annually. This method of waste removal generated 56,000 tons of carbon monoxide, which more than doubled the CO production from all of power plants located in California (Marks, 2005). These emissions of carbon monoxide are known to contribute to greenhouse gases and respiratory illness.

An additional benefit of straw being an agricultural waste product is the association with low upfront costs that may yield further cost savings resulting from a reduction in labor costs and minimal training relative to other building methods. With the progression of interest in the utilization of agricultural fiber to replace timber as a building material, the following are most frequently used: bagasse, cereal straw, cornstalks, cotton stalks, kenaf, rice husks, and rice straw. Additionally, wheat, oats, barley, rye, and flax are all desirable straw options for bale walls (US DOE, 1995). Currently, there is no shortage in fiber resources, which makes straw-bale construction a viable and sustainable option.

3.11 Economic

Various elements of economic impact have been mentioned thus far. Straw presents many long-term financial benefits to owners in terms of energy savings. On a construction and material basis, the straw bales provide further economic advantages. Once again, reiterating the fact that straw is an agricultural waste product, it is quite affordable. Straw can be delivered at approximately $2.30/ bale, or else purchased directly from the field at $0.60/ bale (Amazon Nails, 2001).

Marks, 2005 reported on a cost comparison study that was conducted involving 14-straw bale, 9-cordwood masonry, and 4-cob buildings throughout the United States, British Columbia, and South Africa. All of these materials involved in the study were agricultural materials. Cob, which is a mixture similar to adobe, is a building material that consists of clay, sand, straw, and water. Cordwood masonry construction essentially utilizes trees in a similar stacking fashion used in straw-bale construction where short length pieces of debarked trees are bonded with mortar or cob. For construction projects, the average cost per square foot is the primary measurable economic consideration. The study results demonstrated that average costs of the sustainable agricultural materials were $27.50/sq. ft. Average costs for a stud framed home charge the owner between $65-$75/sq. ft. (Marks, 2005).

The primary material cost savings that are achieved during construction through the selection to utilize straw bales may be found within the wall systems. Specific cost savings can be related to a typical 3-bedroom two-story home of approximately 2150 ft^2. The walls of such a home could be built from about 400 straw bales yielding a cost of $925. Comparative costs from a brick and block wall yields a cost of $15,500 (Amazon Nails, 2001).

Though wall systems most often only account for 15-20% of a home's total costs, this portion of labor is frequently the largest expense. In many cases this may correspond with 50% of total costs (Marks, 2005). As mentioned, the simplicity of straw-bale construction's building methods allow for the inclusion of those unfamiliar with construction techniques. If this includes volunteers on a charitable project, or else the owner and/or builder on a private project, significant overall cost savings can be achieved (Marks, 2005).

The construction of a wall system exercising typical practices utilizing brick and block walls would require a team of two skilled workers and two laborers, with a task duration of approximately 6 weeks. Comparatively, straw-bale walls can employ a team of ten unskilled volunteers under the guidance of a trainer, with an associated task duration of about 2 weeks (Amazon Nails, 2001). On a project of a larger scale, the responsibility of the trainer is lessened, as well as labor times are decreased as the labor force becomes acquainted with the simple and methodical building process.

Chapter 4

CONSTRUCTION METHOLODGY

4.1 General Properties and Procurement of Straw Bales

Throughout history, farmers have stored straw in stacks of bales that are raised off of the ground and covered with a simple roof. This is based upon the developed understanding that a lone bale of straw will become heavily saturated in rainfall; however if stacked, only the outside edges of bales will get wet, and then quickly dry out. Straw as a material does not absorb water in the manner that concrete does. Stacked bales only get as wet as the force of the wind will provide, and this moisture will evaporate quickly, leaving no damage to the bales. It should also be mentioned that straw is a flexible material that contains different properties than typical rigid building materials. Accurate measurement and precision is unnecessary with straw, and building techniques take such factors into account.

When purchasing bales for construction, certain factors should be considered. Straw bales are typically rectangular in shape, about 3 feet long and tied with two or three strings. Bales should be dry, dense, compact, and uniform in size. Storage of bales during construction phases should be protected from damp conditions. Bales should exist within the following moisture levels to protect from fungal and bacterial growth: moisture content should not exceed 15% wet weight basis, or relative humidity should not exceed 70% wet weight basis (Amazon Nails, 2001).

In an article published by the US Department of Energy, a reference was made to straw-bale construction consultant Judy Knox's "How To" suggestions for optimizing the selection of straw bales from the field. The following considerations may help to ensure proper measures are taken when acquiring straw bales for construction purposes.

The optimal time for bales to be purchased is just following the harvest when they are most plentiful, and therefore least expensive. These may be purchased from feed stores or retail outlets, wholesale brokers, or directly from the field. Each option has their associated benefits. If purchased from a retailer, the bales will likely have the lowest costs. Wholesale brokers, are essentially middlemen in the process between the purchaser and the bale supplier and they may offer commercial transportation. Lastly, when buying directly from a farm the purchaser is offered more input regarding specific needs and the quality of the bales. On the other hand, the purchasers must provide their own transportation source (US DOE, 1995). Whatever purchasing source is selected, it is essential for the buyer to confirm all sizes and conditions of bales upon a personal inspection.

The bales should consist of thick and long straw stems that do not contain seed heads. Bales should appear to be dry, and not possess any prior moisture damage. If possible, bales should be tested to ensure the moisture content does not exceed 14%. As mentioned, ideal bale proportions possess a length twice its width. Ideally, bales will be of equal proportions. If this is not the case, as is likely with the irregularity of baling machines, Knox suggests lying ten bales end to end. After measuring this length, and determining an average, this length may be used for future planning and design (US DOE, 1995).

Once bales have been selected, they must be uniformly compact and secured tightly with a durable material. Most often these ties include polypropylene string or baling wire, and bales that are secured with a natural fiber twine should be avoided. The bales should be compact enough that when handling or lifting straw bales, they should not sag or twist (US DOE, 1995).

As straw-bale building has grown into a feasible and desirable alternative to common building practices, the industry has taken notice specifically in the United States and the United Kingdom. Currently in North America there exist at least ten companies currently in construction or planning phases to build manufacturing plants designed to generate compressed-straw building panels, as reported by Environmental Building News (Youngquist, 1996). For builders in the UK, there are wholesalers who produce straw bales specifically for construction purposes. It is likely that as the demand for this industry progresses, the reliability and availability of supply will likewise advance. One particularly interesting product that has arisen from the resurgence of straw-bale construction is Oryzatech's STAK BLOCK.

This product resembles a Lego block that can be stacked and fit in an interlocking manner on top of one another. As shown in Figure 4.1 the product offers an ease of assembly as the block dimensions are 12”x12”x24” and easily coalesce with other common construction modules. Furthermore, each block weighs only 30 lbs. From their website the product is described as “a simple building solution for a sophisticated housing problem. The company has created a hybrid composite building block from the largest bio-waste crop in the world, rice straw. Through a scalable, low energy-production process, the company can make and sell an almost unlimited supply of highly insulating, carbon-sequestering construction blocks”.

Figure 4.1 Oryzatech’s STAK BLOCK

If availability permits, the most affordable way to attain straw bales remains to purchase the bales directly from the field. Further considerations may be made to purchase bales locally in order not to compound environmental implications through increased transportation.

4.2 Straw Bales Utilized For Construction

Though bales may be purchased directly from the field, those used for construction possess varying properties than those simply bundled as an agricultural waste product. Straw bales utilized as a construction material should contain nearly one third more straw than typical, as baling machines should be set to maximum compression. One benefit of straw bales is the variable shapes and sizes that they may be formed into, which ranges from small two-string bales to larger three-string bales and if desired may even include sizeable cubical or round bales. The most preferable straw bales for construction purposes are the medium sized rectangular three-string bales, due to the enhanced structural properties, and a higher R-Value (lower U-Value) (US DOE, 1995).

It must be understood that straw bales are a flexible material that possesses properties that differ from rigid building materials. Therefore, accurate measurement and precision is less of a concern. Baling machines are unable to create bales that are homogeneous, and the strands of grain in the bales possess differing qualities in each direction (King, 1998). A baling machine is able to compress straw through a means of pulsing. The narrow end-faces of the bales are in contact with the baler head, which propels the straw into compression with each pulse. These pulses are able to create compressed flakes that are approximately 4 inches thick. The end result is a bale comprised of several 4-inch flakes along the long axis. Due to a variation of slightly irregular pulses, coupled with the machine only making a cut at the end of a flake, balers are unable to create straw bales of uniform size (King, 1998).

Depending on local customs, builder's preference, design requirements and, or the availability of bales, they will likely select either a two-string or three-string bale. Additionally, the exact specifications of the bales will vary depending upon access and selection of baler, though the following details describe general averages for properties of straw bales. The easier to handle two-string bales weight should exist between 50-60 lbs. and the length must be approximately twice the width. Typically, baling machines produce two-string bales with the following dimensions: 15 in. wide by 12 in. high by 32 to 40 in. in length (Amazon Nails, 2001). Slightly larger, three-string bales will possess the dimensions of 23 in. by 16 in. by 42 in., with an associated weight of 75-85 lbs. (US DOE, 1995). Should the revival and development of straw-bale construction continue upon a trend of growth then it is likely "construction grade" straw bales will be specified by national agencies to provide for uniform dimensions and properties.

4.3 Load Bearing Methods

The use of straw bales as an alternative to typical wall building components impacts the type of foundation required, as well as types of windows, doors, roofs, and finishing materials. On the other hand, plumbing and electrical work is not impacted by the used of straw bale. The primary roles of straw as a building material are to provide structural support and offer enhanced insulation to the building. There are essentially four building methods utilized in straw-bale construction. The building methods range from the straw bales serving a role strictly as structural support, to functioning solely as an insulation material, to various methods bridging the gap. The majority of straw-bale structures in the United States employ the techniques of structural/Nebraska-style building or insulative/non-structural. The various load-bearing methods are listed as follows (Amazon Nails, 2001):

- Nebraska/load-bearing
- Lightweight frame and load-bearing
- Infill-post and beam timber frame
- Hybrid methods that may be inclusive of a mortared bale matrix

4.3.1 Nebraska/Load Bearing

The simplest method is known as the Nebraska method, in which the bales are the sole means of support for the load of the roof. Making use of automatic straw balers, bales become useful as compacted building blocks that are stacked on top of each other (US DOE 1995). Once again, the origins of this building technique may be traced back to the Great Plains' settlers of Nebraska around the turn of the 20^{th} century. The bales become the walls of the structure and are stacked as building blocks that may reach as tall as 20 feet (Amazon Nails, 2001). These bales are fastened and pinned to the foundations for stability. Typically, structures of this method have a wooden roof plate, which is secured to the foundation with additional fasteners as well as strapping. The windows and doors are located within structural box frames, and are pinned into the bales prior to raising the walls, so long as the frames do not exceed 50% of the wall surface (Amazon Nails, 2001). Upon completion of building the wall system, the straw bales are stuccoed on the exterior and plastered on the interior for a means of protection from the elements, as well as to provide for an aesthetic finish. Additionally, this rendering enhances the structural integrity of the wall system (US DOE, 1995).

Due to the simplicity and accessibility of this method, it is quite achievable for non-professionals to design by following basic principles. Additionally, this method is practical for self-builders, due to the straightforward procedure and low cost. Straw is a very forgiving material, and therefore accuracy and plumb is not critical. For minimal additional costs, curves and circles may be constructed without difficulty. *S*imple modifications may be performed in order to adjust designs from one room to two-story homes through an easy to follow, step-by-step approach. However, the Nebraska load bearing method is not necessarily suitable for larger buildings.

4.3.2 Light Weight Frame and Load Bearing

The lightweight frame and load-bearing method serves as a transitional method between load-bearing and in-fill methods. Retaining the benefits of the load-bearing styles, this method utilizes a timber framework that has such minimal weight that it will not stand up on its own. The benefit of this method is that it enables roof construction to occur prior to the walls being built, and therefore provides shelter from adverse weather during the wall raising. This method requires an initial temporary bracing until the straw becomes an essential part of the structural integrity, and can provide enough support to keep the building upright. In the end, the timber and straw share the loads of the floors and roofing. Timber posts are situated at the corners of the building, as well as at the openings for doors and windows. Such posts are designed simply to allow floor and roof plates to fit into slots causing compression on the bales. These compressive forces on the straw-bale infill walls provide the stability of the structure, and may be increased through the use of pins fastened into the base and wall plates of the framework after complete settlement of the walls has occurred (Amazon Nails, 2001). The primary advantages of utilizing this method includes greater stability for window and door frames, as well as provides an extensive reduction in timber requirements compared to traditional methods.

4.3.3 Infill-Post and Beam Frame Method

Requiring more technical expertise, coupled with additional materials, the Infill-post and beam frame method allows the weight of the roof to be supported by a framework skeleton of vertical posts and horizontal beams comprised of wood, steel or concrete. The selection of framing material may be anything that is allowable with local codes. The infill straw bales are attached to one another and reinforced with rebar or bamboo. Next, the connected bales are secured within the structural framework US DOE, 1995). This building method, which is most useful for the construction of larger structures, employs the straw bales to serve solely as infill insulation amidst the framework.

Many design professionals trust this method as it draws upon established structural designs and concepts, diminishing the risk of structural failure. The framework provides bracing that is intended to carry most, if not all, of the seismic forces. Therefore, the reinforced plaster serves to provide for energy absorption and damping (King, 1998). The structural framing is further enhanced with bracing that may include metal straps, steel plates, or all-thread bolts placed diagonally across the bale surface, and protected by the plaster rendering. This bracing must be designed to withstand calculated forces, and be sufficiently secured to the top plate and the foundation. The engineering designs for the Infill-post and beam frame method are enhanced by the fact that even lightly reinforced cement stucco covering a straw-bale wall system has great strength and durability (King, 1998).

This method may be advantageous as it also allows for the roof to be constructed prior to straw installation, as well as it provides the greatest structural stability. Additionally, the method offers the advantage of stacking bales in the longer edge direction and therefore inciting a reduction in wall thickness. Though this decreases the structural capabilities of straw bales, tests have proven that bales stacked on edge have an increased R-value per inch. This higher value provides a compensation that allows for edge-staked bales to have the same net thermal properties of bales stacked in a flat manner (King, 1998).

If considering the design of a large warehouse space, this is the most conducive straw-bale construction method. However, the primary disadvantage of this method, aside from the need for additional skilled labor, is the detrimental environmental implication associated with the increased requirements of resources. Further dilemmas have been recorded regarding difficulties in plastering, regarding how the bales meet the exposed wall, as well as problems creating openings for conduit as bales stacked on edge leave the strings exposed (King, 1998).

4.3.4 Hybrid Methods

As mentioned, cement and similar materials are not typically used in straw-bale construction due to the emphasis on minimal ecological impact; however there exist hybrid methods that may employ a cement mortared bale matrix. Within this method straw bales are used in the same way as bricks and are bonded together using cement mortar, which is composed of Portland cement and sand. Bales are stacked in vertical columns that allow the cement to form posts between the stacks. This becomes beneficial due to the fact that if a failure of the straw bales should ever take place, the lattice structure would remain intact. The mortared bale method was developed in Canada, and successively passes Canadian building codes (US DOE, 1995). The end result produces a building that is rendered inside and out, that once again adds to the structural integrity of the wall system. However, due to the labor-intensive procedure, it is rarely used.

Another hybrid method of straw-bale construction is infrequently used within North America, but is nonetheless worth mention. Straw-clay building makes use of the agricultural waste product of straw; however it is not in baled form. Rather, a mixture of clay and water and stirred into loose straw to essentially provide a straw-reinforced clay mud. The early uses of this building technique placed this straw-clay mixture into double sided wood forms in between the posts and beams of timber framed building. Modern advancements of this technique now replace the wood forms with a lightweight ladder like frame. It is worth noting that many of these structures constructed over 200 years ago in Europe are still standing, as well have passed the passed the most rigorous European fire codes (US DOE, 1995).

4.4 Design Considerations

When contemplating the decision to select straw bale as a building material for the wall system of a structure, a builder lacking straw-bale construction experience may question which implications this may have on the common design considerations. To reiterate, the primary role of straw as a building material is to provide structural support, and may also offer additional primary benefits with its enhanced insulation properties. The use of straw bale directly impacts:

- Foundation type
- Windows, doors, roofs, and finishing materials

Conversely, the following factors remain unaffected by the selection of straw bale as a building material:

- Plumbing and electrical work

The individual factors that are impacted by the use of straw bales are listed below and are described in further detail in the following sections.

- Foundation Selection
- Tie Downs
- Structural Box Frames
- Roofing
- Wall Plate
- Pinning
- Plastering Materials

A document published in 2001 by a group out of the United Kingdom known as Amazon Nails provides an invaluable tool, which details the step-by-step procedure to follow for the construction of a straw-bale home. The group's *Information Guide to Straw Bale Building: for Self-Builders and the Construction Industry* is suggested to anyone interested in attaining further knowledge on any of the construction methods discussed in this chapter.

4.5 Foundation Types

Despite the significant decrease in the overall weight of the building when using straw bales as the wall material, as opposed to common materials, it is still necessary to have some form of a foundation on which to build. In some cases, a natural foundation composed of bedrock may be sufficient, though modern practices typically design for an engineered foundation such as poured concrete strips or slabs.

The primary considerations to evaluate for a foundation selection include the loading on the structure, and the soil type that the structure is built upon. It is essential to have an intimate understanding of local the soil types in the region in which you are building, just as is the case with any other type of building. Drainage and other necessary considerations are then directly correlated to the soil types and foundation designs therefore must be adjusted.

As mentioned, the foundation must support the loading created by the weight of the walls. With this factor in mind, it is very cost effective to use straw bales as the building material. The following comparison shows implications that are affected by the type and cost of foundation. When considering a 1 m^2, or roughly 11.75 ft^2, block of each material, the associated weights are as follows (Amazon Nails, 2001):

- 465 lbs. of brick
- 440 lbs. of block
- 165 lbs. of straw

Straw can provide a savings in loading of 65% compared to brick and 62% compared to concrete (Amazon Nails, 2001). With such a low amount of weight/sq. ft., a one-story home utilizing load bearing straw bale would only require a base plate to secure the bales to the foundation. It will not require trenches to be dug and filled with concrete, as is commonly necessary, and this will clearly provide cost savings.

When selecting a foundation option applicable to a straw-bale structure, the following goals should be addressed:

- Provide a stable base for weight distribution
- Prohibit unequal settlement
- Ensure straw bales are raised off of the ground to avoid damage from excessive rains
- Self-draining foundation can allow for moisture removal if necessary

Regardless of foundation selection these conditions must be attended to:

- Bales are raised off the ground by a minimum of 9 inches
- Raised at least 1 inch above floor level with plumbing
- Bales are secured to the foundations (see pinning)
- Bales are protected from any source of moisture
- Ideally the floor level will be raised high enough above ground level to provide protection from flooding of a 50-year storm

4.6 Tie Downs

No matter what type of foundation is chosen, the design will require a means of securing the wall plate and roof. Tie downs serve as the means to prevent the roof from lifting off by strong winds. This mechanism typically is composed of a metal or plastic strapping. Polythene is a common option that is laid underneath of the foundation in a U-shaped pipe.

4.7 Structural Box Frames

Doorframes, windows, or any other aspects of the structure that must be fixed directly to the foundation should have designed provisions. Structural box frames may accommodate such a need. The box frames are bolted into the foundation or else fixed to the timber base plate. When designing the structural box frames it is essential to take settlement into consideration. The straw-bale wall system will settle under the loading applied by the floors and roofing. It is difficult to estimate exact settlement measurements, but typically 3 inches is a conservative value (Amazon Nails, 2001). With this in mind, structural box frames are often constructed 3 inches below the height of the top of a bale.

4.8 Roofing

When designing and selecting various roofing options for a straw-bale project, the primary consideration for load bearing or compressed framed designs involves ensuring that loading is spread evenly around perimeter walls. To ensure that this condition is met, truss rafters must be spread across the walls. During construction phases it is essential to not store truss rafters solely at one end of the building prior to being fixed, for obvious reasons of structural damage to wall systems. Similarly, as the roof loading is increased by tiling, the loads must be evenly distributed and not allow for half of the roof to be tiled before other half.

4.9 Wall Plate

A wall plate, or roof plate, is a continuous, rigid, perimeter plate located on top of the straw-bale walls. Wall plates are commonly manufactured in sections, and secured together once placed in their final position. The sizing of roofing timbers depends upon loading requirements and designed building span. Designs can incorporate the floor joists into first floor level plate, and therefore reduce the total amount of timber utilized on the project.

4.10 Pinning

Despite the fact that straw bales can serve in a similar building block that may be compared to bricks or concrete masonry units, it is necessary to reiterate that straw has differing behavioral properties. If used in any manner that places load bearing requirements on the bales, it is necessary to brace the straw bales to ensure stability, while bales are stacked beyond four high. Additionally, at each change of direction or corner of a building, pinning is a necessity (Amazon Nails, 2001). To achieve this stability, bales are pinned to the foundation and roof plate in either an internal or external manner.

Internal pinning is essentially quite similar to reinforced concrete structures. Bales may be pinned together with rebar dowels, or else natural options of bamboo or hazel. Again, this pinning is necessary for each section of the wall that changes direction. By allowing bales to become pinned internally, the straw bales truly become a wall system that acts as one as opposed to independent components. Certain building codes do exist that include internal pinning with rebar dowels, however it has become debatable as to the exact amount of structural stability the pins offer to the finished wall system (King, 1998).

For framed typed foundations, external is the commonly utilized method of pinning, which enables the foundations to connect the base plate to wall plate in one continuous piece. Two pins are placed on each bale, and located about 20 inches apart. The pins lay flush with the straw as they are placed within grooves cut into the straw (Amazon Nails, 2001). Reports of construction projects that have made use of exterior pinning have stated that the method provides an easier process of building that produces a stronger wall system (King, 1998).

4.11 LEED Credits

As it has likely become evident throughout this document, one may anticipate that environmental responsibility as it pertains to the building sector is at the forefront of the mind of a straw-bale builder. Though there may be various motivations to choose straw bale as a building material, those involved in the decision making process are likely to be aware of the environmental benefits, and associated public perception. With that said, there may also be a percentage of builders on the cusp of selecting straw bales who make the decision based upon the ability to achieve building credits along the way to constructing a LEED accredited building.

LEED, which stands for Leadership in Energy and Environmental Design, is the rating system that has steadily grown to develop the standard criteria to follow when designing and constructing a "green" building. Developed by the U.S. Green Building Council, USGBC, LEED is internationally recognized, and provides an unbiased third party verification procedure to ensure that sustainable design principles are implemented. These are specifically divided into the categories of sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. As with any successful and innovative new technology or procedure, LEED has its detractors. Many believe that LEED focuses too much on high dollar and high visibility options that may appear to make a building "greener", but are in fact less effective than more obvious and sustainable measures. Whatever one's stance may be towards LEED, it is necessary to accept that it is becoming the standard by which to build, and at least for the short term it appears to be here to stay.

When planning to construct a building that will achieve LEED accreditation, there are various benefits to selecting straw bale that can have direct implications to achieving LEED Credits. The following list of credits directly correlates to straw-bale building:

- MR 4.1 – Recycled Content, 10% (post-consumer + 1/2 pre-consumer)
- MR 4.2 – Recycled Content, 20% (post-consumer + 1/2 pre-consumer)
- MR 5.1 – Regional Materials, 10% Extracted, Processed & Manufactured Regionally
- MR 5.2 – Regional Materials, 20% Extracted, Processed & Manufactured Regionally

- MR 6 – Rapidly Renewable Materials
- EQ 4.1 – Low-Emitting Materials, Adhesives & Sealants
- EQ 4.2 – Low-Emitting Materials, Paint & Coatings
- EQ 4.4 – Low-Emitting Materials, Composite Wood & Agrifiber Products

Though it may possess a less obvious connection to the selection of using straw bale as a building material, it has been described how this material has the ability to achieve long term energy savings benefits. Many of the associated building procedures such as passive solar design, and reduction of energy demands possess a direct correlation to the following energy credit:

- EA 1 – Optimize Energy Performance

4.12 Progression of a Straw-Bale Home Construction Project

The series of images presented in Figures 4.2-4.11 illustrates the materials and methodologies described thus far. The construction crew, which encompasses volunteers involved with an organization discussed in the subsequent chapter known as the Canelo Project, initiated the construction process as usual by laying the foundation. The next phase involves stacking the straw bales within their selection of timber framing. Upon the completion of the stacked bales, the roof plate is laid over top of the completed straw-bale wall assembly. Tie-ins and fasteners are then installed to secure the wall system and ensure structural integrity. Once secure, the bale walls coupled with the timber framing are capable of supporting the installation of a roof truss. The final phases include the creation, mixing, and application of rendering material.

Figure 4.2 Laying Foundation

Figure 4.3 Bale Walls


Figure 4.4 Bale Wall System


Figure 4.5 Lifting of Roof Plate


Figure 4.6 Fastening and Tie Ins


Figure 4.7 Roof Truss


Figure 4.8 Sifting Plaster Mix


Figure 4.9 Mixing Lime and Clay Rendering

Figure 4.10 House Prior to Plastering

Figure 4.11 Finished Clay Rendering

Figure 4.12 displays an aspect of the finished home which is entirely unique to straw-bale construction. Displayed in the image is what is known as a “truth window”. Once a straw-bale structure is completed, the plastering material disguises all indications of the interior straw-bale walls, though in many cases the owners are very proud of their finished product. As a means to display the inner workings of the home, a truth window provides an opportunity and talking point to share their secret material selection to visitors of the home.

Figure 4.12 Truth Window

4.13 Incorporation of Contemporary Architectural Design

The decision to utilize straw bales as a building material does not compromise the ability to incorporate contemporary architecture. Though straw-bale construction is primitive in nature, and may remain that way at the owner's request, there are a myriad of current examples of modern and creative design. Figures 4.13-4.15 display examples of straw-bale construction that utilize unique and contemporary architectural designs.

Figure 4.13 Contemporary Design 1

Figure 4.14 Contemporary Design 2

Figure 4.15 Contemporary Design 3

A common architectural practice of passive solar design is often apparent in a straw-bale home, as evident in Figures 4.16 and 4.17. In passive solar design aspects of a building such as windows, walls, and floors are intended to store and distribute solar energy. The technique presents a method of heat storage in the colder months, and a rejection of heat in the warmer months. This is just one aspect of modern building practices that are capable and frequently used in straw-bale construction designs.

Figure 4.16
Passive Solar Design 1

Figure 4.17 Passive Solar Design 2

4.14 Building Codes and Trade Organizations

Alternative building materials and innovative construction methods contribute substantial benefits towards affordable housing. Despite the fact that the building sector is currently facing increasing poverty and an increased demand on the conservation of the world's resources, most modern building codes are not necessarily conducive to the introduction of these practices. Conventional building regulations are prescriptive, and their basis declares a specific way to design. Conversely, performance based building regulations allow for a utilization of local materials, alternative construction methods, and innovative technology that could encourage lower costs in construction projects.

In order for the straw-bale industry to inherit a place of legitimacy within the building sector, building codes and trade organizations must exist to further establish and regulate this building technique. Throughout recent years the straw-bale industry has begun to achieve these accomplishments with the budding list of dedicated organizations, and building code inclusion becoming more prevalent. There have been several well-established straw-bale housing projects, which serve to generate publicity towards straw-bale construction, as well as focus on the ability to utilize straw bale in the creation of affordable housing options. Some of these housing projects include Builders Without Borders, Red Feathers Development Group, and the widely recognized Canelo Project, which will be further discussed in the following section.

On a larger scale, there currently exists many straw-bale building associations. Some of these groups include the following: California Straw Building Association (CASBA), Straw Bale Association of Nebraska, Straw Bale Association of Texas, Colorado Straw Bale Association, IronStraw Group (Oregon), International Straw Bale Building Registry, Ontario Straw Bale Building Coalition, and Development Center for Appropriate Technology (DCAT). These organizations comprise members who are designers, contractors, owners, builders, and people interested in straw building. As described by CASBA their mission is to "further the practice of straw building by exchanging current information and practical experience, promoting and conducting research and testing, and making that body of knowledge available to working professionals and the public at large". Essentially the goals of this study are very much aligned with many of the practices currently engaged by these organizations.

Building codes throughout the country are beginning to encompass straw bale as a feasible building material. The establishment of these codes will help to regulate, legitimize, and hopefully promote the industry. The most widely recognized building codes are listed as follows:

- Austin City Code - Volume II TITLE 25 LAND DEVELOPMENT\CHAPTER 25-12 TECHNICAL CODES\ARTICLE 1: UNIFORM BUILDING CODE\25-12-3 LOCAL AMENDMENTS TO THE BUILDING CODE Chapter 36 - STRAW BALE CONSTRUCTION

- An Ordinance Amending Chapter 10-5, B.R.C. 1981, Concerning Alternative Building Materials, Including Adobe and Straw Bale Construction and Recycled Lumber. Be it Ordained By The City Council of The City of Boulder Colorado:

- Bill Number: Ab 1314 Chaptered 10/16/95 Chapter 941 Filed With Secretary Of State October 16, 1995 Approved By Governor October 15, 1995 Passed The Assembly September 12, 1995 Passed The Senate September 6, 1995 State of California

- LEGISLATIVE COUNSEL'S DIGEST AB 1314, Sher. Buildings: straw-bale structures. Prescriptive Code for Load-Bearing and Non-Load-Bearing Straw Bale Construction as Approved by the Pima County Board of Supervisors and the Mayor and City Council of Tucson, Arizona, January 2, 1996

If a builder has selected a project site for a straw-bale structure located within one of the above locations, or any other region that has a straw-bale building code, the next step will be to obtain a building permit prior to beginning construction. The building official for the local municipality will be the person responsible for interpreting building codes, as well inspections during construction phases. It is essential for the builder to develop a rapport with building official during planning, design, and building phases, as they are the professional who has the ability to make exceptions to the code if necessary. In some cases the process may be required to begin by forming an acquaintance of straw-bale techniques with the building official if they do not have any prior experience. The responsibility ultimately lies with the builder to have an intimate knowledge and understanding of the building code if it is necessary to defend design decisions upon an inspection.

Chapter 5

SPECIFIC STUDIES

5.1 The Canelo Project

Founded in 1990, the Canelo Project is located on a 40-acre site set in the high desert of southern Arizona and is established by the leading proponents of the US straw-bale housing movement. The site contains adobe houses, as well as a dozen straw-bale buildings. The construction of these buildings utilized the employment of participants interested in the sustainable and innovative procedures associated with straw building, and also developed residential plastering workshops using adobe, which is a natural building material. Adobe is comprised of a mixture of sand, clay, horse manure and water, along with a fibrous or organic material and is dried in the sun. This factor is significant as the Canelo project later began working in Mexico with low-income and impoverished communities, in order to teach these simple self-build techniques established in Arizona. Through this initiative, groups of women were trained to build each other’s houses for approximately $500 (Seyfang, 2008). These homes were comprised of natural, local, and highly affordable materials. The use of straw bales served as building blocks for the outer walls, which were then plastered with adobe. The building methods employed by the project are undoubtedly suitable for the desert climate, and necessary adaptations may be easily developed.

The Canelo Project focuses on ecological responsibility within their building practices. Aside from the common benefits associated with locally available materials, which included mud and straw, the project utilized techniques and processes that were adapted to local culture and skills. Additionally, innovative mixtures of mud and straw were developed to better suit the skills and tools available in for the region.

The project also placed a significant focus on a reduction in its ecological footprint based upon the use of natural, biodegradable, and carbon-neutral materials, along with the avoidance of highly polluting materials such as cement and formaldehydes. Furthermore, the resulting impacts from the enhanced insulation properties reduced heating and cooling loads throughout the buildings' lifetimes.

5. 2 The Navajo Project

The Navajo Nation, which constitutes the largest Native American reservation in the United States, is located within Arizona, New Mexico and Utah. Due to a population nearing 200,000 people spread across 17 million rural acres, the people of the Navajo Nation were in a perpetual struggle to construct adequate housing (US DOE, 1995). Due to the remote nature of the homesteads, the community has been plagued with difficulty in affordable electricity, dwindling firewood, and increasing building costs. In 1991, community leaders decided a change was necessary and appealed to the idea of a construction practice that would bolster the local economy, utilize local materials, and not compromise the Navajo Nation's culture. Furthermore, a focus upon energy efficient construction techniques was at the forefront of the leader's requests. Though based upon these criteria straw bale seems to be an ideal option, it was not decided upon until later.

The culmination of these needs and visions yielded a cooperative demonstration project that joined the U.S. Department of Energy (DOE), the U.S. Department of Housing and Urban Development (HUD), and the Navajo Nation (US DOE, 1995). At the onset of the project it was understood that DOE and HUD would present the funding necessary to provide technical assistance, design reviews, and consulting, while the Navajo Nation would fund the construction of a demonstration home. The concerned parties established a design charette in December 1992 to discern home occupant needs, community desires, as well as potential options for construction and design. Those involved in the charette encompassed experts in the areas of energy, finance, indigenous materials, passive solar design, and Navajo traditions so that all social and technical issues were considered (US DOE, 1995). According to the U.S. Department of Energy, the following criteria were addressed at the design charette when considering the best option of construction techniques and materials:

- energy efficiency
- affordability
- resource-efficient building technology
- use of local materials
- community involvement
- use of local labor, cultural compatibility, and design simplicity, adaptability, and comfort

The U.S. Department of Energy contracted Jim Hanford of Lawrence Berkeley Laboratory to investigate the varying thermal properties of wall materials for the prototype home. The table below, Figure 5.1, displays the wall section thermal characteristics of the materials considered for construction (US, DOE 1995).

Wall Section Thermal Characteristics	R-value	U-value	weight	heat capacity
	(hr-sqft-F/Btu)	(Btu/hr-sqft-F)	(lb/sqft)	(Btu/sqft-
Wall Type				
Wood Frame				
2x4 studs w/R11 batts	10.2	0.098	9.2	2.2
2x6 studs w/R19 batts	15.4	0.065	10.5	2.6
Compressed Straw Panel				
uninsulated 4.8" panel	10.1	0.099	13.4	4.9
insulated 4.8" panel	18.4	0.054	13.7	4.9
Fibrous Concrete Panel				
insulated 3" panel	16.7	0.060	16.9	4.7
insulated 4" panel	19.1	0.052	20.1	5.7
Straw Bale				
23" bale @ R-1.8/inch (-25%)	42.7	0.023		
23" bale @ R-2.4/inch	56.5	0.018	21.4	6.4
23" bale @ R-3.0/inch (+25%)	70.3	0.014		
Foam Blocks				
6" form w/ concrete/adobe fill	26.3	0.038	40.8	7.5
8" form w/ concrete/adobe fill	28.0	0.036	54.2	9.8
Adobe				
uninsulated 10"	3.5	0.284	95.0	17.9
insulated 10"	11.9	0.084	95.3	18.0
uninsulated 24"	6.8	0.147	183.4	34.2
exterior insulated 24"	15.1	0.066	183.6	34.3
Notes:				

Figure 5.1 Wall Section Thermal Characteristics (US DOE, 1995)

The above data is based upon the following assumptions: (US DOE, 1995)

- All walls have stucco exterior and drywall interior, except adobe and straw walls have plaster.
- Wood frame walls have 25 % (R-11) and 20% (R-19) stud areas. The R-19 batt compresses to R-18.
- Compressed straw panel, insulated case, has 2 inches polystyrene on exterior.
- Fibrous Concrete panel have 1 inch polystyrene inside and out.
- Straw bale wall R-value is calculated for 3 unit R-values for straw to cover potential variability.
- Average material thickness across foam block wall sections are as follows:

- 6-inch foam has 2.9 inches polystyrene each side and 3.4 inches of fill.
- 8-inch foam has 3.1 inches polystyrene each side and 4.8 inches of fill.
- Wall properties are based on 75 percent adobe and 23 percent concrete fill.
- Adobe walls, insulated case, have 2 inches of polystyrene on exterior.
- 24 inch wall is two 10 inch layers with 4 inch air gap.

The design charette provided an analysis of life-cycle costs for various design options. Figure 5.2 below displays life cycle cost estimates for a home built with conventional techniques and materials as compared with two straw-bale options. From their research, it was determined that a straw-bale home makes use of half the energy requirements as compared to a conventional home, which correlates to hundreds of dollars in savings each year of home ownership (US DOE 1995). In a following section of this document, an example of a Life Cycle Assessment of various home construction options will be established to evaluate environmental impacts, and may supplement the life cycle costing information.

Table 4. Life cycle cost estimate for conventional vs straw-bale houses

	Construction	Finance	Energy	Total	Savings
Conventional	$82,500	396,000	120,000	532,500	------
Straw bale	$78,375	376,000	60,000	451,675	83,875
Straw Bale*	$40,000	192,000	60,000	260,000	272,500

*owner-built walls, finishing, roofing

Notes:

- Life cycle = 100 years.
- Finance cost = construction cost minus down payment of twenty percent at an annual interest rate of six percent over the one hundred year life cycle (does not include closing costs when the house is sold).
- Energy = the average cost for heating and cooling a conventional home for this analysis to be $100 per month.
- Total = Amount of down payment plus energy and finance.

Source: Working Group Reports, Plastered Straw Bale Conference, "Roots and Revival," Arthur Nebraska, September, 1993.

Figure 5.2 Life Cycle Costing Information (US DOE, 1995)

The results of the design charette culminated in the selection to build a prototype building constructed of straw bale. This produced a 988 sq. ft. home with an associated cost of $58/ sq. ft., which excludes the cost of utility hook ups (US DOE, 1995). Once again, this value should be compared with average costs of a timber framed home ranging from $65-$75/ sq. ft. Those involved with the prototype believed that future straw-bale homes would have a significantly more affordable price tag. During the construction phase, costly modifications were made, some of which were due to an unfamiliarity in procedure. Further unnecessary costs were a result of the double adobe walls, which added $3,000 to the price of the project (US DOE, 1995). In the future, the designers would have constructed all exterior walls entirely of straw bale, which would have significantly lowered costs.

Crews involved with the construction of the prototype comprised a combination of skilled building professionals coupled with volunteers. Though these crews had no prior straw-bale experience, they were able to erect the walls in just one day. The overall costs of the project achieved a significant benefit from the fact that straw-bale construction can utilize the help of unskilled labor, and if another material were chosen this profit would not be attainable. Additionally, the U.S. Department of Energy states that less than one-fifth of the wall system costs are attributed to straw-bale walls, and the remaining four-fifths of the wall costs are attributed to labor. Therefore, by utilizing their own labor, the savings are compounded. The total project involved nearly 2,500 labor hours (US DOE, 1995). Figure 5.3 below details the cost breakdown of construction and labor costs for the prototype home. Consider a previously mentioned example provided by Amazon Nails of a two story three bedroom home of 2150 ft^2, where straw-bale walls cost $925 as compared to the $15,500 brick and block wall. This data is associated with traditional materials costing 16.75 times more than a straw-bale wall. If the table below were to be adjusted by this factor, the $1,572 costs of straw bale would become $26,341.62 in brick costs. This would culminate in an increased total project cost of $ 81,815.62.

Table Two. Construction and Labor Costs for the Straw-bale Demonstration Project at Ganado

	Labor	Material	Labor & Material
Footing	$ 576	$1,022	$1,598
Foundation	2,500	2,938	5,438
Slab	20	3,435	4155
Strawbale	540	1,032	1,572
Adobe	1,920	1,575	3,495
Bond Beam	576	1,022	1,598
Cripple Wall (Framing)	720	3,990	4,710
Insulation	576	664	1,240
Roof Structure	4,032	5,233	9,265
Stuccoing	1,440	3,430	4,870
Interior Walls	864	1,998	2,862
Interior Finishes	1,152	1,615	2,767
Ceiling Finishes	1,440	1,009	2,449
Rough Plumbing	576	621	1,197
Rough Wiring	576	490	1,066
Plumbing Trimming	384	1,041	1,425
Electrical Trimming	384	1,252	1,636
Cabinets	384	1,195	1,579
Floor Finishes	440	1,188	1,628
Fixed Equipment/Wood Stove	1,200	1,296	2,496
Totals	$21,000	$36,046	$57,046

Figure 5.3 Costs of Straw-Bale Demonstration Project (US DOE, 1995)

Chapter 6

SURVEY

6.1 Research Methodology and Overview

The document up to this point has intended to detail the numerous advantages that straw bale may provide builders and designers when utilized as a building material. Additionally, a description of several success stories has been provided to support such claims. As an agricultural waste product that is readily available, the material is an extremely affordable option that can yield both up front and long term cost savings, meanwhile providing a minimization to the environmental damage that much of the building sector has grown to become associated with. Furthermore, it is understood that straw-bale construction is not necessarily an “innovative technology”, but rather a process that has endured a renewed interest in recent decades. In any case, the revival of this industry has certainly been promising. It can be assumed that the stimulus for this interest may be attributed to a segment of responsible members of the building sector that are seeking solutions that will not compound many of the issues that are plaguing the industry. Additionally, the possibility of providing a great potential for an affordable housing option may have made a substantial contribution. Whatever has inspired the straw-bale construction revival, there exists the unfortunate issue that the industry has appeared to have reached a plateau in recent years. One major factor that is a likely contributor is the reality that sustainability and green building issues have achieved a great boost in the mindsets of both building professionals and the general public. Though overall this would appear to be of great benefit, it has developed a myriad of other building processes and options that straw-bale construction is essentially forced to compete with. On the positive side, many new building and trade organizations dedicated to advancing the straw-bale industry have been developing in recent years. Through this research project I have come to learn that a draft of an ASTM Standard is in progress that is striving to address agricultural materials, in particular straw bale. It is an achievement such as this that appears to be necessary in order to legitimize the industry.

With the advantages to straw-bale construction plentiful, and the environmental impacts minimal, it seems that the method should have catapulted into the mainstream of the building sector, but that has simply not been the case. Plenty of research, documentation, and literature have been invested into establishing the industry. It is quite easy for anyone to educate themselves on the benefits of the material, and even come across a how-to guide on building their own straw-bale home. The next step in the evolution of the industry must be to determine the subsequent and necessary steps for development. Essentially, what is required is a determination of the factors that are inhibiting the advancement and widespread use of straw bale as a construction material.

The primary goal of this research project is to identify the barriers impeding the advancement of straw bale as a building material in North America. It is intended that these results may provide engineers, architects, and contractors with effective knowledge of straw-bale construction practices in order to assist them in developing their own projects within this realm of sustainable construction techniques.

In order to attain this goal, the following tasks were completed:

- Quantify the benefits (both environmental and economic) of the material (see also LCA section)
- Evaluate current market barriers hindering the advancement of straw-bale construction
- Develop a database of firms utilizing straw bale as a building material within the construction industry

In order to expand upon information provided through a literature search, an exploratory study was conducted to investigate the viewpoints and experiences of building professionals throughout North America. Project goals were attained by generating two separate surveys, which were distributed among building professionals with varying experiences and skill sets. The building professionals who were involved were specifically chosen to be employed by firms of varying size, as well as encompass the skilled trades of builders, contractors, engineers, architects and consultants.

The first survey, titled Survey SB, focused upon contacting the firms throughout North America that have achieved experience on straw-bale projects in the past. The objective of the survey was to measure their successes and failures thus far in the industry. The second survey, Survey NE, communicated solely with firms in North America that have no prior experience with straw-bale projects. The objective of the second survey was intended to gauge any preconceived notions these firms or professionals may have with straw-bale as a building material and its engineering properties.

The databases compiled for eligible firms or professionals to be involved with the surveys were based upon specific criteria and established experiences. Through a utilization of various straw-bale construction resources such as the California Straw Building Association, CASBA, and the Ontario Straw Bale Building Association, developing the database of experienced straw-bale professionals was aided through the use of existing directories. Survey NE on the other hand, was sent to building professionals who have not been involved with straw-bale construction, but do possess the experience and proven dedication to sustainable building practices within residential building. Similar to USGBC with its established LEED accreditation system for green building, the National Association of Homebuilders also has a similar program. NAHB's Certified Green Professional, CGP, is a title given to those who have proven their green building experience. As detailed on their website, NAHB established this credential to "recognize builders, remodelers and other industry professionals who incorporate green building principles into homes— without driving up the cost of construction. Class work leading to the designation provides a solid background in green building methods, as well as the tools to reach consumers, from the organization leading the charge to provide market-driven green building solutions to the home building industry". NAHB provides a directory of contact information for CGP's categorized by state, and this was utilized to develop the database for Survey NE. Within the NAHB directory, the individual's professional designation, such as designer, builder, etc. is specified. It was decided to select a variety of professional designations in order to maximize the various perspectives of those surveyed. From evidence provided in the literature search and personal experience leading up to the creation of the databases, it had become evident that those directly involved with the straw-bale movement were more than willing to aid and participate in the industry's advancement, while those without prior knowledge or experience were skeptical and less obliged to engage in discussion.

In addition to NAHB, several other directories of green building professionals from various building organizations were utilized to establish the database for Survey NE. Since NAHB's directory of professionals is only inclusive of the United States, various Canadian building organizations provided a necessary addition to the database. Table 6.1 below lists the Canadian building organizations, and if applicable their specific green home building program or designation.

Building Association	**Green Building Program**
Canadian Home Builder's Association, CHBA	EnviroHome-R2000
Greater Toronto Home Builders' Association, BILD GTHBA	-
Greater Windsor Home Builders' Association, GWHBA	-
Greater Ottawa Home Builders' Association, GOHBA	-
Built Green Canada	Built Green Program
Manitoba Home Builders' Association, MHBA	-
Saskatoon Home Builder's Association, SHBA	-
Regina and Region Home Builder's Association, RHBA	-

Table 6.1 Canadian Building Associations

Essentially, the EnviroHome designation provided by CHBA is the governing credential over all other building associations. The additional building associations were simply used to ensure that professionals from all of the Canadian provinces, and large metropolitan areas were included. The EnviroHome program is an initiative that was a joint effort formed by the Canadian Home Builders' Association and TD Canada Trust in 1994. It aimed to recognize and support innovative new home builders. According to CHBA's website the goal was to offer consumers homes that are, "better for you, better for your community and better for the environment".

Through the development of the EnviroHome Initiative, a marketing program for R-2000 builders and R-2000 homes was created. A builder may be considered for the EnviroHome designation only after they complete an R-2000 home and incorporate proven and commercially available features that enhance the indoor air quality and make the home more environmentally responsible. CHBA considers R-2000 homes to be among the most energy-efficient and environmentally responsible new homes on the market. They are designed and constructed by specially trained builders, who are committed to providing the very best for their customer, and every R-2000 home is certified by the Government of Canada. It is builders who have exemplified this level of commitment and knowledge of green building that were targeted for inclusion in Survey NE.

Once the surveys were completed, data results were examined to determine:

- Geographical preferences toward the straw-bale industry
- Statistical analysis of types of materials and building methods used
- Analysis of impact on firm's average size, budget, revenue, etc. may have on industry

Initial research and results prior to the composition of the surveys proved that the majority of professionals with straw-bale experience are typically smaller firms and are located in the southwestern United States, as well as Ontario, Canada. Figure 6.1 displays these results. Survey NE was similarly sent to firms in regions where straw-bale buildings are abundant; however it also served to address firms in regions where straw-bale building has not received widespread development.

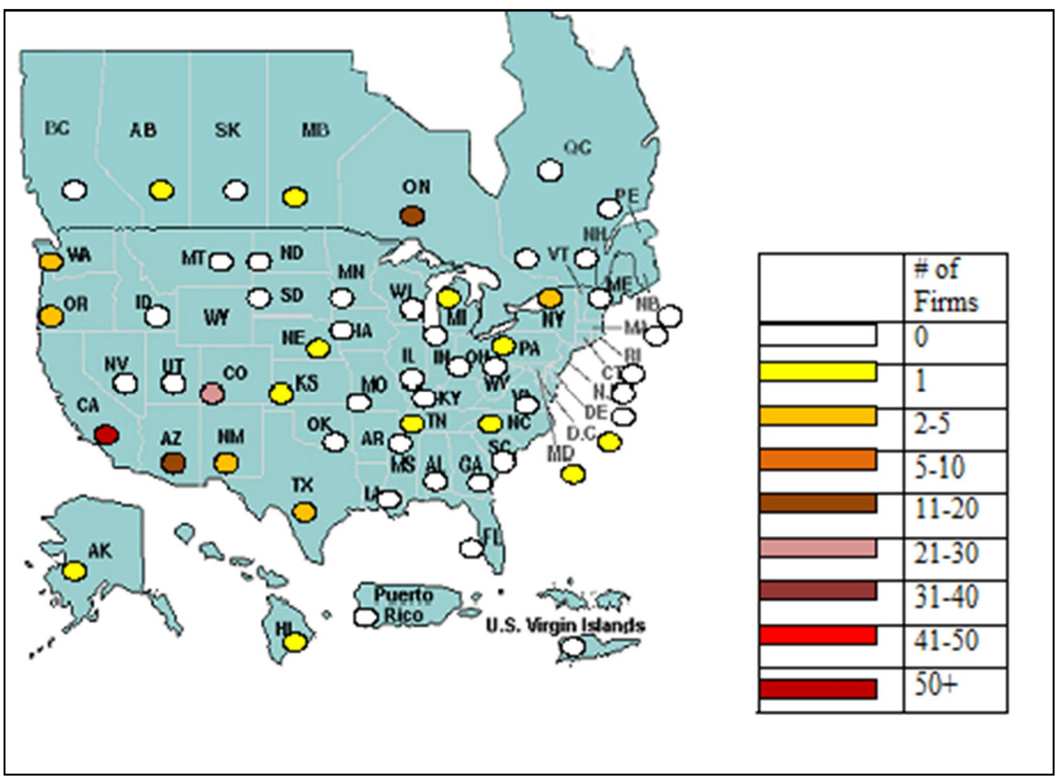
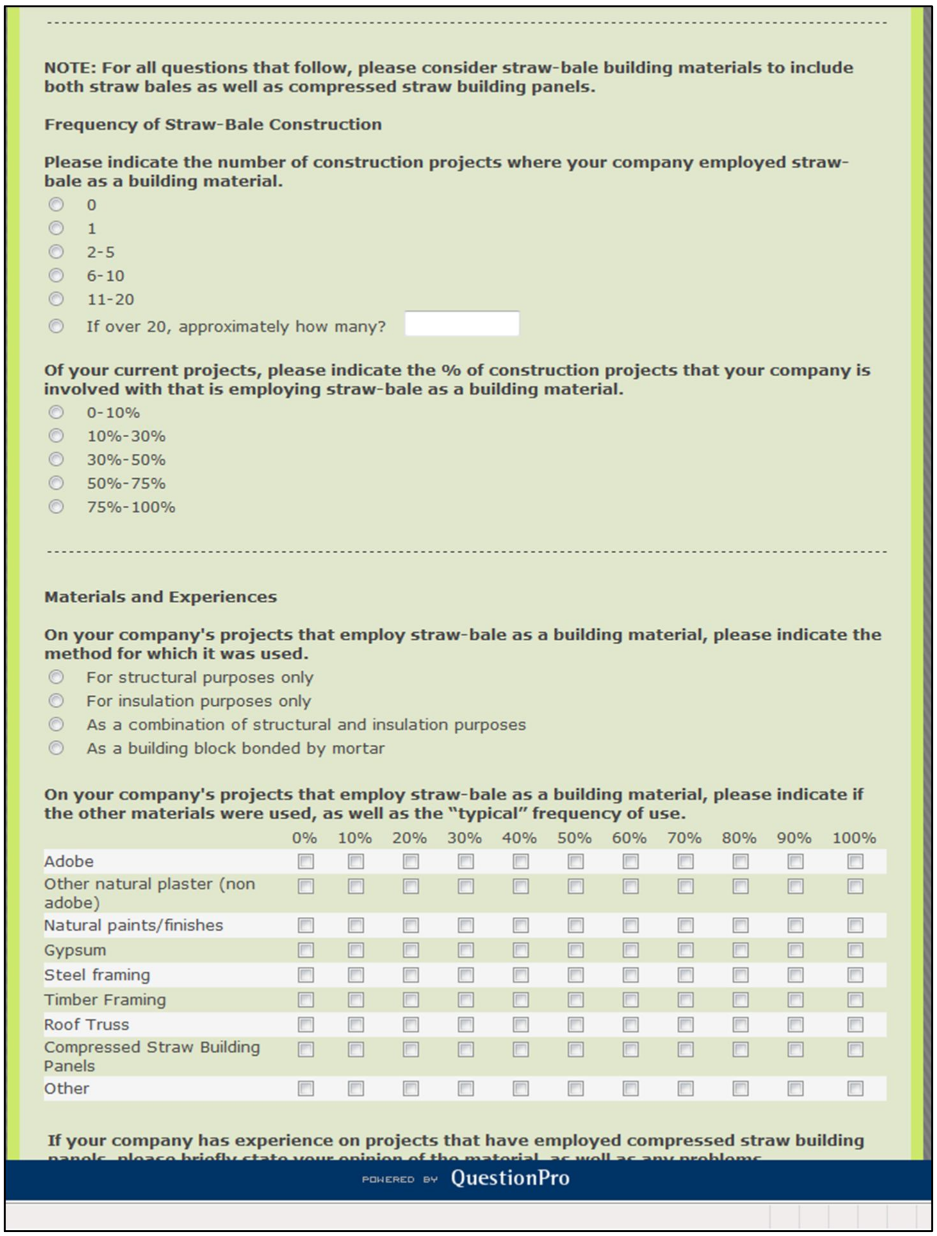


Figure 6.1 – Geographic Distribution of Firms That Were Sent Survey SB

QuestionPro was selected as the program of choice for the surveys as it allowed for a means of survey composition, survey distribution, respondent and results tracking, and a method to export final data into a manageable Excel format. Additionally, it is offered through a monthly subscription as online software. Compositions of Survey SB and Survey NE are included in their entirety in the appendix of this document. As an example, a screenshot of sample questions provided in Survey SB is shown below in Figure 6.2.



NOTE: For all questions that follow, please consider straw-bale building materials to include both straw bales as well as compressed straw building panels.

Frequency of Straw-Bale Construction

Please indicate the number of construction projects where your company employed straw-bale as a building material.

- 0
- 1
- 2-5
- 6-10
- 11-20
- If over 20, approximately how many?

Of your current projects, please indicate the % of construction projects that your company is involved with that is employing straw-bale as a building material.

- 0-10%
- 10%-30%
- 30%-50%
- 50%-75%
- 75%-100%

Materials and Experiences

On your company's projects that employ straw-bale as a building material, please indicate the method for which it was used.

- For structural purposes only
- For insulation purposes only
- As a combination of structural and insulation purposes
- As a building block bonded by mortar

On your company's projects that employ straw-bale as a building material, please indicate if the other materials were used, as well as the "typical" frequency of use.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Adobe											
Other natural plaster (non adobe)											
Natural paints/finishes											
Gypsum											
Steel framing											
Timber Framing											
Roof Truss											
Compressed Straw Building Panels											
Other											

If your company has experience on projects that have employed compressed straw building

POWERED BY QuestionPro

Figure 6.2 Sample Questions from QuestionPro Survey

6.2 Survey Format

The completion of the surveys was entirely voluntary, and all information was to remain strictly confidential. Any data provided was reported only in the aggregate, and the professional's name and information was coded to ensure anonymity. Aside from the benefit of sharing viewpoints and experiences, the only incentive that was offered to the professionals to complete the surveys was the promise that survey results would be tabulated and returned to all interested respondents upon the completion of the research project. At the end of the surveys the option was given to provide an email address in order to offer this correspondence.

6.3 Question Types and Goals

As the surveys were composed, various question types were expected to produce information that would provide a comprehensive investigation of the straw-bale industry. Table 6.2 below lists the various titles for the question categories of each Survey.

SURVEY SB	**SURVEY NE**
Company Information	Company Information
Frequency of Straw-Bale Construction	Frequency of Straw-Bale Construction
Materials and Experiences	Green Construction Projects
Market Drivers	Perception
Problems Encountered While Employing Straw-Bale Construction	Geographic Impacts
Best Strategies for Straw-Bale Construction	Company Policy
Types of Construction	Cost
Incentives	Project Size
Geographic Impacts	Future Trends
Company Policy	-
Procurement Practices	-
Timing	-
Cost	-
Project Size	-
Future Trends	-

Table 6.2 Question Types

6.4 Survey Responses

Survey SB received 38 total responses, while Survey NE collected 36 total responses. As shown below in Figure 6.3, QuestionPro detailed the responses to individual questions. Additionally, overall results may be exported into Microsoft Excel for further analysis.

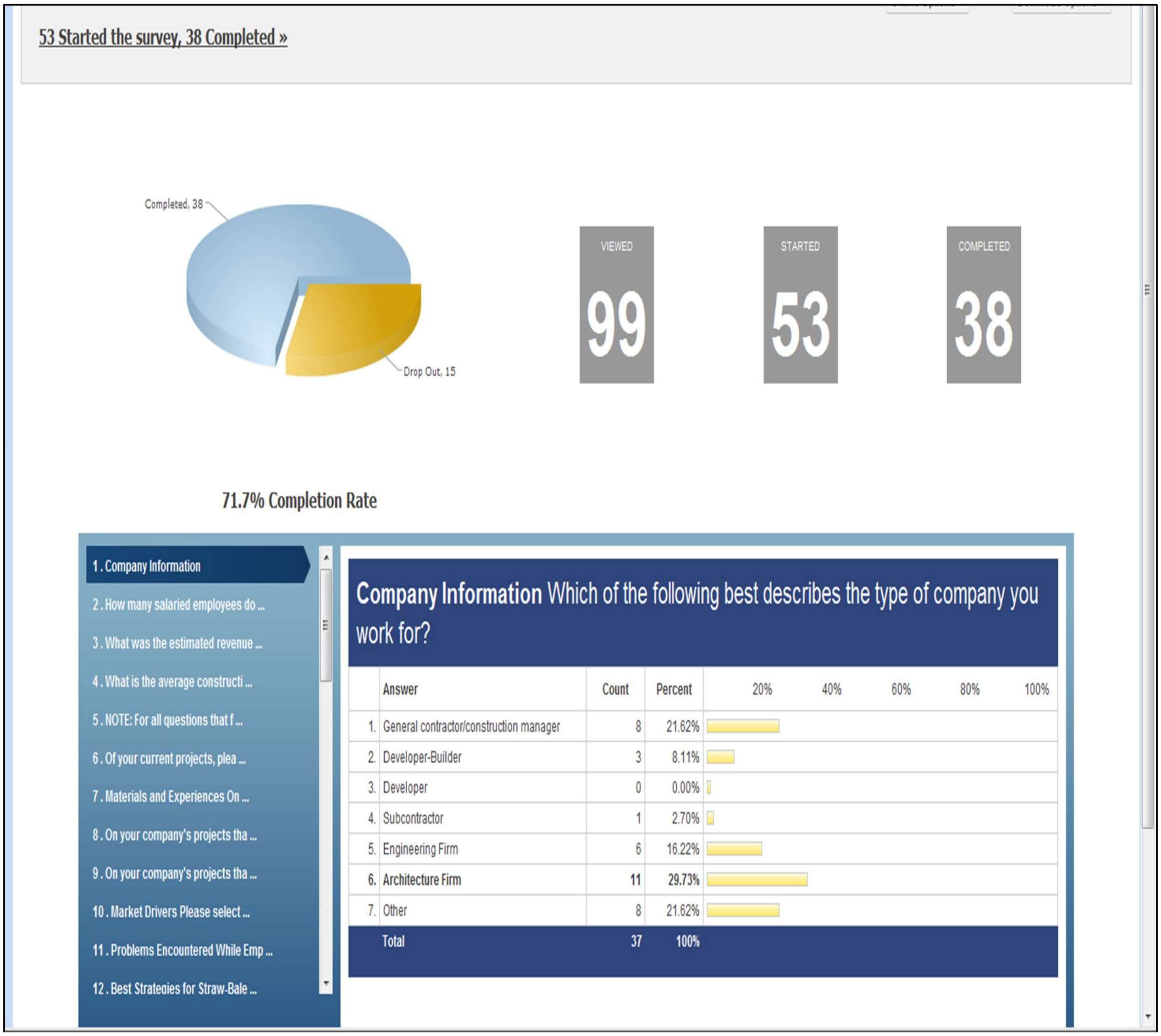


Figure 6.3 Respondent Completion Progress Tracking

6.5 Key Results-Overlapping Questions

6.5.1 Company Information

As it may be noticeable from Table 6.2, the two surveys included similar question types that served as a means of comparison. From such question results certain factors can be inferred, for example the type and size of firms who may be more inclined to participate in straw-bale construction. While Survey SB and Survey NE primarily were composed to achieve varying results, in many case certain questions were applicable for both cases. Various examples of results from questions that were asked to both SB (blue) respondents and NE (green) respondents are displayed on the following pages.

The results provided from Figures 6.4 and 6.5 determined that though the types of firms that may become involved with a straw-bale project will vary, it is quite likely that the firm will have a lesser number of employees. The majority of respondents who have straw-bale experience are most likely to associate their firm with the educated professions of general contractor/construction management, engineer, or architect. These findings are certainly encouraging, as it can be established that highly educated and skilled professionals are those currently supporting and advancing the industry. On the other hand, the industry could evidently benefit from the involvement of larger firms. This would both increase the knowledge and skill base of those who are qualified to work on the projects, as well as it would likely increase the public awareness and visibility of straw-bale projects.

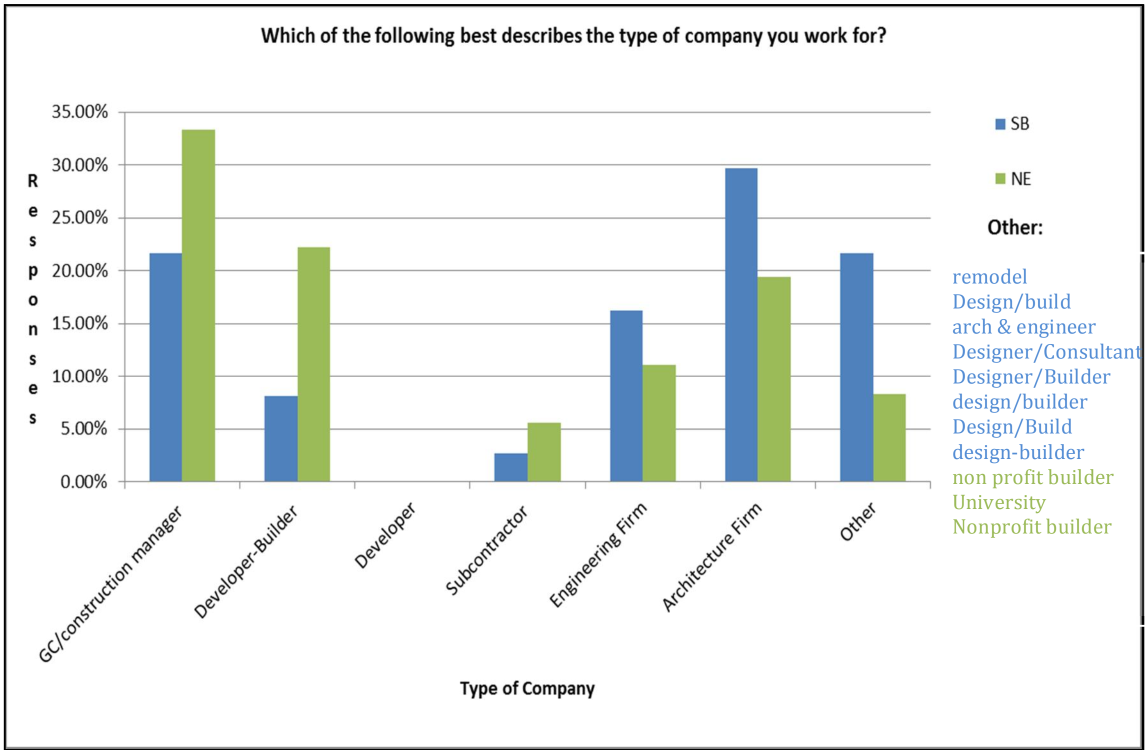


Figure 6.4 Type of Company

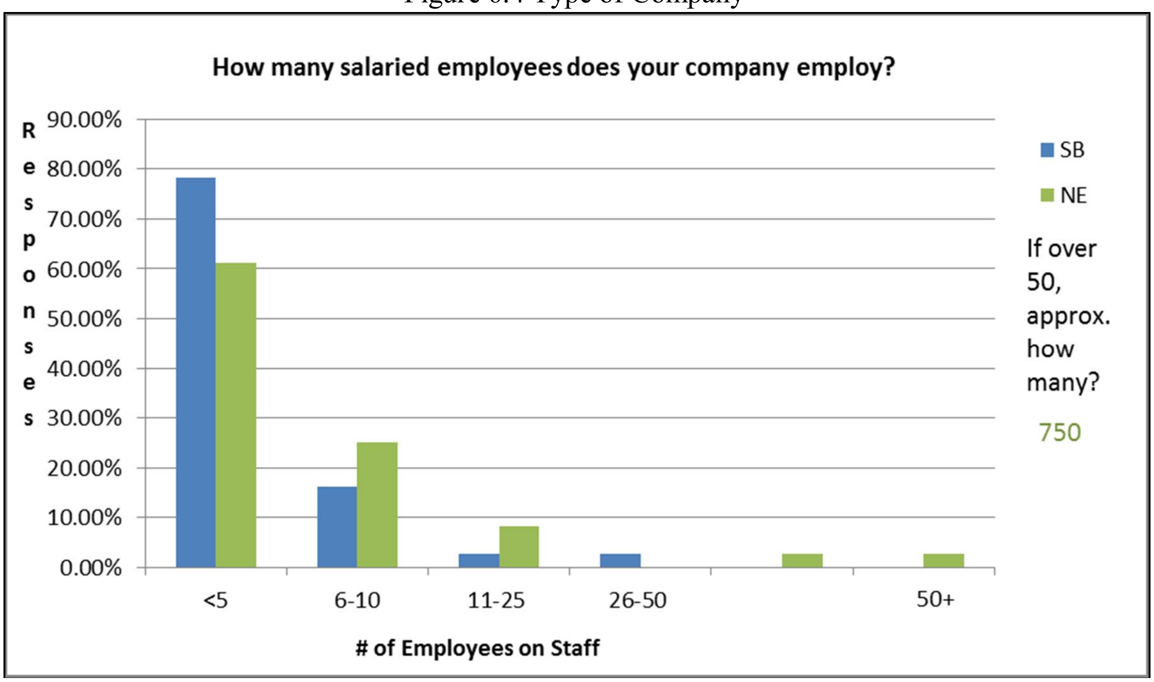


Figure 6.5 Number of Salaried Employees

From the next two charts, Figures 6.6 and 6.7, it is evident that the firms who have achieved experience on straw-bale projects are those associated with lesser annual revenues. An estimated revenue of less than $250,000 and an average construction budget in the range of $100,000 to $500,000 are common figures. The data shows that those firms only complete 1-2 straw-bale homes per year. It is relevant to the previous findings that most firms with straw-bale experience are those with fewer employees. Such a relation certainly would limit the number of projects and associated revenue that the firms would be capable of generating.

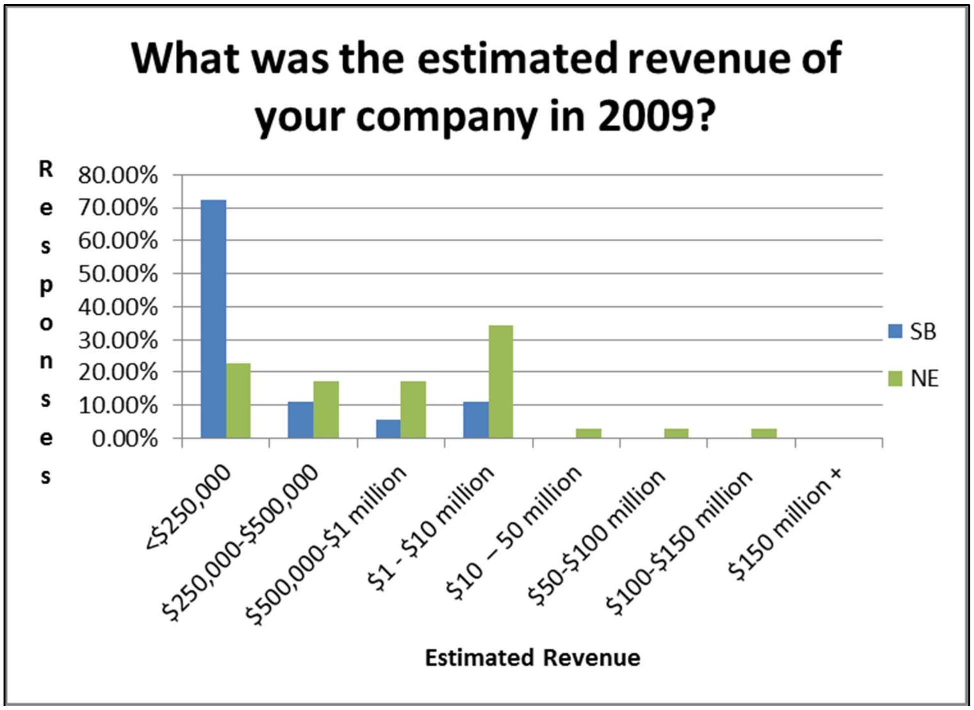


Figure 6.6 Estimated 2009 Revenue

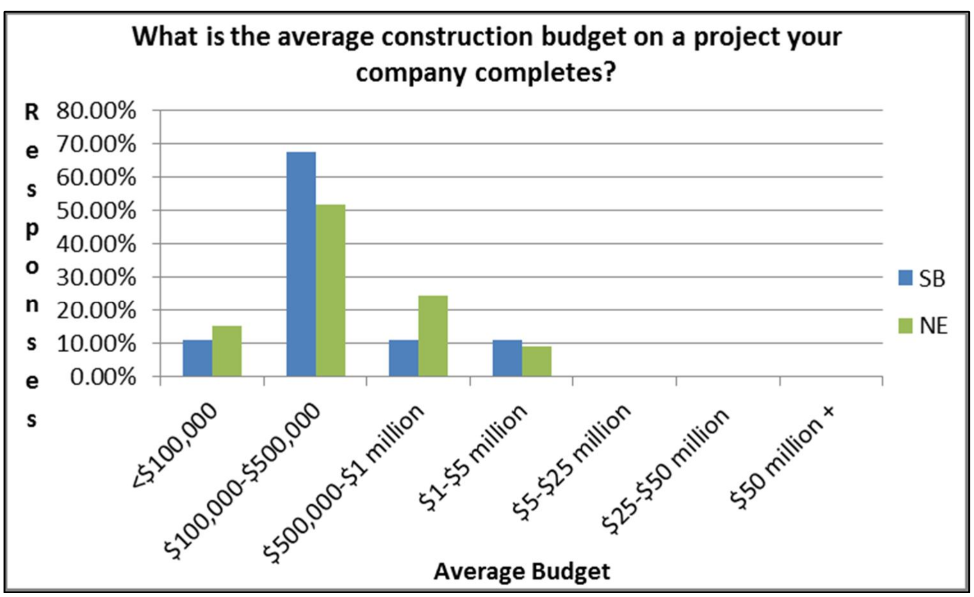


Figure 6.7 Average Construction Budget

6.5.2 Perception of Straw-Bale Industry

The results of Figure 6.8 indicate that there is a general understanding that simply disposing of straw may not provide the most cost effective use of the material. Obviously, the straw-bale professionals were more likely to disagree with the above statement, but similarly the majority of non-experienced professionals are at least neutral to the idea that the disposal of straw is the best option.

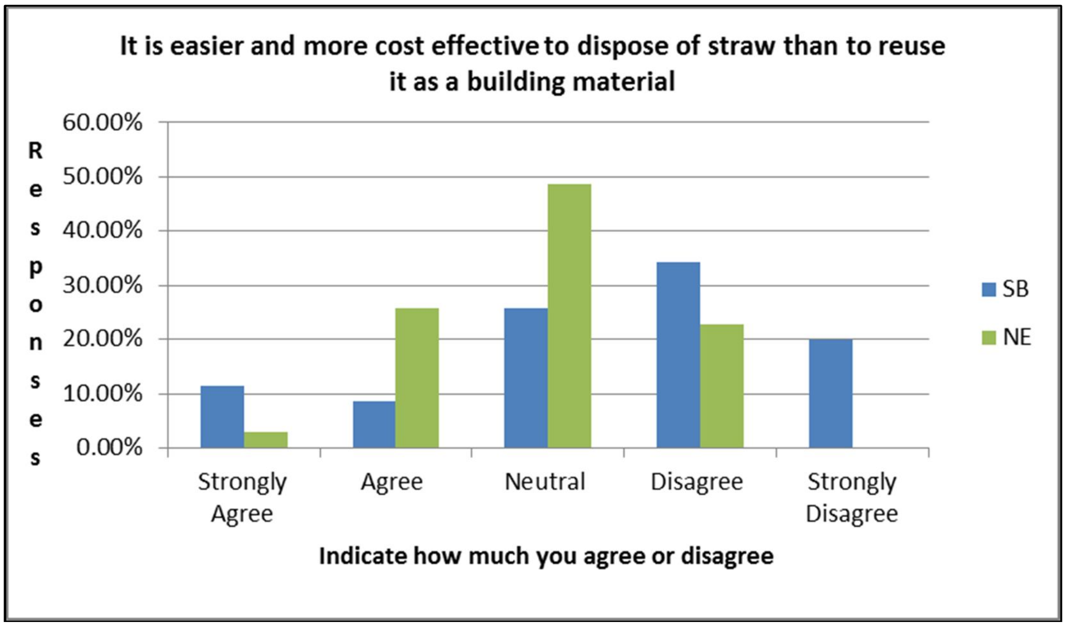


Figure 6.8 Disposal of Straw

Figures 6.9 and 6.10 address the geographic perceptions of straw-bale construction. It is quite evident that the majority of professionals from both surveys do not agree that the feasibility of the construction method is perceived equally throughout North America. Similarly, it is believed that the success of a straw-bale project is dependent upon the geographic location of the project. Though it is apparent by referring to Figure 6.1 that straw-bale construction projects are not distributed evenly throughout North America, it has certainly been displayed that the option is feasible for all climates. It would seem that with the proper marketing techniques displaying successful and long standing construction examples, this perception could easily be altered.

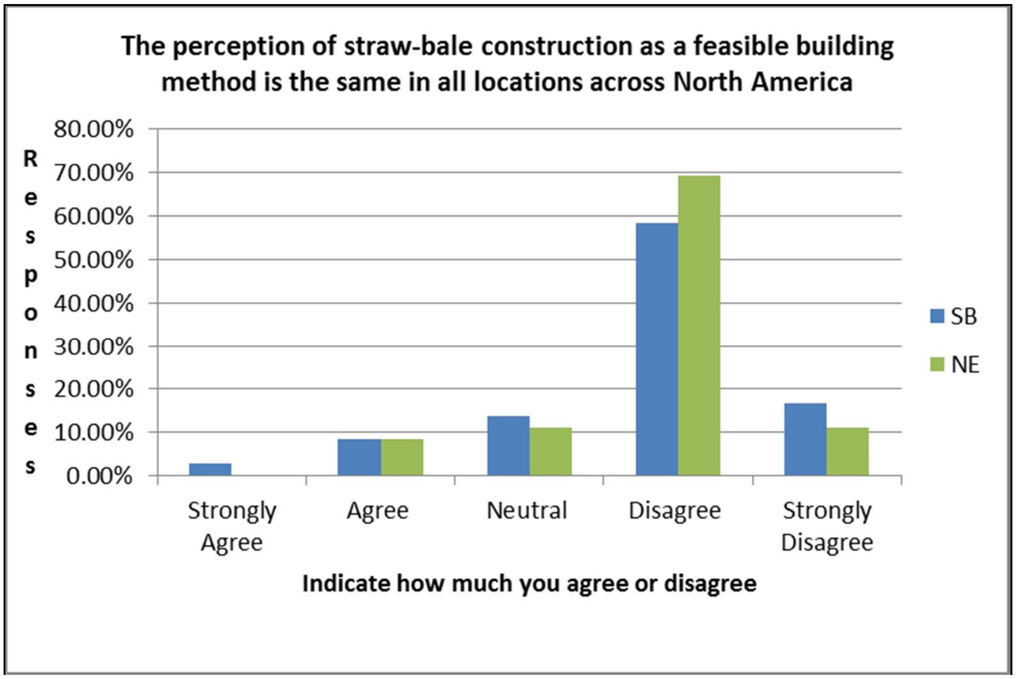


Figure 6.9 Perception of Straw-Bale Construction

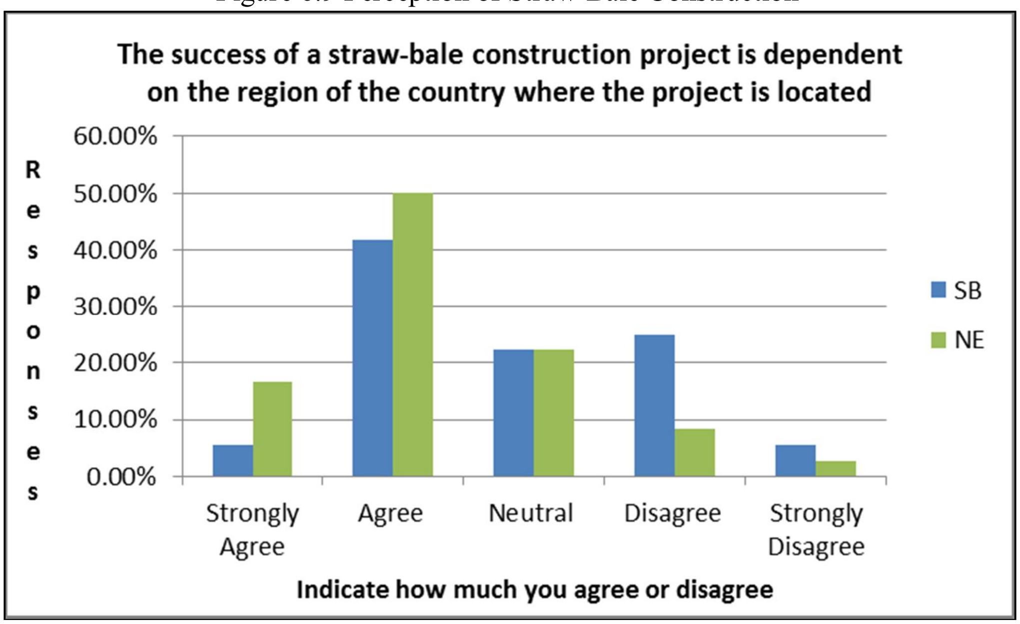


Figure 6.10 Success Based on Location of Project

At the current stage in the development of the straw-bale construction industry, the primary examples of projects are residential. Furthermore, the vast majority of professionals involved with Survey NE are limited to experience with residential projects. Interestingly, there was a wide array of responses regarding the question of whether the size of a project may impact the success of straw-bale construction as shown in Figure 6.11. For the load-bearing usage of straw-bales, a project would be limited in its square footage. Conversely, a project that utilizes straw bales solely for insulation purposes could entail a larger commercial space.

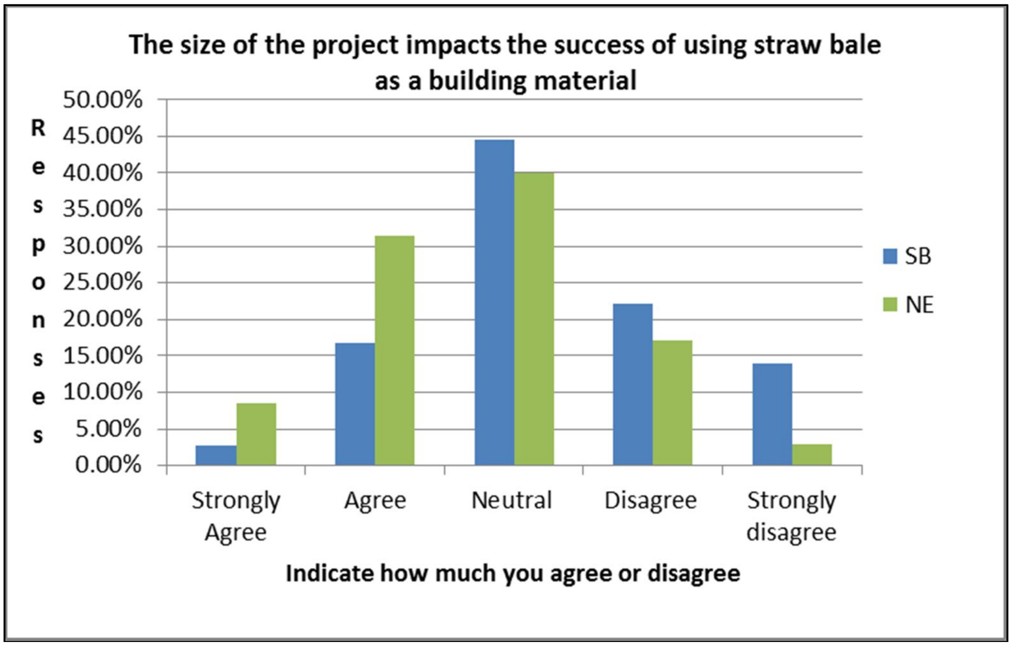


Figure 6.11 Impact on Size of Project

The discrepancy in responses shown in Figure 6.12 is clearly divided amongst those with straw-bale experience and those without. The professionals from Survey SB believe that the method is not a fad, whereas those without experience are more inclined to believe that it will not last. Only time can truly assess this question, though proper marketing of the industry and the capabilities of the construction methodology may be able to change some of the skeptical minds.

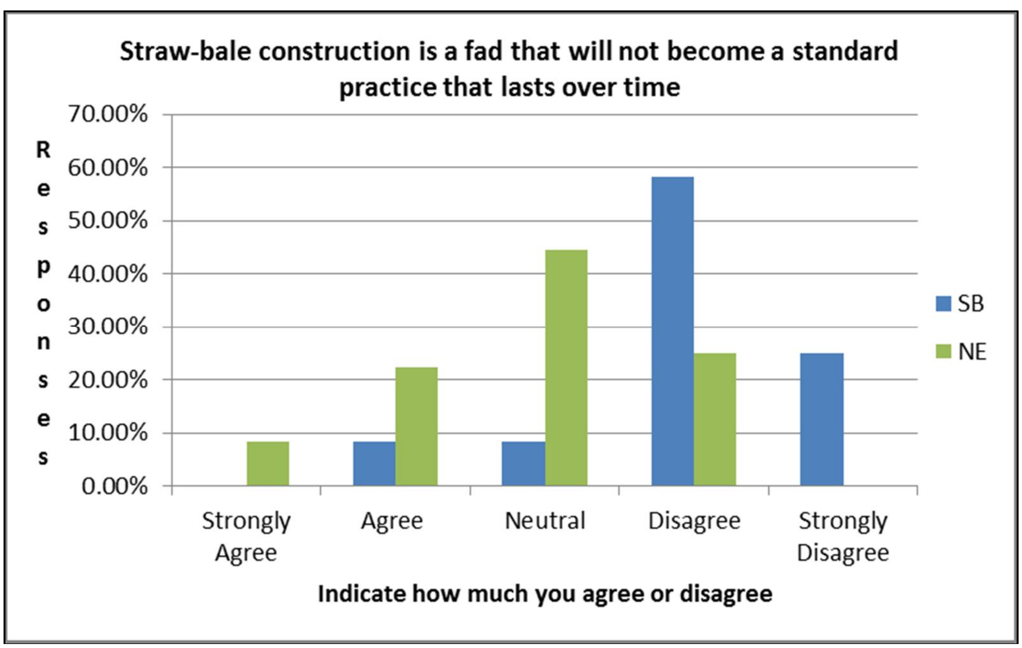


Figure 6.12 Is Straw-Bale Construction a Fad?

Any proponent of the straw-bale movement would be pleased by the results from Figure 6.13, as those surveyed agree that the practice of straw-bale construction will be aided by the development of the industry. Currently there may be many unknown factors about the methodology, as well as lack of suitable firms who have experience and are willing to tackle such projects.

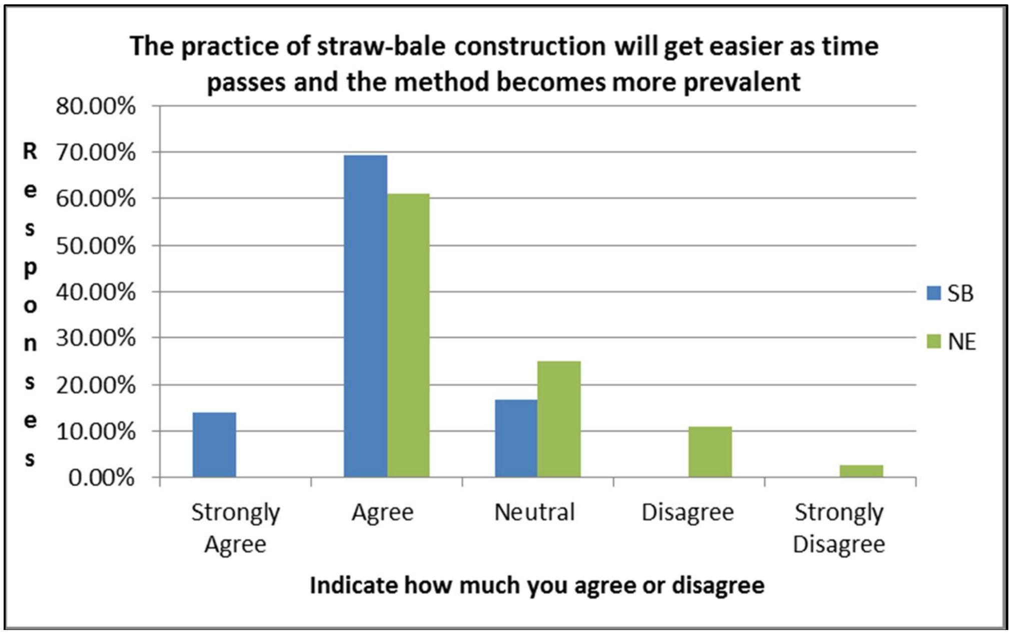


Figure 6.13 Easier as Time Passes

6.5.3 Geographical Feasibility

Lastly, Figure 6.14 displays the geographic distribution of respondents. Considering this data, it is interesting to refer to Figure 6.9. Since it is believed that the feasibility of straw-bale construction is not perceived equally throughout North America, the responses to the surveys may be viewed on a more local perspective. There were a large number of responses to Survey SB from the western and southwestern states, which coincides with where most current examples of straw-bale projects are located. On the other hand, the locations of respondents for Survey NE varied significantly. With responding professionals located across North America, it offered a greater array of perspectives from areas with variable climates and typical methods of construction.

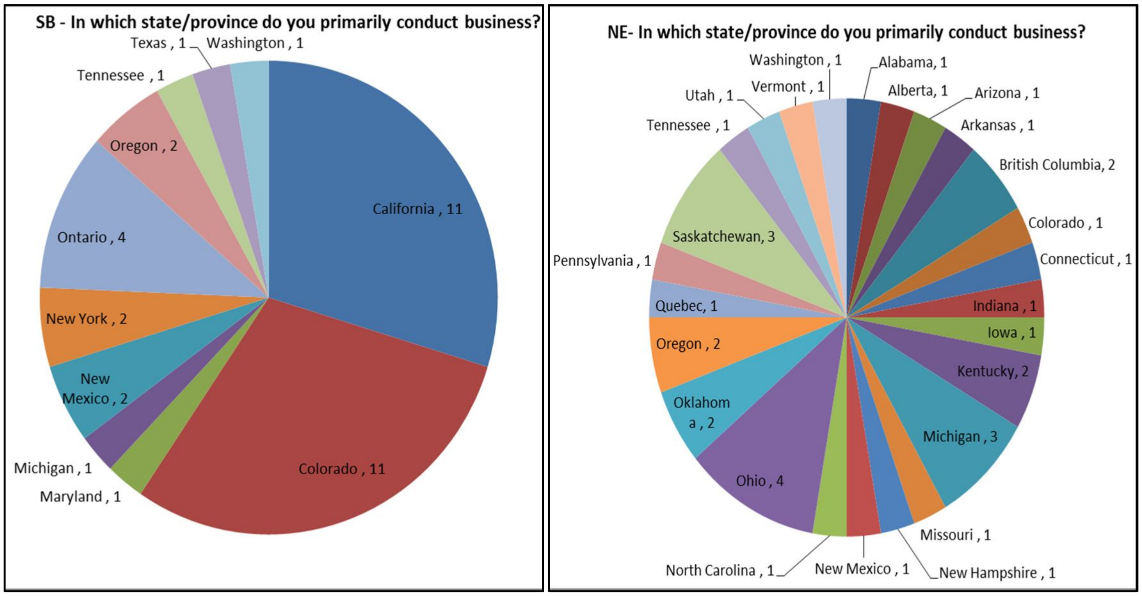


Figure 6.14 Geographic Distribution of Respondents

6.6 Key Results – Survey SB

6.6.1 Company Information

The following results pertain to the questions that were unique to Survey SB. Once again, this survey was directed solely to firms and professionals with previous straw-bale construction experience. While attempting to be as objective as possible, the questions were composed to measure the experiences and associated successes and difficulties that the professionals have encountered on their projects. Of the firms that responded, approximately one out of six stated that their company has a policy that requires the utilization of straw based materials on all projects

The results of Figures 6.15 and 6.16 display that there are several firms that provide an asset to the industry with their substantial experience within straw-bale construction. Of the firms who have straw-bale experience, the majority of their project experiences are vast, as they have completed at least 10 straw-bale projects. In many cases firms have completed up to 40 and 50 straw projects. Additionally, those surveyed clearly believe that straw bale is a feasible building material as they continue to select it for their projects. Two-thirds of the firms polled state that the majority of their projects involve straw bale as a building material. Similarly, more than one-third of the firms are currently utilizing straw on at least 50 % of their projects.

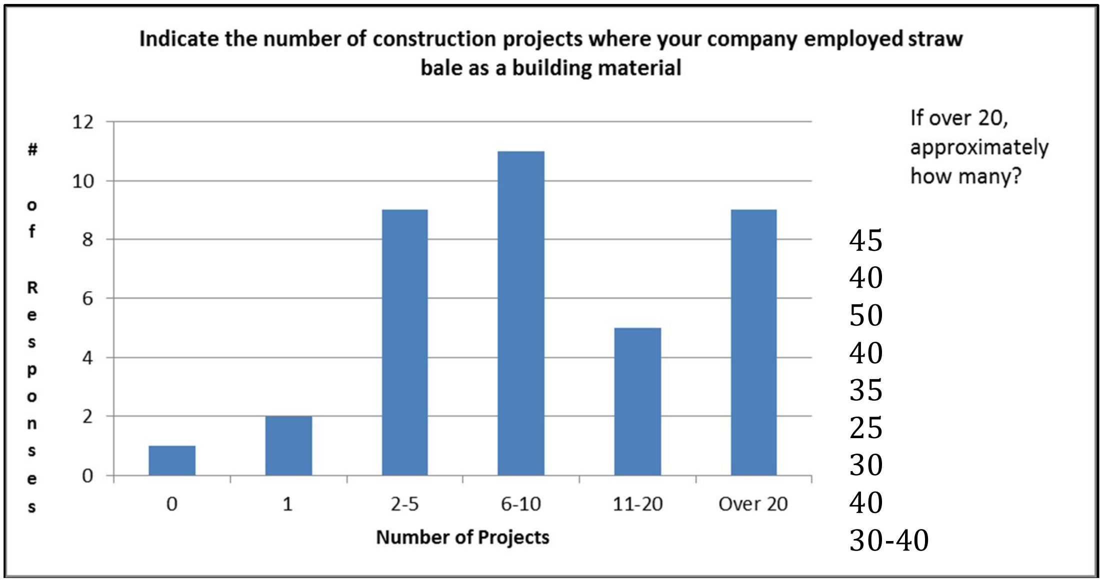


Figure 6.15 Number of Projects that Employed Straw Bales

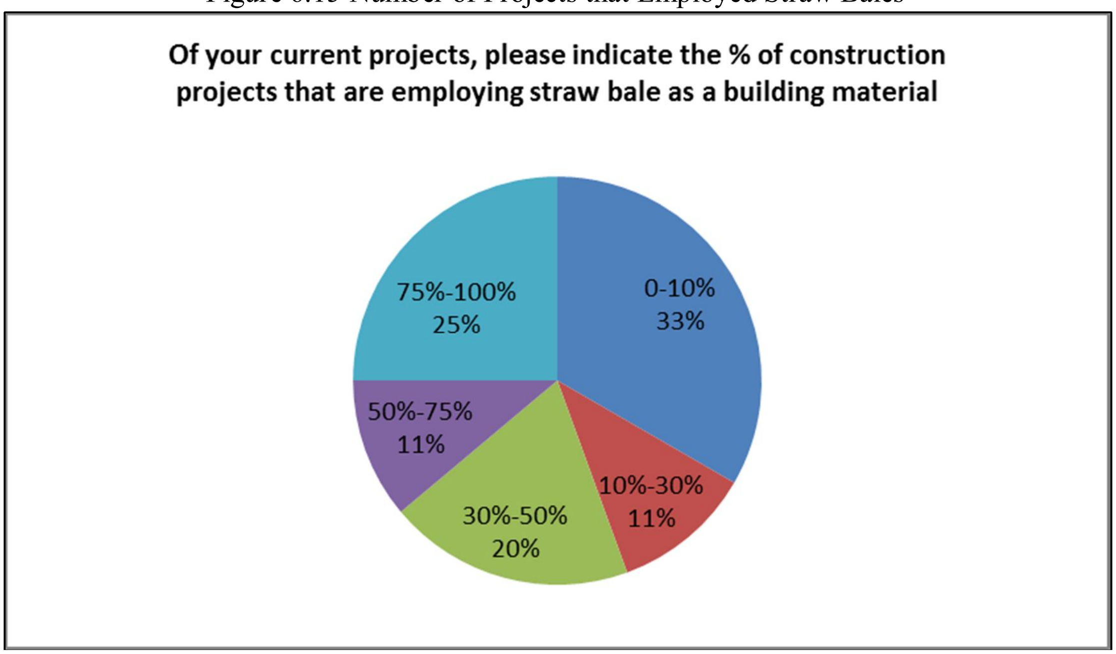


Figure 6.16 Percentage of Current Projects that Employ Straw Bales

There is a myriad of ways to utilize straw on a construction project, and of those options, they may essentially be broken into 4 construction methods. It was interesting to learn that no firms identified their use of straw bale to be solely structural. The majority of uses, 58%, involved the utilization of straw bales for insulation purposes only. The remaining responses identified with employing the joint benefits of structural and insulative benefits of straw for their projects.

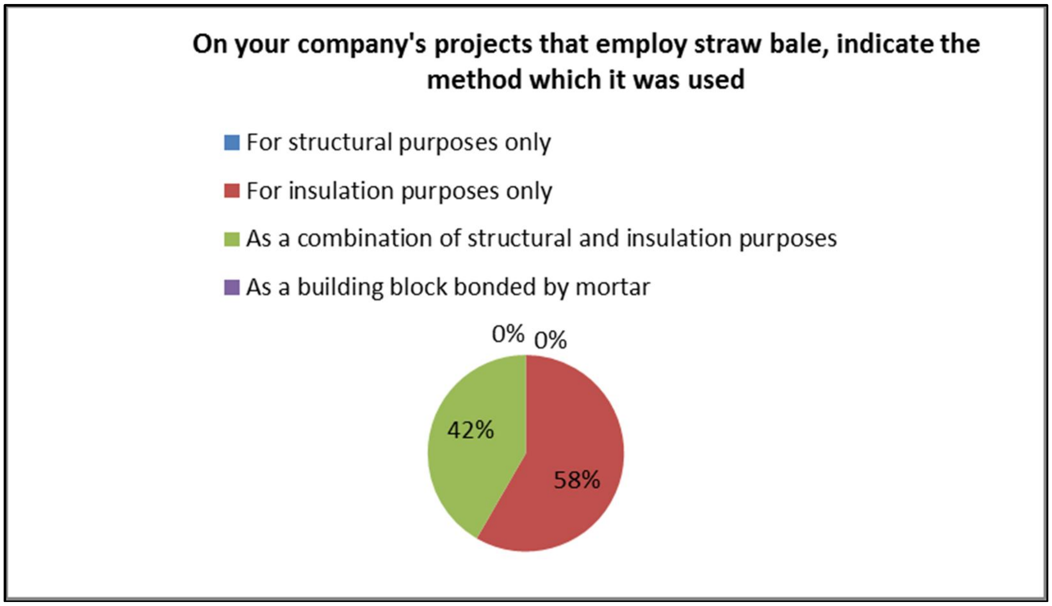


Figure 6.17 Method of Utilization

6.6.2 Material Options

The following question detailed the potential uses, and percentage thereof, for materials that are commonly utilized along with straw bales. Figure 6.18 below displays the way the question was presented to the surveyed professionals. Though this question was formulated as one inquiry, there is seemingly not a feasible way to analyze all of the data in aggregate. As a means of comparison, the material options are displayed with an associated chart, Figures 6.19 to 6.21, based upon similar material types in order to display the frequency of use.

On your company's projects that employ straw-bale as a building material, please indicate if the other materials were used, as well as the "typical" frequency of use.	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Adobe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other natural plaster (non adobe)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Natural paints/finishes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Gypsum	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Steel framing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Timber Framing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Roof Truss	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Compressed Straw Building Panels	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure 6.18 Format of Frequency of Use Question

Figure 6.19 reflects upon the plastering and paint material selections and display that it is a common practice to further enhance the natural material use on a straw-bale project by utilizing natural plasters and finishes. While it is evident that the majority of practitioners make the selection to render the building with natural materials, it is not the only option. Clearly a percentage of professionals do not make this consideration as it is supported by the large percentage of gypsum use. This could perhaps be relative to owner's requests, cost, and familiarity issues. Furthermore, though adobe is a common option in the southwestern states, it is evident that it is not a widely employed material throughout the industry.

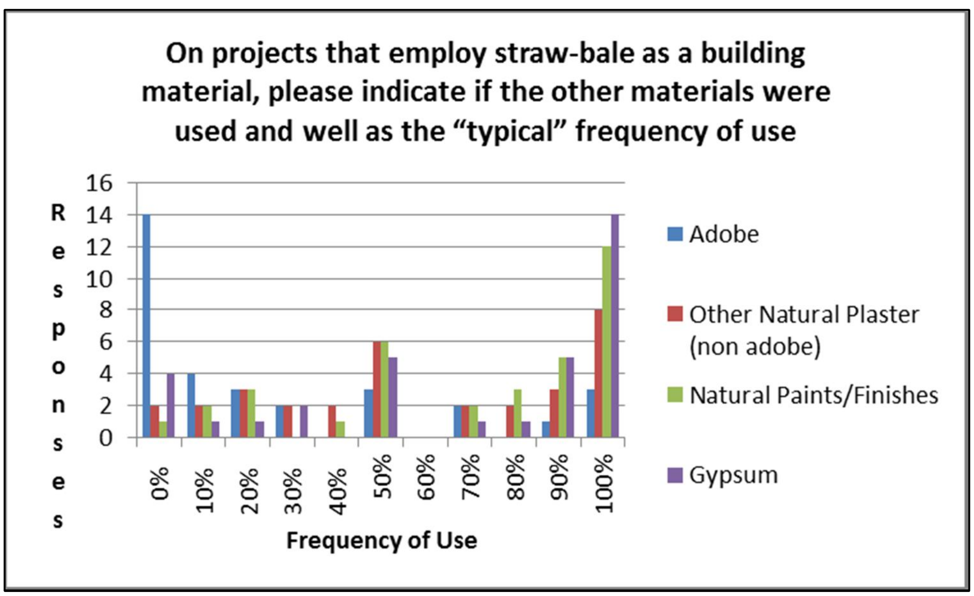


Figure 6.19 Plastering Materials Frequency of Use

A comparison of framing options displays that it is far more common to employ timber framing on a straw-bale construction project as compared to steel framing. A likely contributor to this result is likely cost considerations, as steel is more expensive. In many cases overall cost is at the forefront of a straw-bale project, and steel seletion is not necessarily aligned with these goals. Figure 6.20 also provides evidence that regardless of the material selection, a roof truss is a necessary and commonly utilized aspect of a straw-bale construction project.

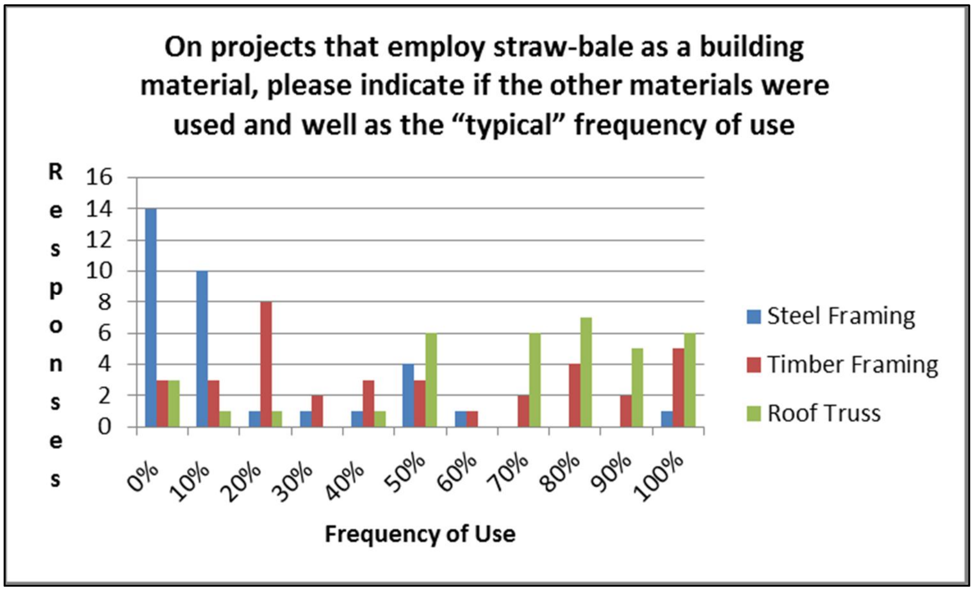


Figure 6.20 Framing Frequency of Use

The remaining material considerations were an inquiry regarding the use of compressed straw building panels or the potential use of any other material not previously included. Since the focus of this project is simply relevant to the use of straw bales, it was not desired to delve too deeply into the current innovation of compressed straw panels. On the other hand, it appeared likely that those involved with straw-bale construction would possess an awareness of the material. As it turns out, regardless of whether or not the professionals are familiar with the material, compressed straw building panels are very rarely used on a straw-bale project.

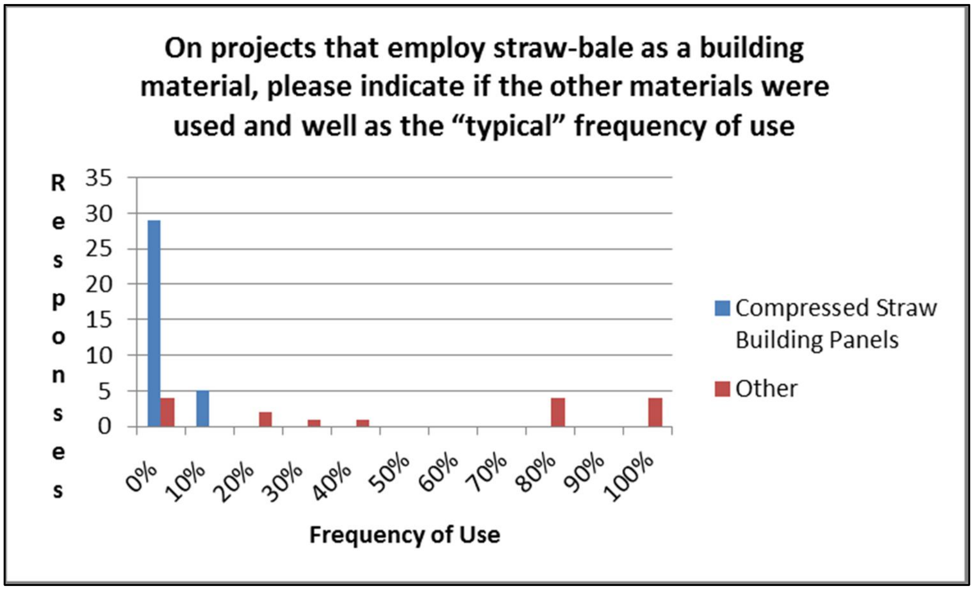


Figure 6.21 Compressed Straw Building Panels Frequency of Use

A separate open ended question examined the following: If your company has experience on projects that have employed compressed straw building panels, please briefly state your opinion of the material, as well as any problems encountered. A variety of answers were given, that comment on the benefits and disadgantages to the material selection. Again, it appears that the utilization of compressed straw building panels are most commonly present on projects that did not utilize straw bales. The following responses provide details of past experiences, opinions, and issues with the compressed straw building panels.

The responses varied from a complete lack of familiarity of the material, to those who utilize the material and even have experience manufacturing and assembling the material. Some respondents admitted to having never heard of the material, but are interested in following its development for future use. Others have intentionally not used the material, due to the fact that they believe it to be too expensive and complicated. One respondent stated that he appreciates that there are other creative products coming from such a useful resource (straw), but he feels that it is best used in the bale form. In his opinion "simple is better and more sustainable".

A large portion of the respondents stated that they often utilize the material and appreciate the benefits. Most frequently compressed straw panels are utilized for partitions and cabinetry. One respondent shared that the technology was first developed in pre-World War II Germany, and has since remained a feasible construction material. From those respondents who have utilized the material, several complaints regarded the heavy nature of the material to produce difficult weight issues. Furthermore, like straw in bale form, there are concerns regarding imperfect finishes and cutting issues. Though far more suitable than in bale farm, the material is still not homogenous, and the edges may be imperfect.

Figure 6.22 displays the options of various agricultural fibers that may be utilized throughout the world for the creation of straw bales be employed for construction purposes. It is quite evident that of those projects experiencd by the professionals involved with Survey SB only cereal straw, bagasse, rice straw, and one other material not listed were employed in North America. Of those parictular materials, cereal straw and rice straw are the only fibers used consistently.

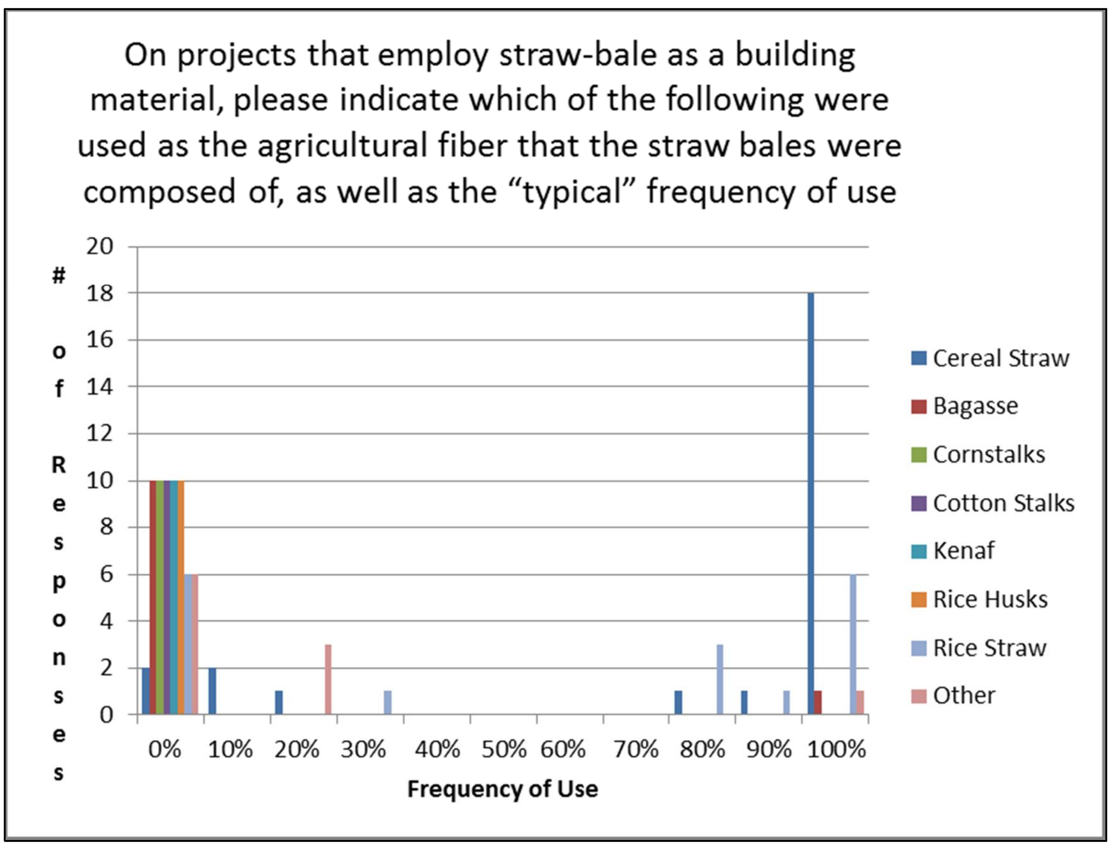


Figure 6.22 Agricultural Fibers Frequency of Use

6.6.3 Straw-Bale Experience

The selection of utilizing straw bales as a building material has a myriad of benefits, and therefore can become associated with many factors that would impact the decision to use the material. Aside from a specific request from an owner, or else an ecological mindset at the onset of a project, the results displayed in Figure 6.23 offer a variety of responses. It can be viewed that the diversity of responses to this question exemplify the many advantages that straw bale may offer, primarily the insulation potential. In addition to those displayed above the following responses were included as the other option: 1) superinsulation 2) sustainability 3) Beauty, Thermal Mass, Excellent Day-Light distribution 4) socially responsible 5) the home was located on a farm and we wanted to use materials from the site 6) beauty 7) Local & regional Supply 8) Performance (superior insulation w/thermal mass) 9) Energy reduction 10) Insulation factor.

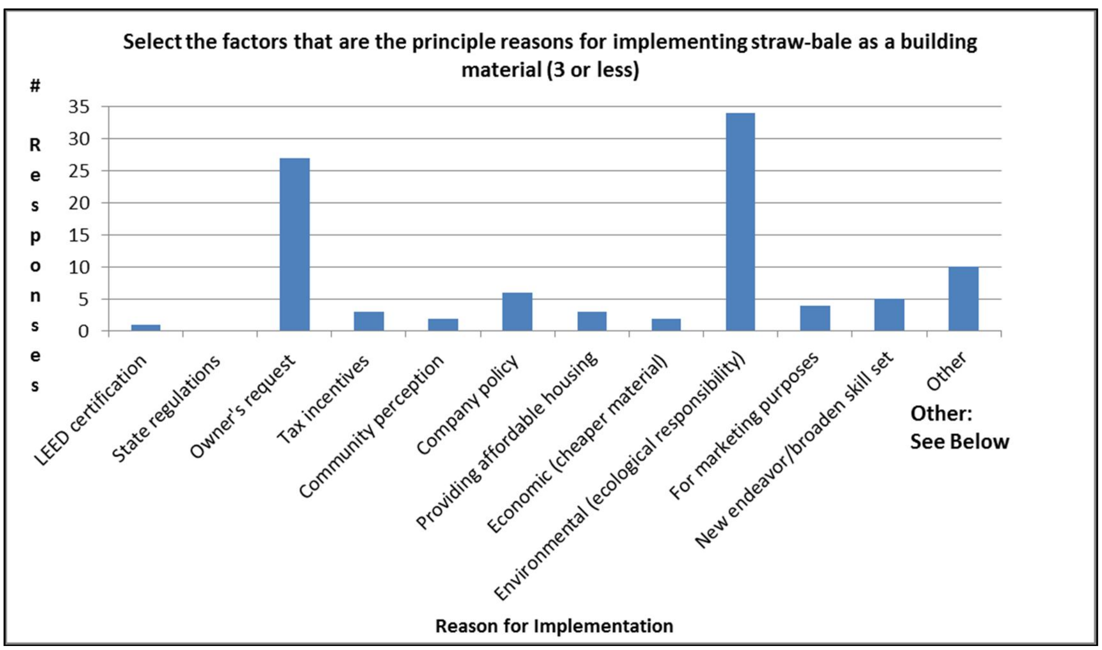


Figure 6.23 Reasons for Implementation

The professionals queried in Survey SB offer the unique benefit of being able to offer their problematic experiences with previous straw-bale projects. It is principally apparent that the derivation of most issues is related to a lack of experience with the construction process. Whether it is a lack of experience of subcontractors or unfamiliarity with the material by both those involved with the construction as well as the general public, it would certainly be a costly and time squandering issue. Additionally, a lack of experience within the industry displays a direct correlation to a lack of firms and builders who are capable of undertaking such a project. Simple economics explain that a lack of competition amongst firms can allow those firms possessing experience to charge higher prices.

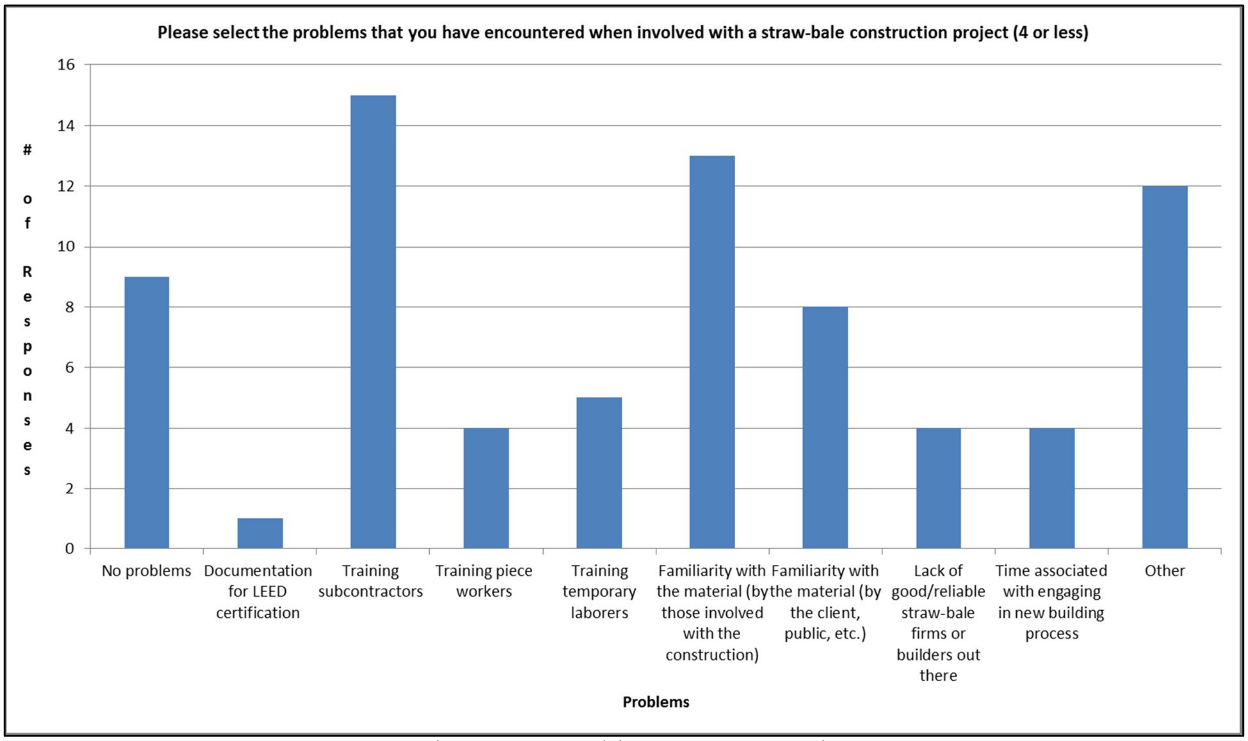


Figure 6.24 Problems Encountered

The question offered a response of "other", and a variety of useful details were offered within the option. High labor and additional engineering costs and overall time added to the construction process were mentioned on multiple occasions. It is understood that straw-bale construction is a labor intensive process, and as time is wasted due to errors or excessive training, labor costs increase. As more firms garner the necessary experience then labor teams will increase efficiency and lower costs. A segment of responses commented on difficulties with educating code officials, appraisers, insurance representatives, building inspectors and clients. A similar comment regarded the lack of standardized technical reference materials. The establishment of such standardization would likely have a positive effect on the education and justification of the material selection to all of the individuals previously mentioned. Lastly, a portion of responses were directly weather related. One particular difficulty arose in the seasonal ability to employ natural plasters, which likely is attributed to the amount of sunlight necessary to dry the plaster. Also, one professional commented on moisture problems occurring from interior plastering in the winter months.

An open ended question asked the experienced professionals to briefly document any aspects of a project involving straw-bale building materials that particularly surprised them. There appeared to be a segment of professionals who were initially skeptical of the quality that would be produced in the end result. Various comments explained their surprise as to “how nice the end product is, and that it is comfortable, quite, secure”. Similarly a professional stated that they were pleasantly surprised how the final product was “warm, beautiful, and sound deadening”. Several comments regarded the surprising amount of “strength and resilience” provided by the straw-bale home. In particular “the structural stability obtained by the plaster coat when cured/dried” and “the strength of the combined synergy of plaster, bale, and plaster” were comments that provided testament to the material’s structural capabilities.

On the other hand, others experienced an unfortunate realization regarding the overall costs of the project. It was stated that “although the material is inexpensive, the labor cost made it unaffordable for most clients” and “there is a general belief that because straw is relatively inexpensive that other building components such as doors, windows, cabinets, plumbing, etc. are somehow inexpensive, too”. One professional even came to the conclusion that from his experience “it is not less expensive but a little more expensive than conventional construction”. Other unfortunate revelations involved an overall unfamiliarly with the building material. One professional was disappointed in the "public's general lack of knowledge, as well as the cost for a contractor build straw bale building".

The following comments were also provided, though do not particularly relate to any of the previously mentioned statements:

1) The way straw bale building is a kind of Trojan Horse or Gateway Material that gets the owners thinking about more and other natural materials that can be used.
2) How engaged and excited project owners get when participating in construction at a bale-raising.

The results of Figure 6.25 begin a series of questions regarding the impact that business practices and policies may have upon a straw-bale construction project. The question displayed above inquires about the best strategies that yield a successful straw-bale project, and the primary response was that prior experience with the material and building techniques provide the greatest advantage. Additionally, it is beneficial to involve experienced subcontractors. It is also interesting to learn that it is considered beneficial to build in a region where other visible straw-bale projects are present. The following responses were given to describe any practices not listed that have increased efficiency and ease of construction on previous projects:

- early involvement of a bale builder in the building design process
- network of experienced builders
- remembering that the sequencing is different than stick building
- need more working straw bale homes that fit the mainstream ideal
- spending adequate time, training for bale installation, preparing for plastering, and using plywood patterns of form to shape consistent window reveals
- Design & Build
- a new framing method
- Energy Star designation and compliance
- have own in-house straw & plaster crew
- architect / designer must be straw bale proficient and have built with it themselves
- running the jobs myself
- building wrap as opposed to structural use

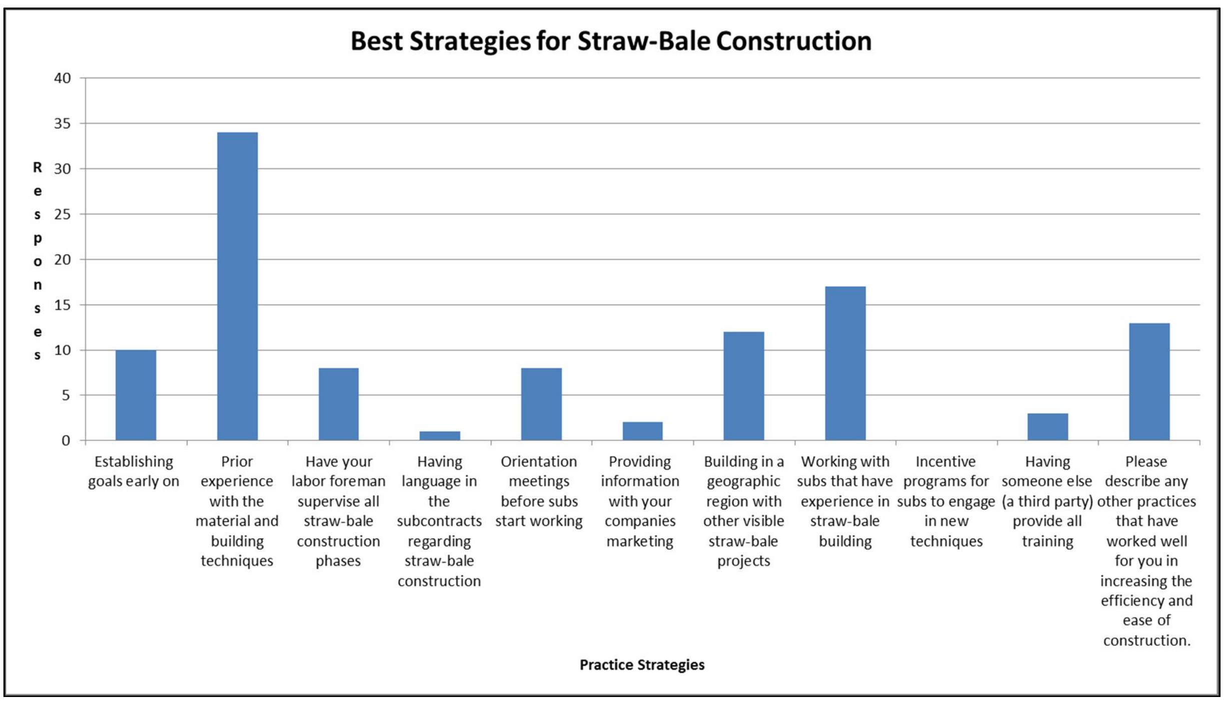


Figure 6.25 Best Strategies for Straw-Bale Construction

6.6.4 Breakdown of Experienced Employees

The data above displays a relatively even dispersal of types of employees that have engaged in the construction process on a straw-bale project. Though evidence of charitable involvement has been present within the industry in the past, none of the respondents identified with the utilization during their experiences. As it will later be mentioned, recent charitable work has been employed to construct straw-bale homes in Haiti's recovery from the 2010 earthquake. It is a positive result to notice that various types of employees have garnered experience in straw-bale construction as this can serve to broaden the amount of professionals who are achieving the applicable skills and methodologies. An additional "other" response option was available to respondents, though it is not displayed in Figure 6.26. The other option asked if volunteers or charitable organizations were involved, what percentage of your straw-bale projects have included this. It was determined from the other response option that the workers were used on a volunteer basis and not through a charitable organization. The following wide range of replies was given detailing the overall percentage of construction work that the volunteers were involved with (some values may have been offered multiple times): < 10%, approx. 15-20%, 20%, 25%, 50%, and 100%. Additionally, some responses did not imply a percentage, but offered exact tasks that were completed. These tasks included: 1) first coat of exterior adobe plaster, 2) all tasks to some degree, especially around initial bale installation, 3) usually through a straw-bale stacking workshop at the site.

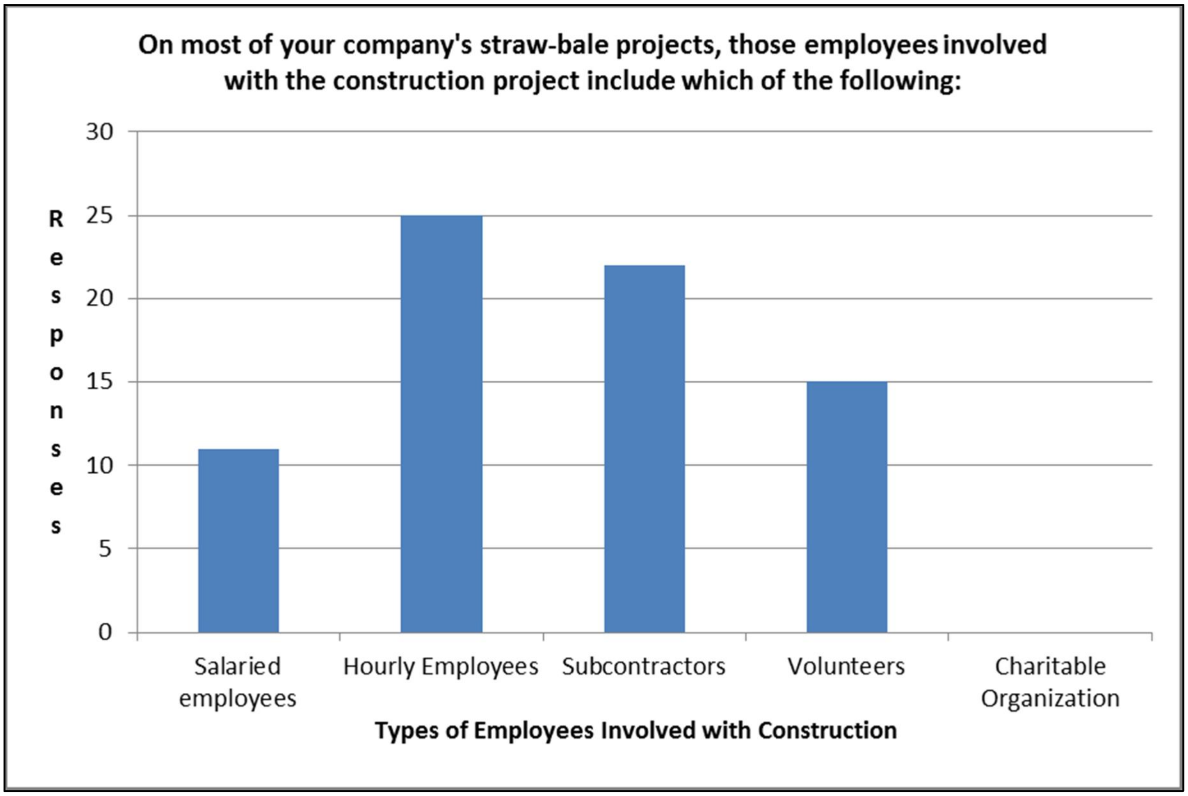


Figure 6.26 Type of Employees Involved with Construction

The survey results provided in Figure 6.27 relate to the utilization and involvement of hourly employees on the straw-bale projects. The majority of responses indicate that it is beneficial to educate hourly employees on straw-bale construction, and most of the firms are practicing this training process. This is quite obviously a worthwhile endeavor if your firm has the intention to continue to work in this realm of construction, as the staff will be prepared for future projects. Additionally, the more professionals involved with the process can only serve to advance the awareness and skill of the straw-bale industry.

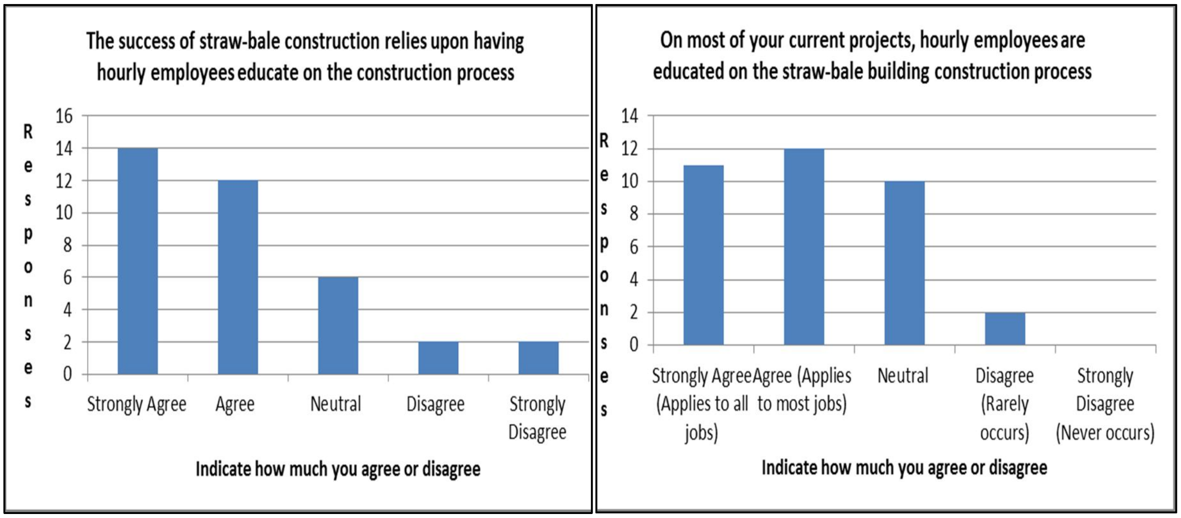


Figure 6.27 Utilization and Involvement of Hourly Employees

6.6.5 Construction Methods

The interpretation of the results to Figure 6.28 can be related to Figure 6.17. It must be considered that the responses indicate that the majority of projects utilize straw bale for insulation purposes, and therefore are placed within structural framing. It is evident that this is a successful method of construction and it is further enhanced by the fact that they agree or strongly agree that the type of structural system affects the ease of construction.

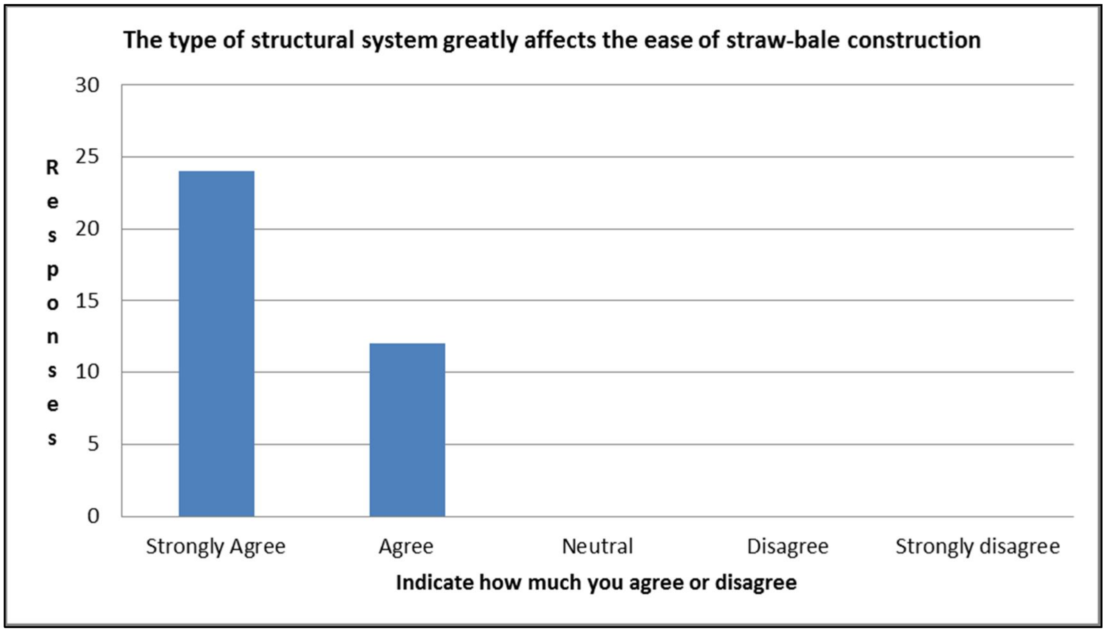


Figure 6.28 Impact on Type of Structural System

The results of Figure 6.29 indicate the relative ease of construction for the various structural methods that may be utilized for a straw-bale project. It is immediately evident that timber framework is the preferred and "easiest" method to utilize, whereas straw bales bonded with mortar is inversely considered the most difficult method. The results for stacked bales supporting all loading are rated closely in each category ranging from difficult to easy. Lastly, the responses regarding steel and concrete framework are nearly equivalent, with a large discrepancy between those that believe it to be most difficult, while others believe it to be quite easy.

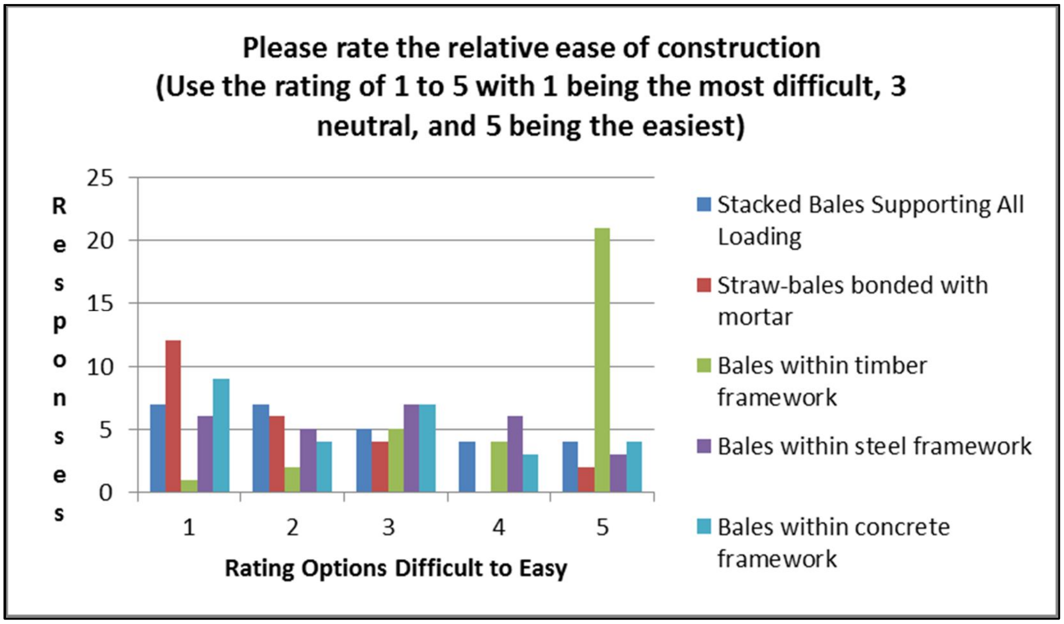


Figure 6.29 Relative Ease of Construction

6.6.6 Perception of Straw-Bale Construction Benefits

Though straw bales are a highly affordable construction material, it is interesting to find from Figure 6.30 that of those professionals surveyed, the vast majority do not believe it is an overall cost saving measure. The results of this question should be considered to only involve upfront and construction costs. Again, this is likely attributed to the fact that it is a labor intensive construction method. If the labor is not affordable, skilled, efficient, and familiar with the building techniques, then the labor and overall costs will quickly rise. Should straw-bale construction continue to grow, it is likely that the method will prove to be a more affordable option as the familiarity and skills of those involved continues to increase.

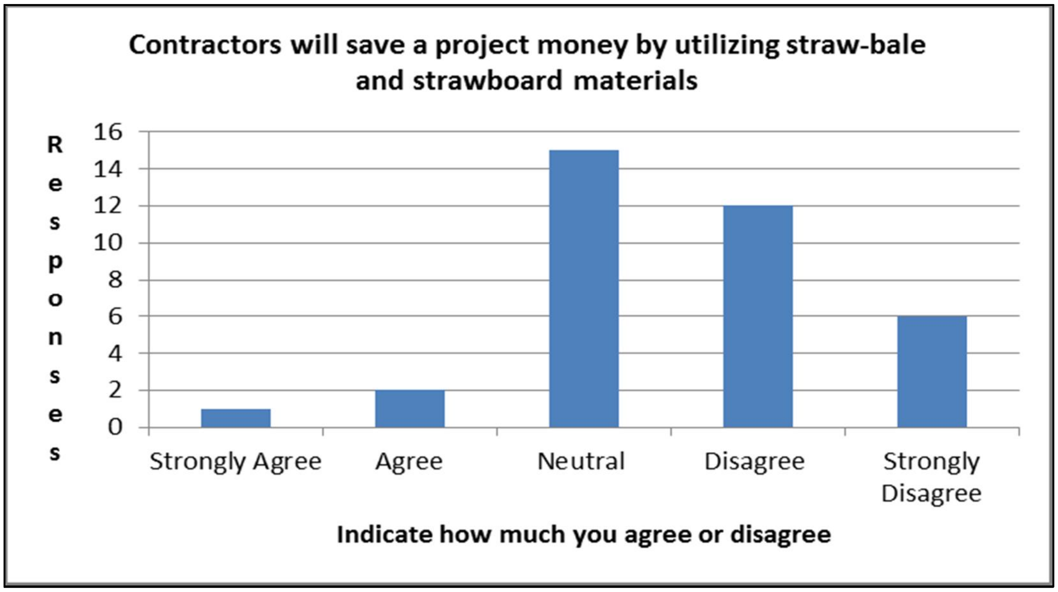


Figure 6.30 Will Contractors Save Money

The results of Figure 6.31 expand upon the previous question and consider the operational costs and energy savings of a straw-bale structure after the completion of construction. Though the experienced straw-bale professionals did not agree that the material would cut costs during construction, they overwhelmingly agree that the owners will experience energy savings throughout their period of ownership. This is again relevant to the great insulation capabilities of straw, and explains why the majority of its use is directly for insulation purposes.

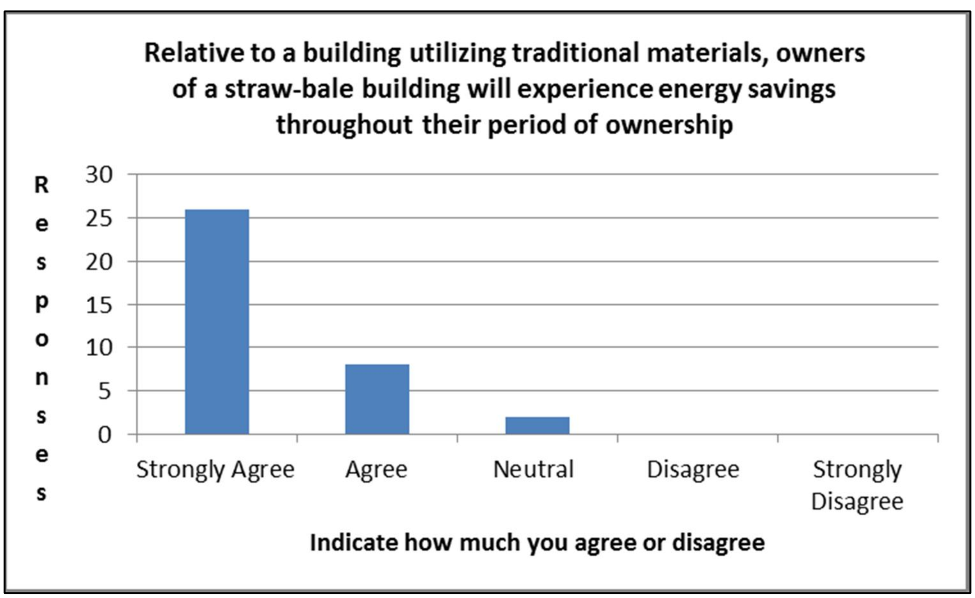


Figure 6.31 Will Owners Experience Energy Savings

Positive results from Figure 6.32 indicate that an overwhelming number of professionals agree that a straw-bale building will yield a reduction in carbon-based greenhouse gas emissions. As many of the straw-bale projects target the environmentally aware owner, this is quite obviously a necessary trend. In a following section, a life cycle assessment will evaluate the environmental comparisons of various building options during construction phases.

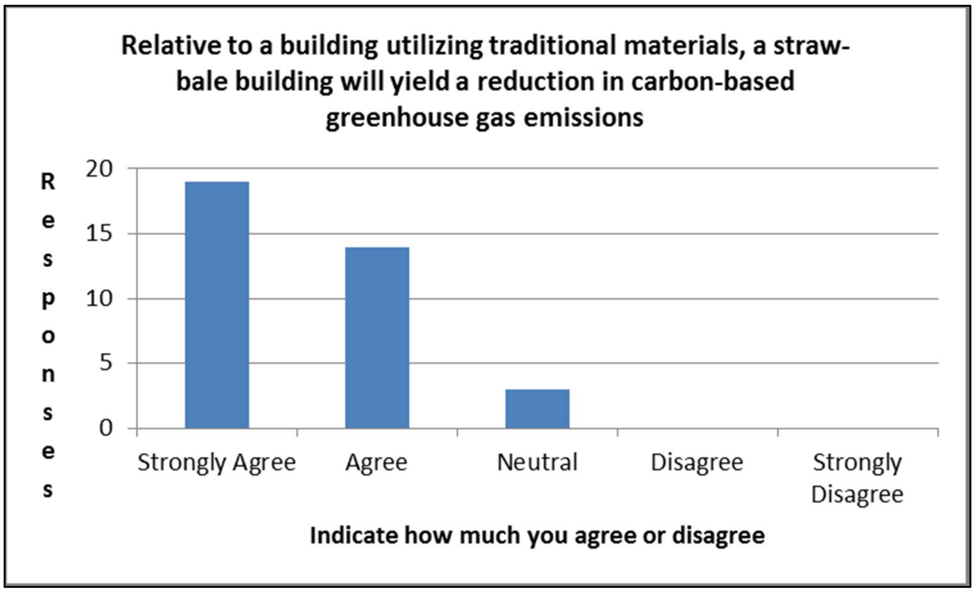


Figure 6.32 Reduction in Greenhouse Gas Emissions

Experience throughout this project has displayed evidence that those professionals involved with the straw-bale industry are willing and eager to advance the practice. Figure 6.33 displays that for all questions regarding lessened fire risk, sufficient structural integrity, sufficient waterproofing, and providing an improvement upon the "sick building syndrome", the respondents overwhelmingly agree that a straw-bale project would provide a favorable improvement in comparison of traditional materials. While recalling the honesty displayed in other questions, in particular the economic factors of a straw-bale project, the truthfulness of the respondents should not be questioned, and the validity of these benefits should be trusted.

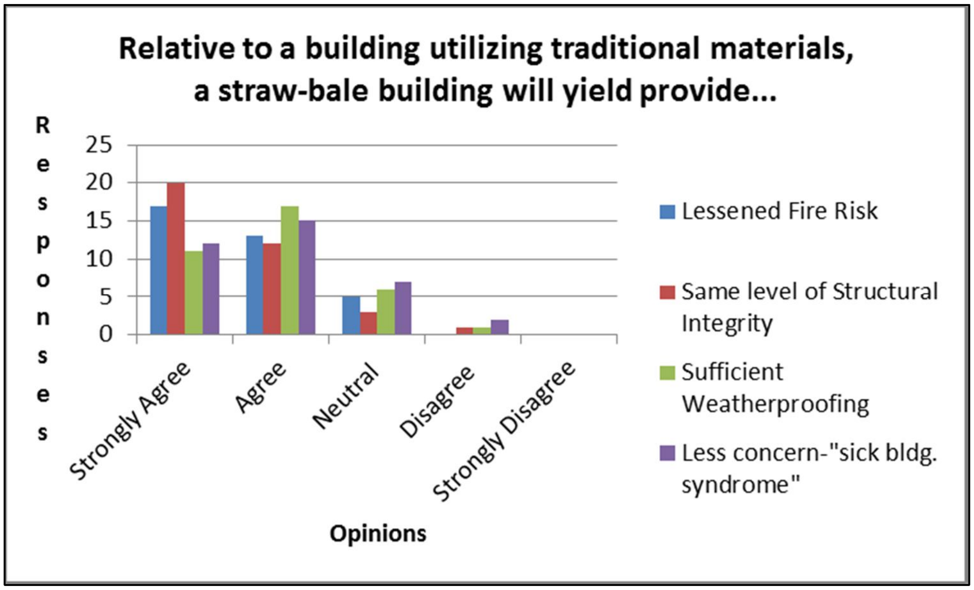


Figure 6.33 Comparison of Common Building Performance Measurements

6.6.7 Aspects of Construction Management

Data in Figures 6.34 to 6.36 consider the possibility of a relationship to aspects of traditional construction projects prior to building phases. Though it may be practiced and some professionals are found to agree, it is not necessarily conclusive that there exists any added benefit provided by establishing straw-bale costs prior to a pre-bid meeting. Additionally, the professionals tend to have a neutral opinion regarding the impact that the type of project delivery system may have a significant impact upon the success of a straw-bale project. Of the options provided, the Design-Build construction method appears to be preferred. On the other hand, the traditional hard bid (low bid general contract) is the least conducive method for a straw-bale project.

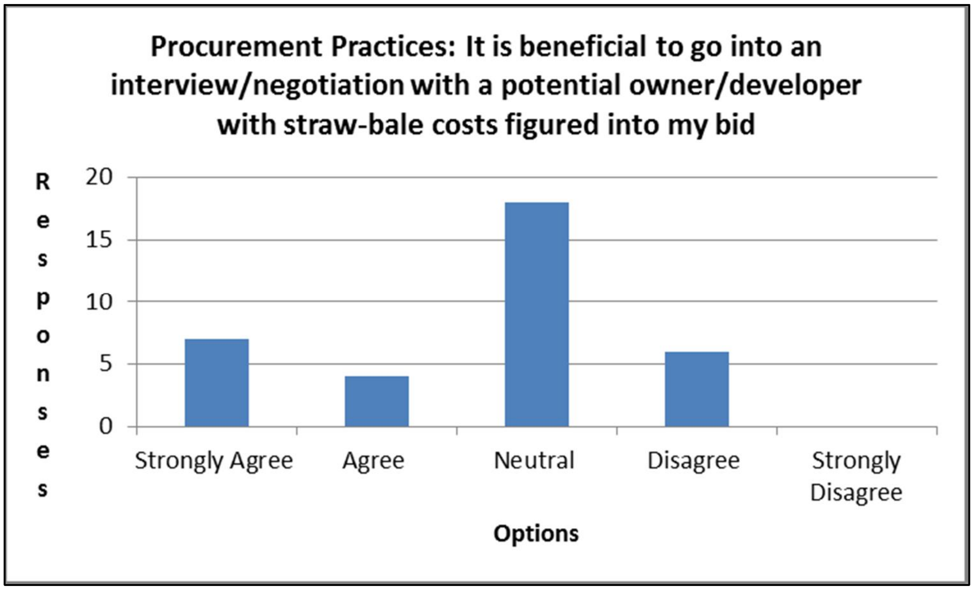


Figure 6.34 Procurement Practices

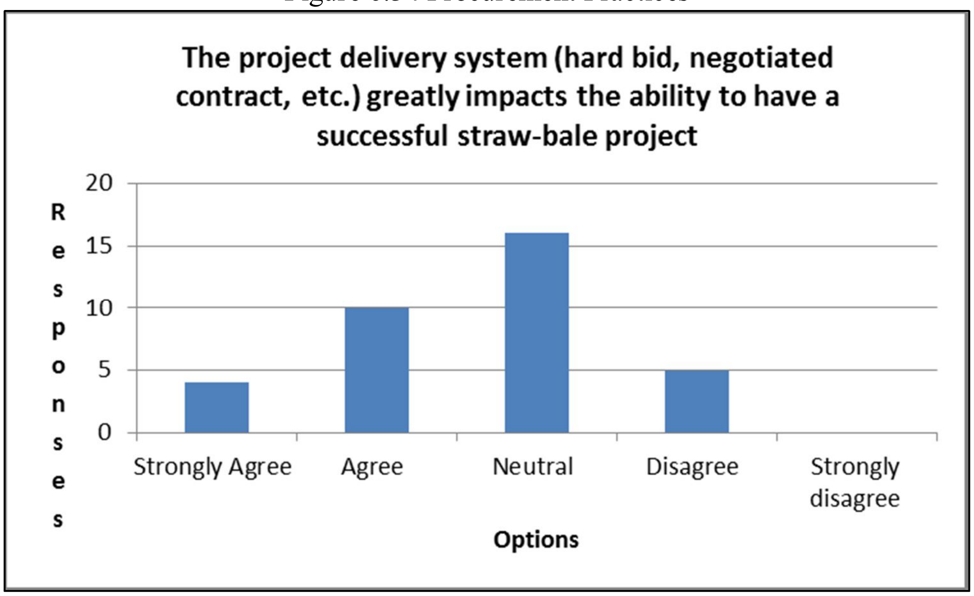


Figure 6.35 Project Delivery System

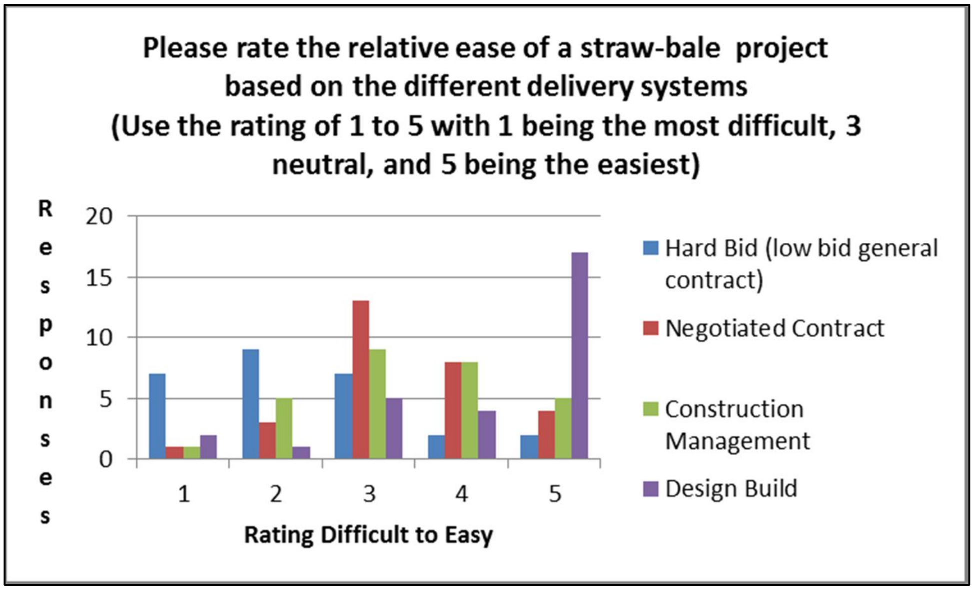


Figure 6.36 Relative Ease of Delivery System

As evident from Figure 6.37 and 6.38 the experienced building professionals strongly agree that the timing of the decision to utilize straw as a building is crucial to the success of the project. Furthermore, their experiences have provided that the design period is noticeably the most suitable time period for implementation. After the decision is made to utilize the material, and design phases have been completed it is necessary to select the method to acquire the bales. Figure 6.39 below displays that the most common method is to have the bales delivered from the field, and purchased by a per bale basis. A small percentage of respondents have the capability of purchasing the bales directly from the field, though this is likely dependent upon the location of the project in relation to bale wholesalers.

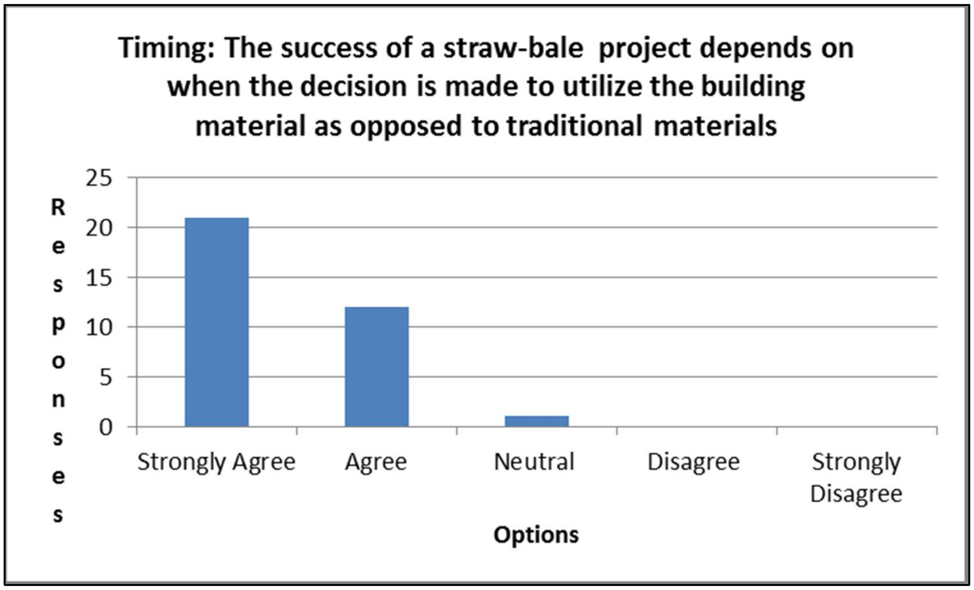


Figure 6.37 Timing of Decision to Utilize Straw Bales

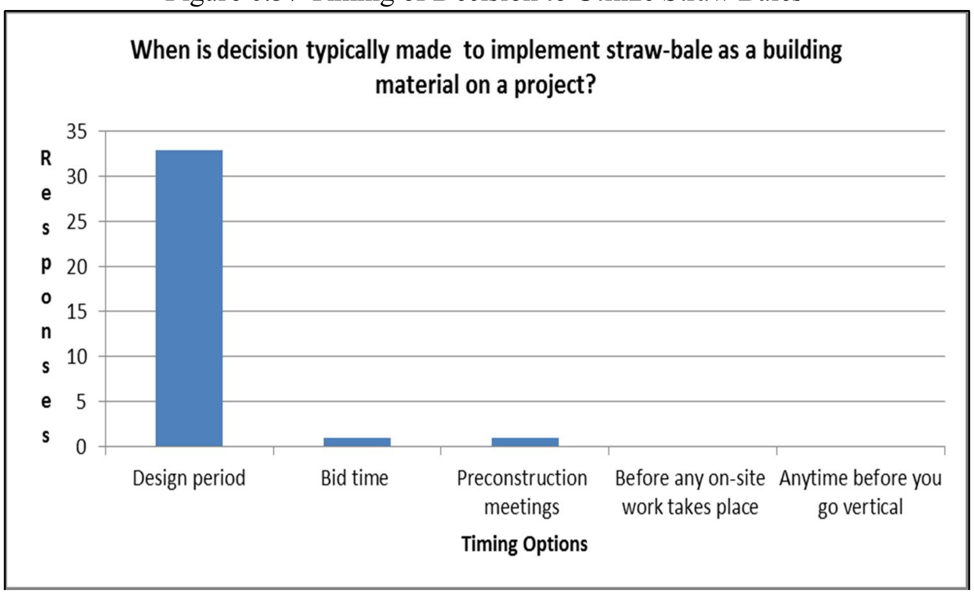


Figure 6.38 Decision to Implement Straw Bales

As it is established that bale delivery is the primary method to acquire the building material, building professionals were asked to indicate the price and quantity that they are paying for straw-bale building materials. From a variety of responses, it was ascertained that though there are several factors that impact price, the bales typically range from $3.00-$6.00/bale. Seasonal and rainfall changes affect costs, as does the rise and fall of the diesel that powers the combines. It appeared common that the SB professionals would typically purchase 300-500 bales per project. In certain cases, bales were purchased in quantities of 1500 and even 3000 bales.

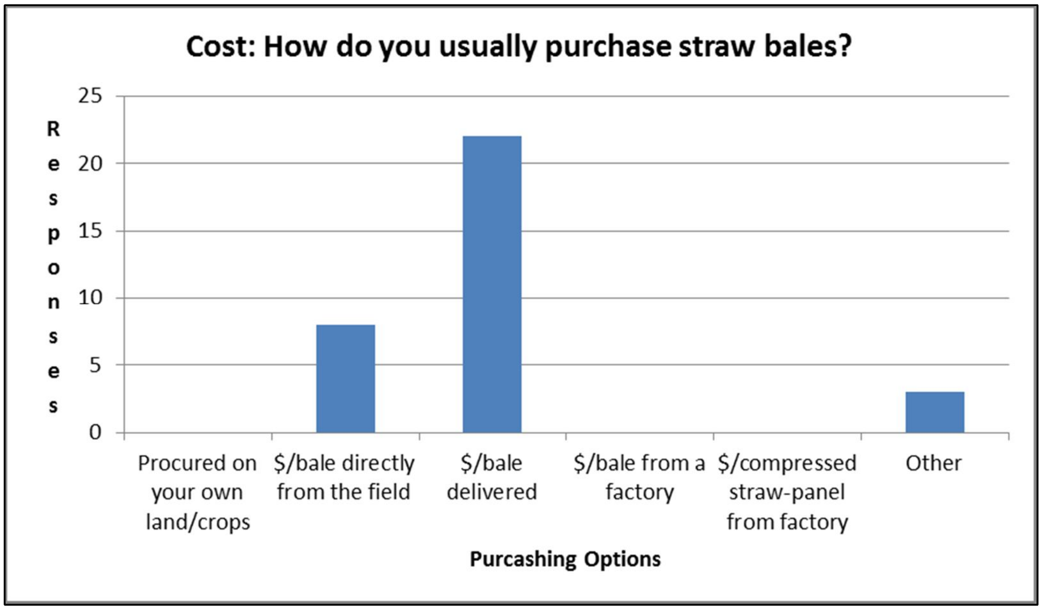


Figure 6.39 Method of Purchase

6.7 Key Results – Survey NE

6.7.1 Company Information

The following results were derived from the question responses given by those professionals queried in Survey NE. Once again, this survey was directed solely to firms and professionals who were not expected to have any previous straw-bale construction experience. The questions served to inquire as to whether the professionals would be inclined to become involved with the straw-bale industry and to gauge their preconceived notions on the feasibility of the practice. As it turned out, roughly 14% of the professionals had in fact possessed previous experience on a straw-bale project. In either case, one commonality shared amongst all of the professionals is a proven dedication to green building practices. An initial question inquired whether in their opinion it is necessary to be educated and regularly practice "green" construction techniques in order to remain competitive in the industry. As may be expected, 100% of the respondents believed this is a necessary endeavor.

The responses displayed in Figures 6.40 to 6.42 show that the “green movement” in construction is clearly established, as well as provides an illustration of the various ways that it may be enticing to builders. The vast majority of respondents indicated that their firms regularly conduct employee training on sustainable, innovative, and/or alternative construction practices. It is evident that the majority of the professionals surveyed strongly believe that addressing various steps to ensure that a project would be considered “green” is a worthwhile endeavor, and that it is a practice they implement on most of their projects. The results of Figure 6.42 demonstrate a vast array of incentives that provide the driving force for implementing green practices. It is encouraging to notice that most professionals identify that it is simply the responsible thing to do. Similarly, in many cases the owners are in agreement as it becomes their request to take green measures within the construction project. Many respondents believe that it is a worthwhile endeavor for their firm to broaden their skill set, as well as appear more marketable to the general public and future clients. In addition to LEED certification it is evident that accreditation is a significant incentive as many of the Canadian homebuilders stated the following motivations in the other option: Built Green Alberta, NAHB Certified Green Professional, NAHB Green, and R-2000 Builder & BuiltGreen member.

Though these questions to do not possess a direct correlation to straw-bale construction, it can be inferred that a building industry that does not place a prominence on green practices would be less likely to attempt new construction methods. Therefore it is likely that those directly involved within the straw-bale industry would be encouraged by such results. One question did however directly pertain to the straw-bale industry as it was asked whether their company would consider becoming educated on straw-bale construction to be a beneficial endeavor in order to remain competitive in the industry. Of those responses, 53% indicated an interest in at least becoming educated further on the practice.

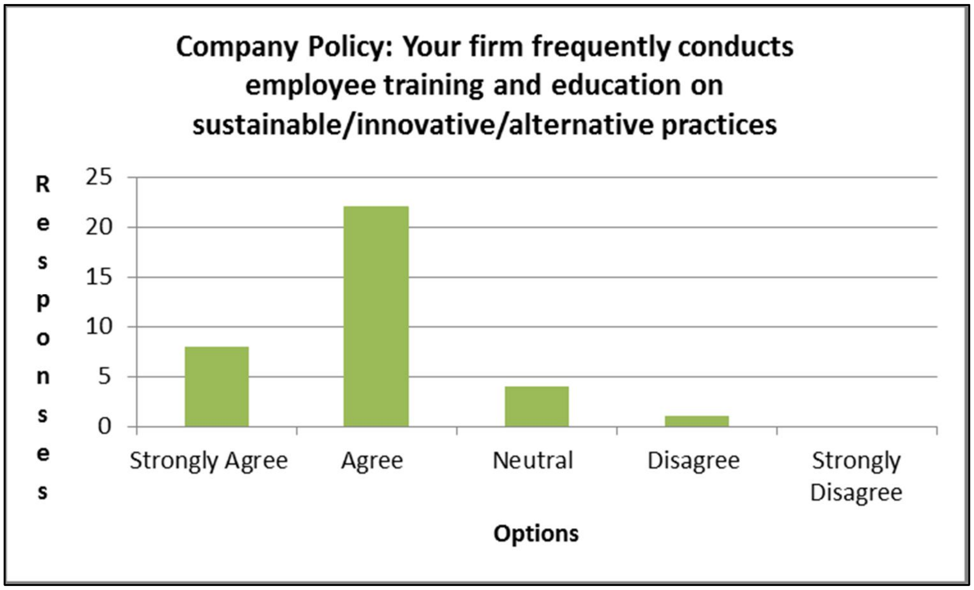


Figure 6.40 Employee Sustainability Training

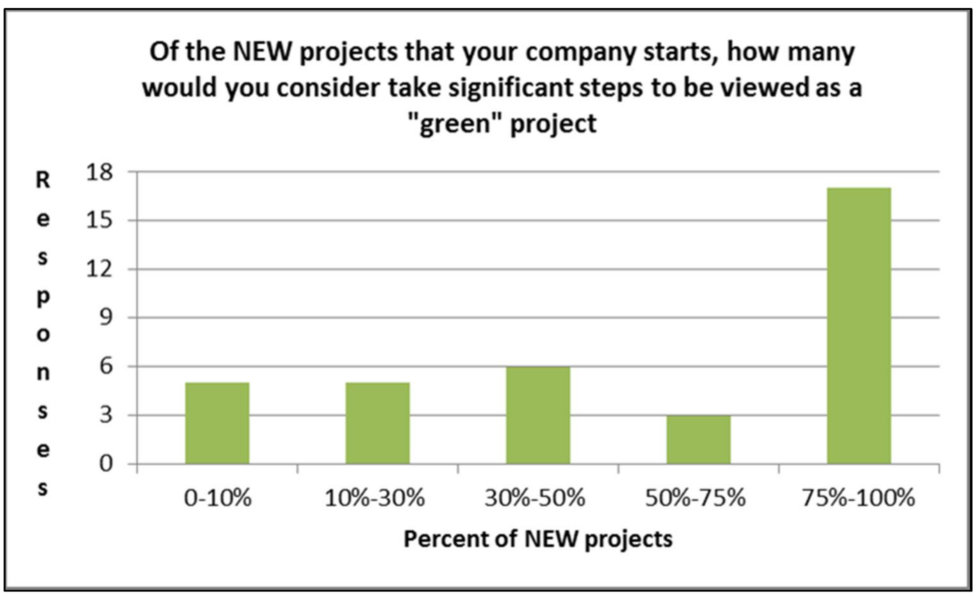


Figure 6.41 Number of “Green” Projects

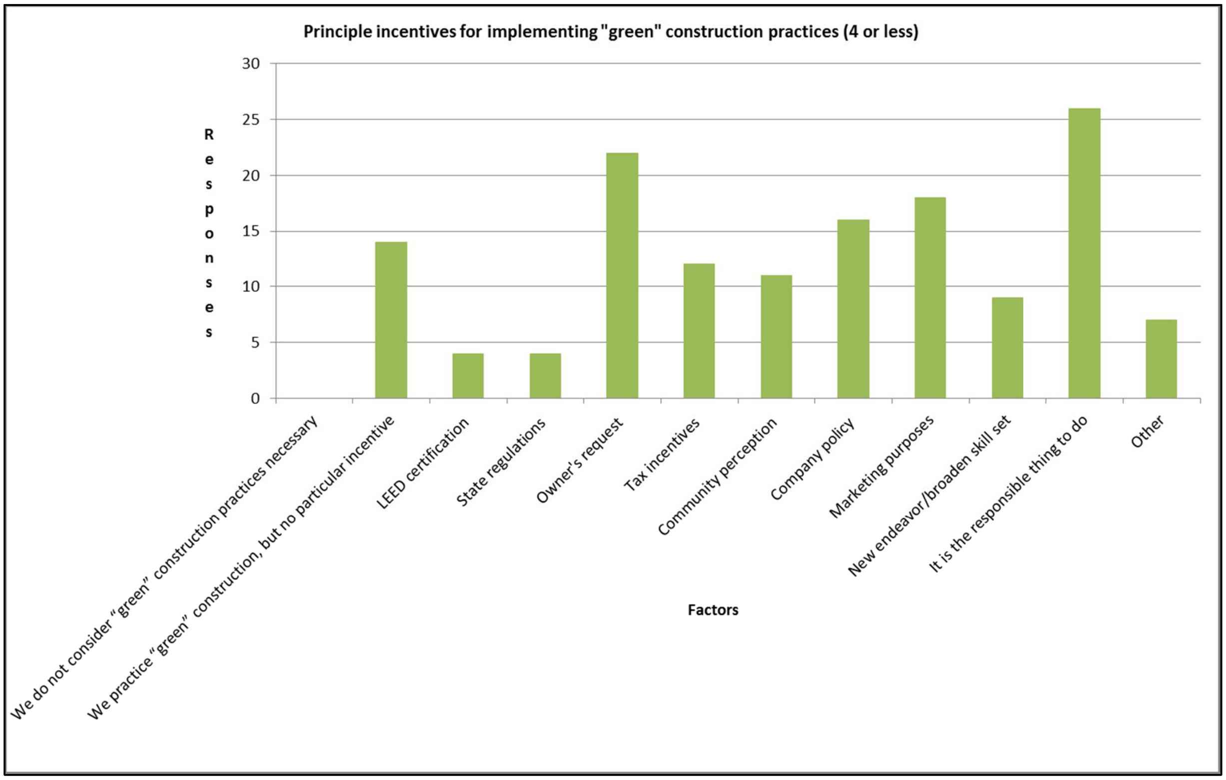


Figure 6.42 Incentives for Implementing "Green" Practices

6.7.2 Perception

The following questions begin to detail the perceptions of a straw-bale construction project. While it has been established that the professionals place a great deal of credence on sustainable construction, it was initially uncertain as to how this may translate into straw-bale construction. As is evident by Figure 6.43, more than half of the professionals are neutral or do not agree that the public perception of a straw-bale project would be a positive one. Clearly this is a significant factor that must be addressed in order for the industry to grow. In conflicting results however, Figure 6.44 offers that the majority of those professionals believe that the utilization of straw bale as a building material would contribute positively to a project focusing on sustainable practices. There is noticeably a disconnect, as it has been established that a primary incentive to pursue a green project is for a firm's public perception, and though straw bale would positively contribute to such a project, it is believed that the public would not possess a positive perception of a straw project. A determination as to specifically why the professionals do not believe the public would be tolerant of a straw-bale project could become a very constructive discovery.

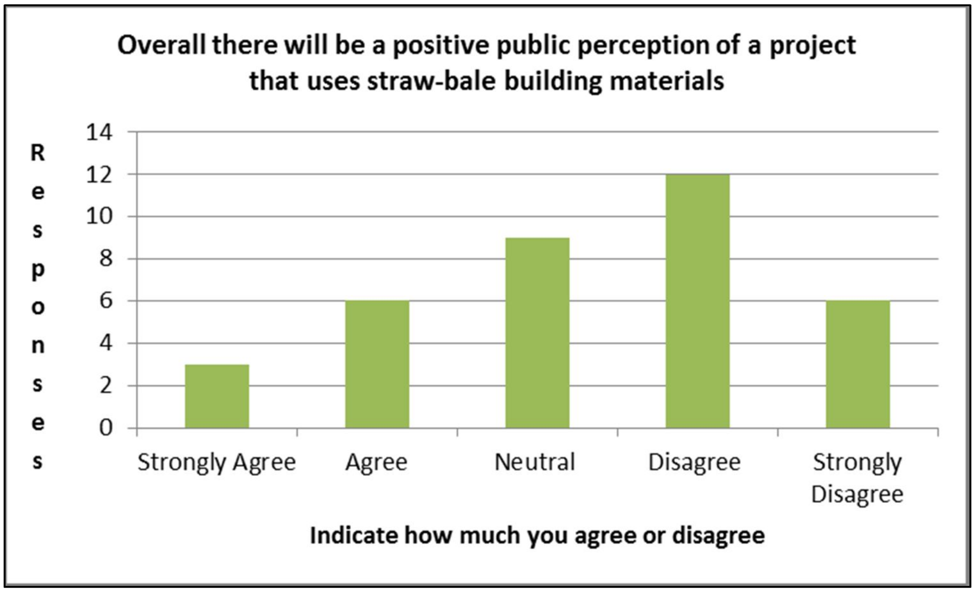


Figure 6.43 Public Perception of a Straw-Bale Building

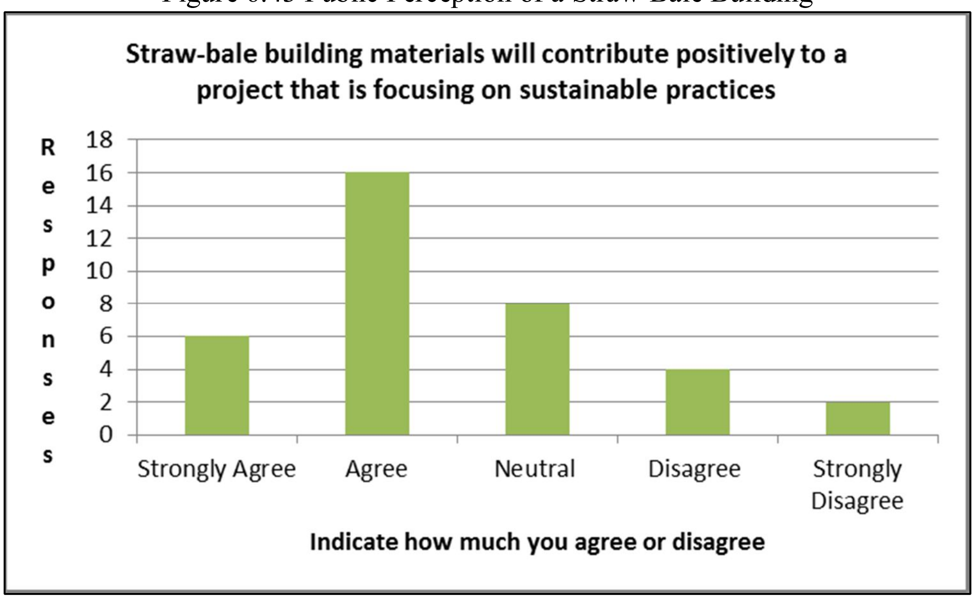


Figure 6.44 Positive Contribution to Sustainable Project

One of the factors that may make professionals weary regarding the public perception of a straw-bale project could be established in the results of Figure 6.45. As it is revealed many professionals agree that straw-bale construction has a perception of being a “hippie” and unprofessional endeavor. It is understandable that the accessible nature of straw-bale construction methods, as well as the historical practices of charitable and self-building could shed such a light on the profession. It is a goal of this project to ensure to those who may be skeptical of the professionalism that there is a great deal of educated and experienced professionals involved with the straw-bale industry. With a reference to Figure 6.4, the majority of professionals responding to Survey SB who have achieved straw-bale experience are most likely to associate their firm with the educated professions of general contractor/construction management, engineer, or architect. Such results should establish that those highly educated and skilled professionals are the ones currently supporting and advancing the industry.

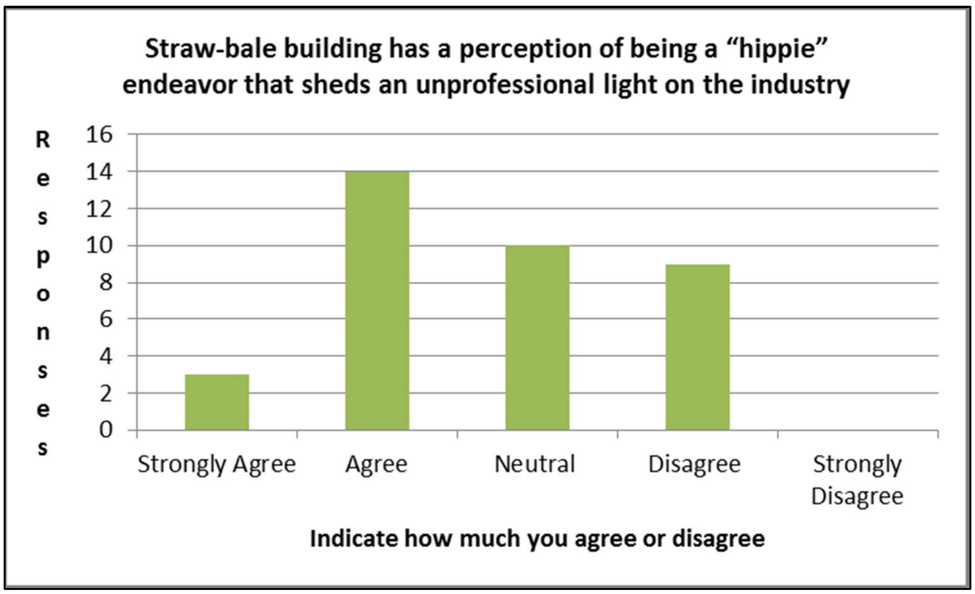


Figure 6.45 "Hippie" Perception

6.7.3 Geographic Feasibility

Lastly, Figure 6.46 asks the professionals whether they believe that straw-bale construction is equally utilized throughout North America. The vast majority of professionals were in disagreement with this statement. Based upon Figure 6.1 it is evident that there is not an even distribution of straw-bale firms and projects throughout North America. On the other hand, the varying climates and locations where current straw-bale structures do exist proves that it could be a feasible construction method in any location. It is simply a matter of properly marketing and expanding the industry to those regions where it is not currently abundant or present.

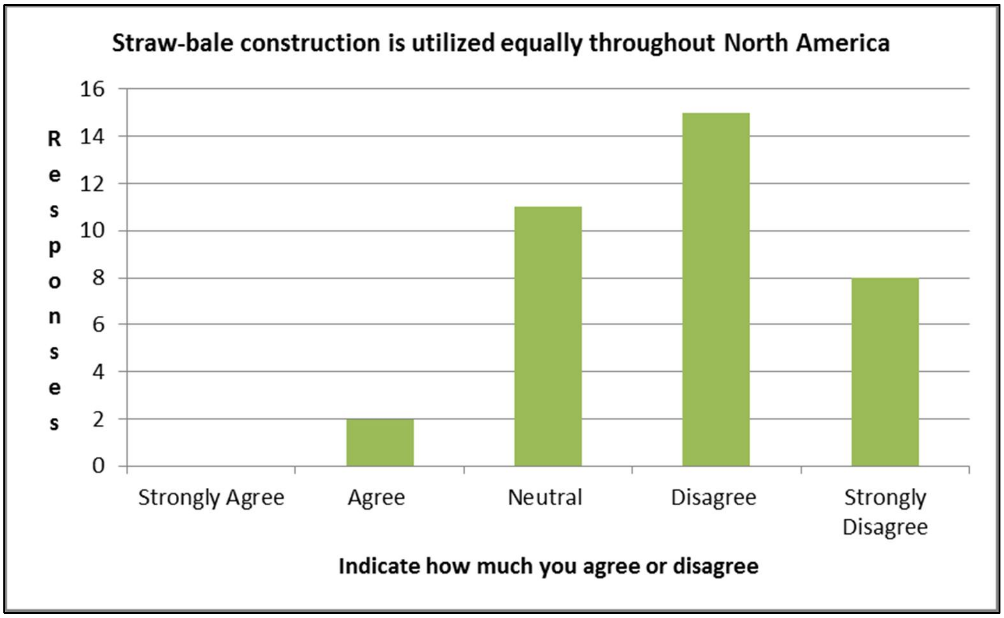


Figure 6.46 Equally Utilized Throughout North America

6.8 Additional Email Commentary

In addition to the completion of the survey, many professionals offered additional commentary through email. In one special circumstance, a building professional from a Saskatchewan residential building firm generously elaborated on their green building experiences. This particular professional was employed by a firm in Canada that has displayed a commitment to expanding their company's green education and experiences. Even though they were involved with Survey NE, it turned out that they have experience with straw building. The professional shared that through her previous projects, she has come to the realization that "straw bale is not the greatest and these items need to be addressed before it is something that will really take off". The building professional even went so far as to apologize for her negative outlook on straw building, though I reiterated that that goal of the project was to compose an open-minded and objective investigation into the industry.

The first concern that the building professional detailed was that straw bales require a large percentage of square footage for wall area, and therefore the house has to be 20% larger to get the same amount of living space as a conventional house. For example, if you are building a house with 2000 sq. ft. of living area, your foundation will have to be 2400 sq. ft. to accommodate the wall thicknesses. This becomes a significant increase in cost, not only for the foundation, but for the framing as well. The professional went on to state that it is an "awkward way to build", as you are not dealing with standard lengths such as inches, but with bale sizes or portion of bale sizes. She believes that when you build, everything should be based on accuracy, but with a straw-bale house, it is very difficult to be accurate because of the random sizes of bales. It is a complaint such as this that may significantly be aided by the composition of a building standard.

Additionally, the building professional stated their weariness regarding mold growth within the bale walls. She stated an example of a home recently built near her firm where the bales became wet during construction, and then were rendered and mold growth became an issue later on. Though this statement is valid, the measures addressed in the paper regarding moisture conditions and precautions should compensate for this scenario. Next, the professional addressed her concerns of fastening a wood frame roof to straw bales. She fears it is not cost effective nor is it structurally sound, and went on to state that "it will be interesting to see how many of these houses have major problems twenty years from now." Though structural integrity is clearly a valid concern, and a common one within straw-bale construction, fears should be mitigated by the examples provided by those old Nebraskan buildings, which are still standing. Lastly, though entirely subjective in my opinion, the building professional believes that "we have yet to see an attractive straw-bale house. It seems that any element of good design or aesthetics gets left out of the equation." The building professional's closing remarks stated "the overall economics just don't make sense when there are many other 'green' options out there, which are every bit as good and a lot cheaper".

I received several follow up emails from other building professionals that echoed similar sentiments and concerns with straw bales utilized for construction. Whether or not one agrees with the arguments stated by those survey respondents, the viewpoints must undeniably be viewed as beneficial to the project. It is quite likely that the concerns they shared are aligned with thousands of other building professionals throughout North America, and if straw-bale construction is to overcome such stigmas, remediation to these concerns must be addressed.

One of the most beneficial contacts was that of Dmitry Ozeryansky who has earned a Master of Science in Structural Engineering. As the principal of Ozeryansky Engineering Sustainable Structural Design in Memphis Tennessee, Dmitry was surveyed for his experience with straw-bale construction for Survey SB. After the completion of his survey, Dmitry contacted me to request a phone conversation. He explained that though he has not directly designed a straw-bale structure, he did possess experience in the realm of straw building. He had recently been commissioned to compose an ASTM Standard that addresses agricultural fibers, including straw bale. The intention of the standard, which is displayed below is to serve as a guide to agricultural fibers in building materials and products. It is of particular significance because it is the first ASTM standard to mention straw bale, or even straw explicitly as a building material.

Work Item: ASTM WK30419 –
New Guide for the Use of Agricultural Fiber in Construction
1. Scope

This standard provides guidance for the use of agricultural fiber in building products. There is a great range of agricultural products in various stages of development for a great range of building products. This guide primarily addresses the use of the residues of food production, such as straw and seed hulls, but also includes the use of plants or plant parts grown specifically for their utility, such as hemp and bamboo. This guide explicitly does not cover the use of wood or other forest products, which are covered by many other standards. The construction industry has always been by far the biggest user of physical materials, and the products and by-products of farming have always been a part of the builder's palette. In the past few centuries, natural fibers, oils and ashes have fallen from favor with the advent of the Industrial Revolution and its signature, intense use of fossil fuels. With the supply and cost of those fossil fuels becoming increasingly uncertain, materials dependent on them as feedstock and/or production energy will become more expensive and their supply uncertain. In this context the renewed use of agricultural residues, especially for insulation and structure, becomes more and more appealing: supplies of oil and gas will vary, but for so long as we grow food we will have agricultural by-products, and usually from nearby. This standard guide will provide a framework within which a great number of products now in development can enter the marketplace, such as fibrous blocks and panels, hemp insulation, bamboo, and straw bale buildings.

Bruce King, a member of the California Straw Building Association and founder of the Ecological Building Network, was previously a colleague of Dmitry's within the same structural engineering firm in the San Francisco Bay area. Bruce received a governmental grant to develop an ASTM standard for straw bale, with the intention that it would garner more attention towards the industry. The hope was that with this standard, more funding would ultimately be directed towards the establishment of straw-bale construction. Bruce, along with other advisory board members of CASBA, was to be responsible for the composition of the standard. However, in recent months their efforts were redirected towards Haiti, as nearly all professionals involved with CASBA were on location building straw-bale homes to help with the relief aid from the earthquake of 2010. Due to the fact that Bruce King had other responsibilities with Haiti, Dmitry was subcontracted to write the standard.

During our phone conversation in January, I had the unique opportunity to discuss my intentions of this project with an individual seeking similar results. The initial draft of the standard was to be submitted in March, and at that point he was in search of input regarding how to most effectively achieve the desired outcomes from the standard. Dmitry expressed that one of the primary issues hindering the development of the straw-bale industry is that most materials, e.g. timber and steel, which are standardized are in capital intensive industries that compete against each other in a market that can support testing. Unfortunately, straw bale does not have this advantage. Considering the other materials, as more money is generated on the material, then more money can be invested in testing leading to a progression of the material. With this being the case, it is very difficult to legitimately introduce and establish new and competitive building materials. Additionally, the building sector is a very conservative industry and remains highly dependent upon appraisals, insurance and labor, and is therefore resistant to new technology. Currently though, Bruce King has completed ASTM fire testing on straw bale, which is clearly a step in the right direction.

Dmitry went on to express that the goal of his project was to develop a straw bale and agricultural material standard, and not a building code. Standardizing terminology, and classifying products was an easier feat, but the ability to specify performance requirements would prove to be a significant challenge. Furthermore, he believes that straw-bale construction in the United States will have an uphill battle due to the fact that it is so labor intensive and so difficult to standardize. Though the current economic situation in our country may provide labor at a more affordable price, it is still more feasible in developing countries where labor is cheaper.

An additional benefit to contacting Dmitry was the inclusion of an email trail directed to the Task Members involved with the composition of the building standard, which included Bruce King. As mentioned, Dmitry wished for feedback from those interested in the development of a straw-bale standard, so that it would not only be effectively written, but fully able to aid in the future development of the industry. The email may be found in the Appendix of this document.

An established architect with nearly 20 years of straw-bale construction experience replied to Dmitry's inquiry stating that the most essential needs of the building standard would be to clarify what would qualify as a "bad" unprocessed agricultural fiber. Specifically for straw bales this would require the following:

1. the straw is not weakened by rot
2. the straw is not so moist that it can support the microbial growth that rots it
3. the straw is not chopped short in processing, as some threshers do
4. the stems have not been crushed in processing, as some threshers do

The architect confided that *any* fiber meeting these criteria will be sufficiently insulating, offer structural integrity, etc., (when correctly baled) for building purposes. To ensure these details are met, a field test could be devised for (1); a bale moisture meter would suffice for (2); and visual inspections would suffice for items (3) and (4). Ultimately, the architect believes that the primary benefit of the standard could be utilized in material specifications on projects, and as a useful tool able to guide those interested in purchasing bales for construction purposes.

A professor of Civil Engineering from Santa Clara University, who holds a PhD and is currently researching the seismic design of "green" materials followed up the architect's email to state the benefit of adding quantitative limits that describe the characteristics that the standard is seeking. Specifically for straw bales, all bales used in building construction would have a moisture content not exceeding x and moist (or dry) density not less than y. Additionally default R-values could be established for either the straw alone or for different straw-bale assemblies with different specified plasters, that can be used in lieu of experimental tests. The professor suggested that enough information has been captured in proven building experience, as well as testing, that now it is simply a matter of putting it into an enforceable format.

The final commentary was provided by an additional architect who has experience with straw-bale construction, design, and testing since 1995. Additionally, this individual has been involved with the development of building codes for sustainable building materials and systems since 2001, and is a contributing author of the book "Design of Straw Bale Buildings". The architect has helped introduce straw-bale construction to earthquake-affected Pakistan with the organization Pakistan Straw Bale and Appropriate Building, and has just recently returned from Haiti with a team from the Earthquake Engineering Research Institute to represent Builders Without Borders. This architect also agrees that existing testing, for example the 1998 Oak Ridge Tennessee testing should serve as a starting point. The specifications of the bales used in previous testing should serve as the characteristics for the ASTM standard guide. He went on to caution that specifications regarding grain types may become too restrictive.

6.9 Survey Conclusions

As this project provided the beneficial opportunity to directly relate to building professionals opinions toward the straw-bale industry, valuable conclusions could be drawn as to the current status of the building material and its associated methods. It was concluded that though the types of firms that may become involved with a straw-bale project will vary, it is frequent for the firms to have very few employees. Similarly, average revenue of less than $250,000 and an average construction budget in the range of $100,000 to $500,000 are common figures for such firms. While the number of professionals involved with such firms is often minimal, the majority are highly educated and likely to be associated with the professions of general contractor/construction management, engineer, or architect.

It was determined that the majority of professionals do not believe that the feasibility of straw-bale building is perceived equally throughout North America. Professionals from both surveys agree that the success of a straw-bale project is dependent upon the geographic location of the project. In an associated observation, the professionals from Survey SB believe that the method is not a fad, whereas those without experience are more inclined to believe it less likely to stand the test of time. While some may be skeptical that straw-bale building will in fact become a method that advances to a common practice those surveyed agree that the practice of straw-bale construction will be aided by the passing of time and the awareness of the industry may continue to grow.

Since the primary examples of straw-bale projects are residential, coupled with the fact that majority of professionals involved with Survey NE are solely involved in residential construction it was concluded that the professionals would believe the method to only be applicable to smaller sized projects. On the contrary, there was a broad distribution to the responses regarding whether the size of a project may impact the success of straw-bale construction.

The firms who have straw-bale experience evidently considered the utilization of the material beneficial as nearly 17% stated that their company has a policy that requires the utilization of straw based materials on all projects. More than half of these firms are currently utilizing straw on at least 50% of their projects. Additionally, firms with straw-bale experience commonly have completed at least 10 straw-bale projects, while many have completed up to 40 and 50 straw projects.

While there are essentially four construction methods that may be employed in straw-bale construction not a single firm identified their use of straw bale to be solely structural, while 58% involved the utilization of straw bales for insulation purposes only. A comparison of framing options displays that it is common to employ timber framing on a straw-bale construction project as compared to steel framing. Additionally it was evident that timber framework is the preferred and “easiest” method to utilize. With regards to agricultural options only cereal straw, bagasse, rice straw, were answered to have been employed in North America. Of those parictular materials, cereal straw and rice straw are the only fibers used consistently.

Respondents identified various benefits as being the primary advantages associated with utilizing straw bales as a building material and such results confirm the many advantages that straw bale may offer. The insulation potential of the material was viewed as the most frequent response. Considering the troubling experiences that straw-bale professionals shared, it was quite evident most were related to a lack of experience with the construction process by both subcontractors and the general public. High labor and additional engineering costs coupled with time squandered on unfamiliarity were also concerns expressed by the professionals. In addition, difficulty is present with educating code officials, appraisers, insurance representatives, building inspectors and clients. Many considered it beneficial to build in a region where other visible straw-bale projects are present.

The lack of standardized technical reference materials provides a detriment to the industry. Though straw bales are a highly affordable construction material, the vast majority do not believe it is an overall cost saving measure regarding a consideration of upfront and construction costs. While experienced straw-bale professionals did not agree that the material would cut costs during construction, they overwhelming agreed that the owners would experience energy savings throughout their period of ownership. This may be of significant benefit to the advancement of the industry as the American Recovery and Reinvestment Act of 2009, also referred to as the "Stimulus bill", offers specific incentives based upon energy efficiency. Home builders have the ability to achieve federal tax credits under the Tax Provisions as of 2009 for Conservation and Energy Efficiency. Specifically, $2,000 tax credits are available for home builders designing a new energy efficient home that achieves 50% energy savings for heating and cooling over the 2004 International Energy Conservation Code (IECC) (Recovery Act, 2009).

In a related measure, results indicated that an overwhelming number of professionals agree that a straw-bale building will yield a reduction in carbon-based greenhouse gas emissions. Similarly, respondents overwhelmingly agree that a straw-bale project would provide a favorable improvement in comparison of traditional materials regarding lessened fire risk, sufficient structural integrity, sufficient waterproofing, and providing an improvement upon the "sick building syndrome".

Regarding the procurement of the bales, the most common method is to have the bales delivered from the field, and purchased on a per bale basis. Commonly bales costs range from $3.00-$6.00/bale and they are typically purchased 300-500 bales per project, while in certain cases these values may be greatly exceeded.

The professionals who were involved with Survey NE shared that 100% believe it is necessary to be educated and regularly practice “green” construction techniques in order to remain competitive in the industry. Similarly, the vast majority of those firms regularly conduct employee training on sustainable, innovative, and/or alternative construction practices. When asked whether their company would consider becoming educated on straw-bale construction to be a beneficial endeavor in order to remain competitive in the industry, 53% agreed.

There was a noticeable disconnect that while more than half of the professionals were neutral or in disagreement that the public perception of a straw-bale project would be a positive one, the majority of those professionals felt that the utilization of the material would contribute positively to a project focusing on sustainable practices. In a related question it was revealed that many professionals agreed the straw-bale industry has a perception of being a “hippie” and unprofessional endeavor.

Concluding realizations acquired through the surveys provided that one of the primary issues hindering the development of the industry is that common standardized materials are in capital-intensive industries that compete against each other in a market that can support testing. As more money is generated in the individual industries, additional revenue is generated that may be invested in testing which could lead to a progression of the material. Unfortunately, as of yet straw bale has not received that level of prominence.

Chapter 7

LIFE CYCLE ASSESSMENT (LCA)

7.1 Introduction

As the building sector's technology has led to an advancement of highly educated and specialized professionals encompassing a vast array of unique and versatile skill sets, it has also increased the difficulty for all of those involved to remain in communication. At the origins of straw-bale building, and continuing up until recent decades, those professionals involved in the construction industry were essentially generalists capable of designing and constructing all aspects of a building. Today the design, construction, and maintenance of a building have grown to include a myriad of special trades (Roodman, 1995). Though the development of specialization may positively increase the quality of the work, it creates a disconnect between those who are involved with the initial extraction of the materials from those who receive the final product. As would be expected by the pressures of a deadline based and profit driven industry, professionals are concentrating upon their individual responsibilities, which may include an expedited extraction of a natural resource, lowering upfront costs, or speeding up the design process. As a result, extravagant resource consumption can become a consequence of this lack of communication.

At the onset of the decision to build, one of the first considerations to make is the choice of materials. Each material has its associated benefits and drawbacks. At a minimum, the selection must provide for an ease of use, provide proper insulation, inhibit air and moisture, offer necessary strength requirements, possess fire resistance, have a reasonable price tag, and depending on the owners requirements "look good" (Roodman, 1995). Up until recent decades, a consideration of these selections was sufficient. Though not required, a contemporary and environmentally responsible designer must not only satisfy all of the above requirements, but also consider the ecological detriment associated with their building material selections. The materials may appear to simply be delivered to a jobsite and that's the beginning, but it must be understood that many of these materials have already endured a long process prior to arrival. A material is born into its extraction or manufacturing process, is utilized during its lifespan, and eventually there comes a time where it's recycled or sent to the landfill. Each phase of this process possesses associated environmental, health, and energy detriments.

The primary tool that can be utilized to evaluate these impacts is a Life Cycle Assessment, or LCA. In an LCA, a cradle-to-grave examination of a product is conducted. This tool is commonly implemented in the manufacturing industry, and is not as widely used in the building sector. An apparent example of this can be displayed by the fact that it would be easier to conduct an LCA on a toothbrush or a child's toy than it would be to examine a home, with all the nuts, bolts, 2x4's, and gallons of paint that are involved. Nonetheless, it is evident that the building sector has become associated with environmental degradation, and the utilization of new tools and processes is necessary.

When selecting a construction material, an environmentally aware designer must consider the energy involved in its creation. The energy involved from when a material is made up until the building is completed is known as embodied energy. Operational energy is that which is involved after the building has become inhabited. The embodied energy of a material includes energy involved with is processing, the transportation fuel and emissions, and the pollution that is created. Natural materials that include wood, stone, adobe, and straw have a minimal environmental impact; whereas many modern materials have grown to place far more of a demand on energy and pollution creation (Roodman, 1995).

As it has previously been mentioned, one of the primary goals that this project strives to achieve is to quantify the economic and environmental benefits and disadvantages of straw-bale construction. As a means to measure such values, a Life Cycle Assessment of various residential building options was evaluated. The potential building options and assemblies included mostly timber, mostly steel, and straw bale, and were based upon homes constructed of 2438 sq. ft. This size was selected as it was the 2009 national average for square feet of floor area in new single-family houses according to the U.S. census.

It must be understood that a complete LCA of a home and all of the interrelated components would be a tedious, and nearly impossible task to complete. To account for such measures, databases were utilized with predetermined values. The Athena Institute's EcoCalculator and Impact Estimator were the tools selected for utilization of the LCA, and the inner workings and assumptions of the software are discussed in detail in subsequent sections.

7.2 Environmental Protection Agency-LCA 101

The United States Environmental Protection Agency was responsible for the standardized development of Life Cycle Assessments in this country and recognizes the procedure as a valuable tool for the advancement of sustainable measures. As this technique is not as widely employed in the United States as compared to Europe for example, the EPA provided a document to initiate an introductory overview and means of clarification about the tool. Life Cycle Assessment: Principle and Practice was composed by Mary Ann Curran in 2006 and expanded upon the previous document titled LCA 101 published in 1996. Within this document the four basic stages of conducting an LCA are presented, and provide the basis for the procedure utilized within this project.

While environmental stewardship as associated with business and industry has garnered an increased level of observation in recent decades, there has become a need to quantify such issues. Certainly a company can boast that their product, or in this case newly constructed home, is "green", but there must be a means to allow for objective comparisons. The completion of a Life Cycle Assessment can provide such a solution. As a holistic and comprehensive approach to pollution prevention strategies and environmental management systems, LCA evaluates a product's entire life cycle (Curran 2006). Specifically LCA considers a "cradle-to-grave" approach. This process is initiated by considering all involved raw materials extracted from the earth and culminates in the end result of the product returning to the earth.

Through the completion of an LCA, all environmental impacts affecting each stage of the product's life cycle may be evaluated. The life cycle of a product is considered to include the following: raw material extraction, manufacture, associated transportation, use, maintenance, and final disposal

(Curran, 2006). Figure 7.1 below references the EPA's Life Cycle Assessment: Principle and Practice with regards to the possible life cycle stages that are considered in an LCA.

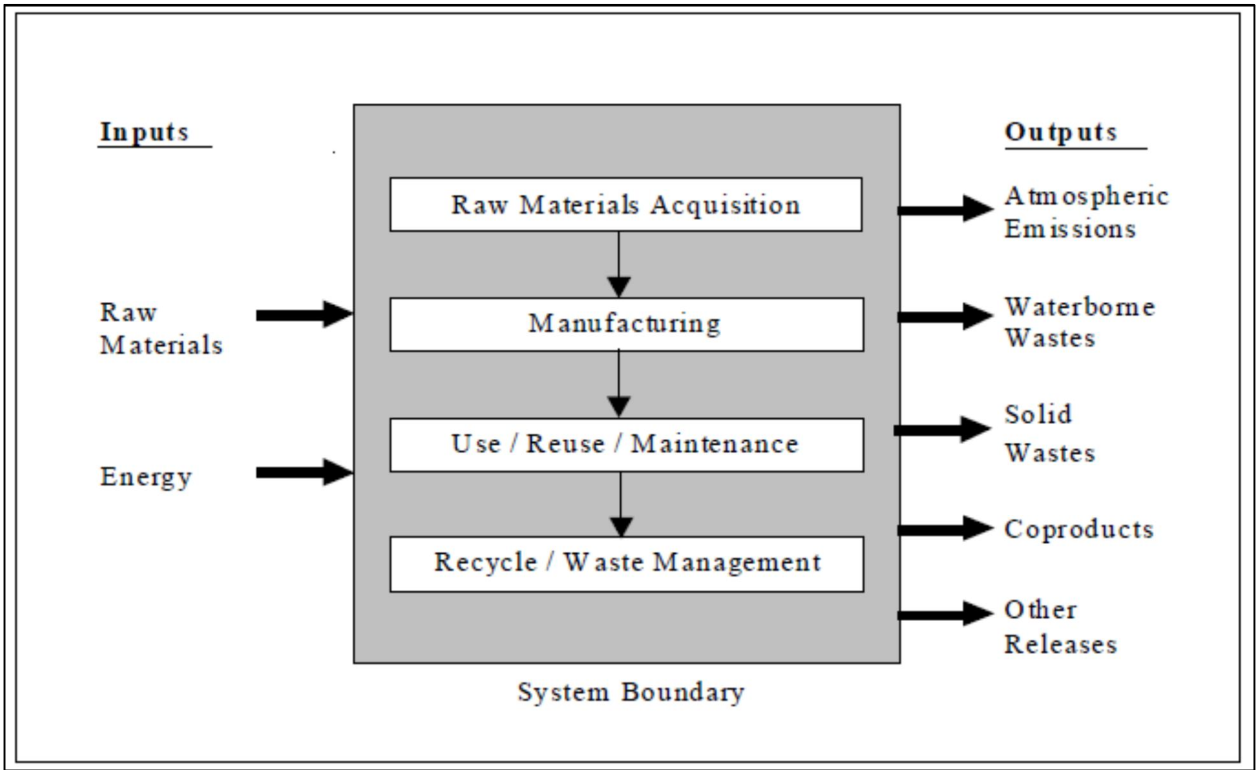


Figure 7.1 Life Cycle Stages (Curran, 2006)

The main achievements provided through an LCA include the following (Curran 2006):

- Compile an inventory of relevant energy and material inputs and environmental releases
- Evaluate the potential environmental impacts associated with identified inputs and releases
- Interpret the results to help decision-makers make a more informed decision

A comprehensive LCA procedure is based upon four primary divisions that include: goal definition and scoping, inventory analysis, impact assessment, and interpretation (Curran, 2006).

In certain cases databases are utilized with such information predetermined based upon previous assessments and information. In such a case, a panel of experts is tasked with making assumptions and assigning values. The Athena Institute employs the expertise of various professionals on their EcoCalculator Advisory Council in order to provide advice and broad-based input from the building community on further development and continuous improvement of their software for life cycle assessment of building assemblies (The Athena Institute, 2011). The members of the Advisory Council encompass representatives from the following organizations:

- Alliance to Save Energy (ASE)
- American Institute of Architects (AIA)
- Canada Green Building Council (CaGBC)
- Green Building Initiative (GBI)
- National Association of Home Builders (NAHB)
- National Institute of Building Sciences (NIBS)
- Natural Resources Canada (NRCan)
- Royal Architectural Institute of Canada (RAIC)
- Sustainable Buildings Industry Council (SBIC)
- US Environmental Protection Agency (EPA)
- US Green Building Council (USGBC)

Within this project, the aforementioned software of EcoCalculator and Impact Estimator has necessary information embedded into the system. For example, values of impacts regarding a timber based wall system are given in the system based upon the vast amount of knowledge and experience using this material. For the examination of a straw-bale home, straw values were not predetermined, and the four divisions of an LCA were required. According to the EPA's document, the four divisions are defined as follows (Curran, 2006):

> 1. *Goal Definition and Scoping* - Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.
> 2. *Inventory Analysis* - Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).
> 3. *Impact Assessment* - Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.
> 4. *Interpretation* - Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

It should also be mentioned that the completion of an LCA provides the ability to "avoid shifting environmental problems from one place to another" (Curran, 2006). Essentially, it offers the capability to identify when an environmental detriment is transferred to another source as opposed to solved or remediated. The EPA offers the example that eliminating air pollution by creating additional wastewater effluent is not a solution. An applicable example to this project could be the transfer of impacts from one life cycle stage to another. For example the impacts from the use and reuse of a construction material instead of the raw material extraction phase.

7.3 EcoCalculator/Impact Estimator Assumptions and Calculations

A major aspect of this project has been described as quantifying the environmental and economic impacts of utilizing straw bale as a construction material. At the onset of this objective it was evident that an LCA would be the appropriate procedure to develop such values. On the other hand, various obstacles were present with this portion of the project. As mentioned, it is one task to develop an LCA on a simple product such as a toothbrush. It is another undertaking entirely to develop an accurate LCA on a complex system of components such as a residential house. It is known that for a complex system it is nearly infeasible to evaluate all of the components individually. To alleviate these concerns, databases of predetermined values are utilized. Though the great detriment that the building sector has inflicted upon the environment has been acknowledged in recent years, an LCA of housing options is not a common practice. In fact, it is relatively unprecedented. Fortunately however, software has recently been developed that can assist an interested party in developing an LCA of a home based upon common building techniques and materials. The Athena Institute has developed the Impact Estimator for Buildings and the EcoCalculator. For the requirements of this project the EcoCalculator and a limited trial version of the Impact Estimator for Buildings were utilized.

The Athena Institute is a non-profit organization that has spent the past decade helping architects, engineers and other professionals to evaluate the environmental impacts of new and existing buildings through life cycle assessment. The group has stated its dedication to improving the sustainability of the built environment by meeting the building community's need for better information and tools. With offices in Canada and the United States, the Athena Institute seeks to advance the use and science of LCA for the building sector through software, databases and consulting services (The Athena Institute, 2011).

Both software options utilize the development of values based upon Athena's datasets and data from the US Life Cycle Inventory Database. The National Renewable Energy Laboratory, NREL, along with the collaboration of its partners created the U.S. Life Cycle Inventory (LCI) Database to provide LCA developers the information necessary to complete their own assessments of building options. The data provided within the database accounts for the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S. More specifically, the EcoCalculator data values take into account:

- Resource extraction and processing
- Product manufacturing
- On–site construction of assemblies
- All related transportation
- Maintenance and replacement cycles over an assumed building service life
- Structural system demolition and transportation to landfill

The distinction has been expressed regarding operational versus embodied energy. The full version of the Impact Estimator has the ability to address both types, though the EcoCalculator is limited to an evaluation of embodied energy. Furthermore, for the sake of this project the evaluation of embodied energy will be a sufficient measure of environmental impact on residential building options.

The EcoCalculator provides an accessible and user-friendly software program that offers architects, engineers and other professionals access to instant LCA results for hundreds of common building assemblies. Essentially composed to replicate an Excel spreadsheet, the EcoCalculator has embedded data that is based on comprehensive assessments that are also detailed in the Athena Impact Estimator for Buildings. The Athena Institute partnered with the University of Minnesota and Morrison Hershfield Consulting Engineers to develop the EcoCalculator. After development, the tool was commissioned by the Green Building Initiative (GBI) for use with the Green Globes environmental assessment and rating system. The Athena EcoCalculator is offered in two versions based upon the needs of the designers. For the goals of this project the EcoCalculator for Residential Assemblies was used, while the option is also available as the EcoCalculator for Commercial Assemblies. The Residential version was developed to assess single family residential buildings.

The most beneficial aspect of the EcoCalculator is it that the foundation of the evaluations is based upon individual building assemblies. Any new construction project, retrofit, or major renovation may be evaluated based upon the following assembly categories:

- Foundations and footings
- Columns and beams
- Intermediate floors
- Exterior walls
- Windows
- Interior walls
- Roofs

With this approach overall building impacts can be established, or more specific individual building assemblies may be evaluated. With the comparisons based upon individual assemblies, problematic areas of construction may be highlighted. Furthermore, as is particularly applicable to this project, the most relevant assemblies can be compared, such as exterior walls. The number of assembly options for each of the above categories is based upon the possible combinations of materials and varies accordingly. For example, the exterior wall category offers nine basic wall types, seven cladding types, three sheathing types, four insulation types and two interior finish options. Each potential combination of these options is available as an assembly option. Regardless of the assembly category, all are assessed on the following performance measures:

- Fossil Fuel Consumption
- Material Resource Use
- Global Warming Potential
- Acidification Potential
- Human Health Respiratory Effects Potential
- Eutrophication Potential
- Ozone Depletion Potential
- Smog Potential

The following section will detail the Environmental Protection Agency's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). Within this tool, the last 6 performance measures listed above are explained, and the methodology used to evaluate such measures is detailed at a greater length. For all performance measurements except Fossil Fuel Consumption and Material Resource Use, the Athena Institute utilized TRACI when developing the values within their database.

Additional enhancements and intricacies to the accuracy of the EcoCalculator are provided by the option to regionalize the data. After the initial selection of residential assemblies was chosen, the next choice considers cities or climatic regions. The following geographic options are offered by the EcoCalculator: Atlanta, Calgary, Halifax, Los Angeles, Minneapolis, Montreal, New York City, Orlando, Ottawa, Pittsburgh, Quebec City, Seattle, Toronto, Vancouver, and Winnipeg. If desired, the user may select the climatic regions of USA Zone 3 or Zone 6. The selection was made to utilize the embedded data for Pittsburgh based upon its relatively central location, considering latitude. Furthermore, it possesses a climate that does not include any particular extremes in rainfall, arid conditions, harsh winters, etc.

After the initial conditions for the building site and type are created for the EcoCalculator, the subsequent steps simply involve assigning square footage values for the appropriate assemblies. If it is appropriate, the software will allow for the selection of more than one assembly type in each category. If such a decision is made, the overall impact measurements will be displayed in combination for the total environmental impact of the category. The outputs of the EcoCalculator are updated in real time and provide both tabular and graphic depictions of environmental impacts based upon the eight performance measurements.

As a supplement to the EcoCalculator, the Athena Impact Estimator for Buildings may be utilized for additional results. Essentially the programs offer the same tools, however the Impact Estimator is more advanced in offering the ability to fine tune the intricacies of the assemblies. With the ability to specialize the assemblies, the Impact Estimator is capable of modeling 95% of the building stock in North America. The software takes into account the environmental impacts of:

- Material manufacturing, including resource extraction and recycled content
- Related transportation
- On-site construction
- Regional variation in energy use, transportation and other factors
- Building type and assumed lifespan
- Maintenance and replacement effects
- Demolition and disposal

An example of the detail that is provided is that while the EcoCalculator simply asks the user to specify the square footage of a 4” concrete slab, whereas the Impact Estimator allows the user to specify the % of concrete fly ash, type of rebar, and psi of concrete utilized within the 4” slab. For the sake of this project since much of the LCA will be based on generalities and assumptions, the intricacies of the assemblies will not be modified, and that which is provided in the EcoCalculator will be sufficient.

7.4 TRACI

As mentioned in the previous section, six of the eight performance measurements that are the means to quantify the environmental impact in Athena's EcoCalculator are based upon the EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, or as it will be referred to from here on, TRACI. The origins and inner workings of TRACI are detailed in a 2003 article within the Journal of Industrial Ecology. In said article, TRACI is described as a stand-alone computer program that facilitates the characterization of environmental stressors that have the following potential effects: ozone depletion, global warming, smog formation, acidification, eutrophication, human health cancer, human health noncancer, human health criteria pollutants, eco-toxicity, fossil fuel depletion, land use, and water use (Bare et. al., 2003). As it relates to this project, only the 6 measurements associated with the EcoCalculator will be considered.

TRACI was created to address the aforementioned issues regarding budget, time, and feasibility issues in the completion of an LCA. In an ideal scenario these factors would not impact the ability to complete the assessment, but as is so often the case the comprehensiveness of an LCA is jeopardized by one or more of these factors. While often data from databases may be utilized, there also exists a necessity to create new values. Such was the case with this project. While the EcoCalculator had predetermined values for timber and steel assemblies, it would not allow for the addition of a straw-bale wall. With the tools presented in Athena, a systematic and impartial ability to create such values is made available.

The environmental impacts found within TRACI are based upon two general types and include depletion categories such as land and water use, and pollution categories such as smog potential. (Bare et. al., 2003). Bare mentions that exact selections of performance measurements and combinations thereof may be decided upon by the tool designer as is applicable to the case study. The factors known as “midpoint levels” become the impact assessment measures within TRACI. Due to the fact that midpoint levels are essentially averages, they have received a higher degree of public consensus regarding their impacts, and therefore the levels are fair and conservative. For example, Figure 7.2 below is taken from the article in the Journal of Industrial Ecology and exemplifies the cause and effect chain of ozone depletion along with the various midpoint impacts levels, such as crop damage.

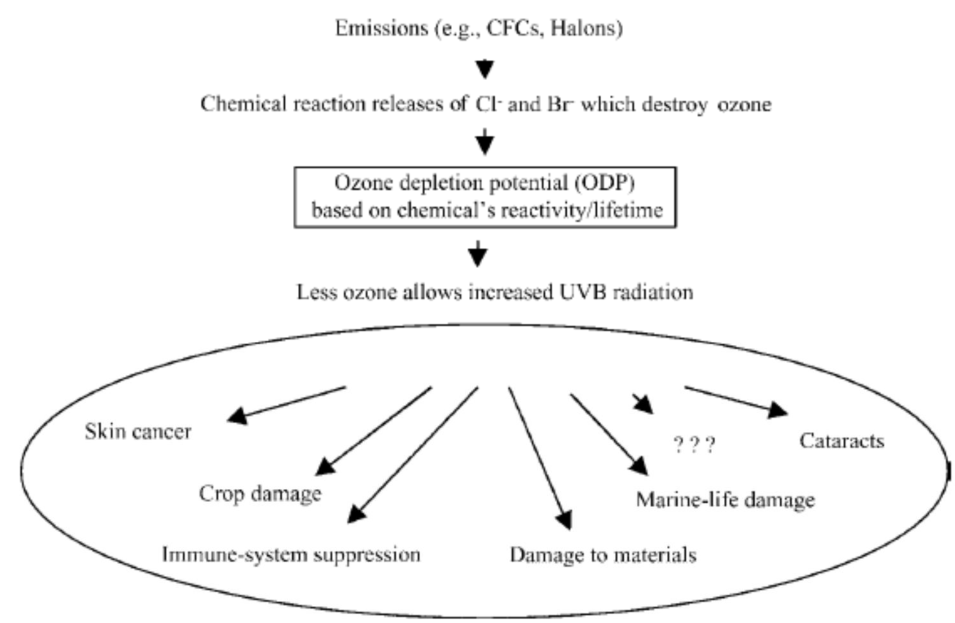


Figure 2 Ozone depletion midpoint/endpoint modeling. The rectangle indicates the midpoint and the oval indicates the endpoints.

Figure 7.2 Ozone Depletion Midpoint Modeling (Bare et. al. 2003)

The most beneficial aspects of TRACI, as well as those most valuable to this project include the ability to set values of performance measurements that can be added to the Athena EcoCalculator. In a subsequent section, the specifics and derivations of such values will be detailed.

7.5 LCA Methodology

With an understanding of the capabilities offered by Athena’s software, as well as an awareness of the goals of an LCA as defined by the EPA coupled with the ability to create and supplement necessary values through the use of TRACI’s methodology, the ability to perform an accurate LCA is established. As mentioned, the LCA will consider three potential housing options. The first will be a home comprised mostly of timber materials, another mostly of steel, and lastly a home utilizing straw bales for the exterior walls. Though varying issues would impact an architect or builder's decisions regarding material selection, these housing options were selected to display the various extremes. Table 7.1 displayed below details the material selections for the various housing options. All selections, with the exception of straw-bale exterior walls for the straw building type are predetermined offerings within the EcoCalculator.

BUILDING TYPE	ASSEMBLY	SELECTION
Steel	FOUNDATION AND FOOTINGS	4" poured concrete slab
Timber		4" poured concrete slab
Straw		4" poured concrete slab
Steel	COLUMNS AND BEAMS	Hollow Structural Steel column / Wide Flange Steel beam
Timber		Wood column / Glulam beam
Straw		Wood column / LVL beam
Steel	INTERMEDIATE FLOORS	Steel Joist w/ OSB Decking
Timber		Wood I Joist w/ OSB Decking
Straw		Wood Joist w/ OSB Decking
Steel	EXTERIOR WALLS	Steel Stud 1-5/8 x 3-5/8 16" o.c. OSB
Timber		Wood Stud 2x6 16" o.c. OSB
Straw		Straw Bales
Steel	WINDOWS	Aluminum - Operable
Timber		Wood - Operable
Straw		Wood-Operable
Steel	INTERIOR WALLS	Steel Stud 1-5/8 x 3-5/8 16" o.c.
Timber		Wood Stud 2 x 4 16" o.c.
Straw		Wood Stud 2 x 4 16" o.c.
Steel	ROOFS	Steel Joist w/ Plywood decking
Timber		Wood I Joist w/ Plywood Decking
Straw		Wood I Joist w/ Plywood Decking

Table 7.1 Material Selections for 3 Housing Options

As has been mentioned, the assembly options are based upon the possible combinations of materials. For example, the selection of Wood Studs 2x6 16" o.c. w/ OSB boards were selected for exterior walls within the timber building option, but beyond this selection various rendering options may be designated. The information presented below offers specific details that specify associated building materials that were used in combination with those presented in Table 7.1.

Foundation and Footings
Concrete mix data was predetermined

Columns and Beams
The assemblies of column and beam types are based on the square footage of the floor and roof they are supporting and an 8 ft. column height is assumed. Beam selections varied as follows:

Steel: Wide Flange Steel Beam
Timber: Glulam beam, made by gluing 2x material on top of one another.
Straw: LVL beam, laminated veneer lumber

Intermediate Floors
After the selection of floor structure, the interior or crawl space ceilings were associated with the following finishes:
Steel: 1/2" Gypsum Board,2 Coats Latex Paint
Timber: 1/2" Gypsum Board,2 Coats Latex Paint
Straw: 1/2" Gypsum Board,2 Coats Latex Paint

Exterior Walls
Steel: Clay Brick Cladding w/ 1" Air SpaceR9 XPS Continuous InsulationR13 Cavity Insulation Weather Resistant Barrier 1/2" Gypsum Board + 2 Coats Latex Paint
Timber: Clay Brick Cladding w/ 1" Air Space R20 Cavity Insulation Weather Resistant Barrier 1/2" Gypsum Board + 2 Coats Latex Paint
Straw: N/A

Windows
Regardless of window type selection, all glazing types were Low E, Argon Filled

Interior Walls
Steel: 1/2" Gypsum Board, 2 Coats Latex Paint
Timber: 1/2" Gypsum Board, 2 Coats Latex Paint
Straw: 1/2" Gypsum Board, 2 Coats Latex Paint

Roofs
Steel: Asphalt Shingles, Organic Felt based, 20 year R49 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint
Timber: Asphalt Shingles, Organic Felt based, 20 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint
Straw: Asphalt Shingles, Organic Felt based, 20 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint

Once building material selections have been determined for 7 assembly types, the simple and user-friendly nature of the EcoCalculator simply requires the user to enter the desired square footage for each assembly. Table 7.2 details the square footage required for each assembly. Though the material selections differ for the timber and steel housing options, the square footage requirements remain relatively similar. On the other hand, various modifications were required for the straw-bale home.

As mentioned the 2009 census stated that the average size of a home is 2438 sq. ft. In order to conduct a fair assessment, equivalent living spaces for all housing options was a necessary consideration. For the timber and steel options a floor plan of 41’x60’ achieved a home of 2460 sq. ft., which is suitably close to the 2009 national average. As was established in the Survey portion of this document, straw-bale wall systems are thicker than typical wall systems and that affects the size of the foundation and other material considerations. One respondent mentioned that a 20% increase in the size of the foundation is required to achieve equivalent living space dimensions. Upon analysis, a 17% increase in the size of the foundation would be sufficient for this example. Since the largest straw bales that would be used for construction would not exceed 2 feet in width, it is conservative to add 4 feet to each dimension of the floor plan. Therefore, a 45'x64' floor plan of 2880 sq. ft. was utilized for the straw-bale housing option.

Designed as a means to standardize square footage selections, Figure 7.3 illustrates a sample floor plan designed to roughly accommodate the average size of a 2438 sq. ft. home, as well as an expanded 2880 sq. ft. floor plan for a straw-bale option. Such a floor plan was utilized to establish square footage values for the various housing options. Furthermore, many comparisons offered earlier in this document refer to a two-story three bedroom home of 2150 sq. ft., and this floor plan was designed to offer a comparable reference. In the figure, the yellow hatching represents the expanded space required by exterior straw-bale walls.

ASSEMBLY	**SQUARE FOOTAGE (Timber and Steel)**	**SQUARE FOOTAGE (Straw Bale)**
Foundation and Footings	2460 foundation, 6.7 cyd footing	2880 foundation, 7.2 cyd footing
Columns and Beams	2460	2880
Intermediate Floors	4920	5760
Exterior Walls	4040	4360
Windows	540	540
Interior Walls	2600	2600
Roofs	2460	2880

Table 7.2 Square Footage per Assembly Type

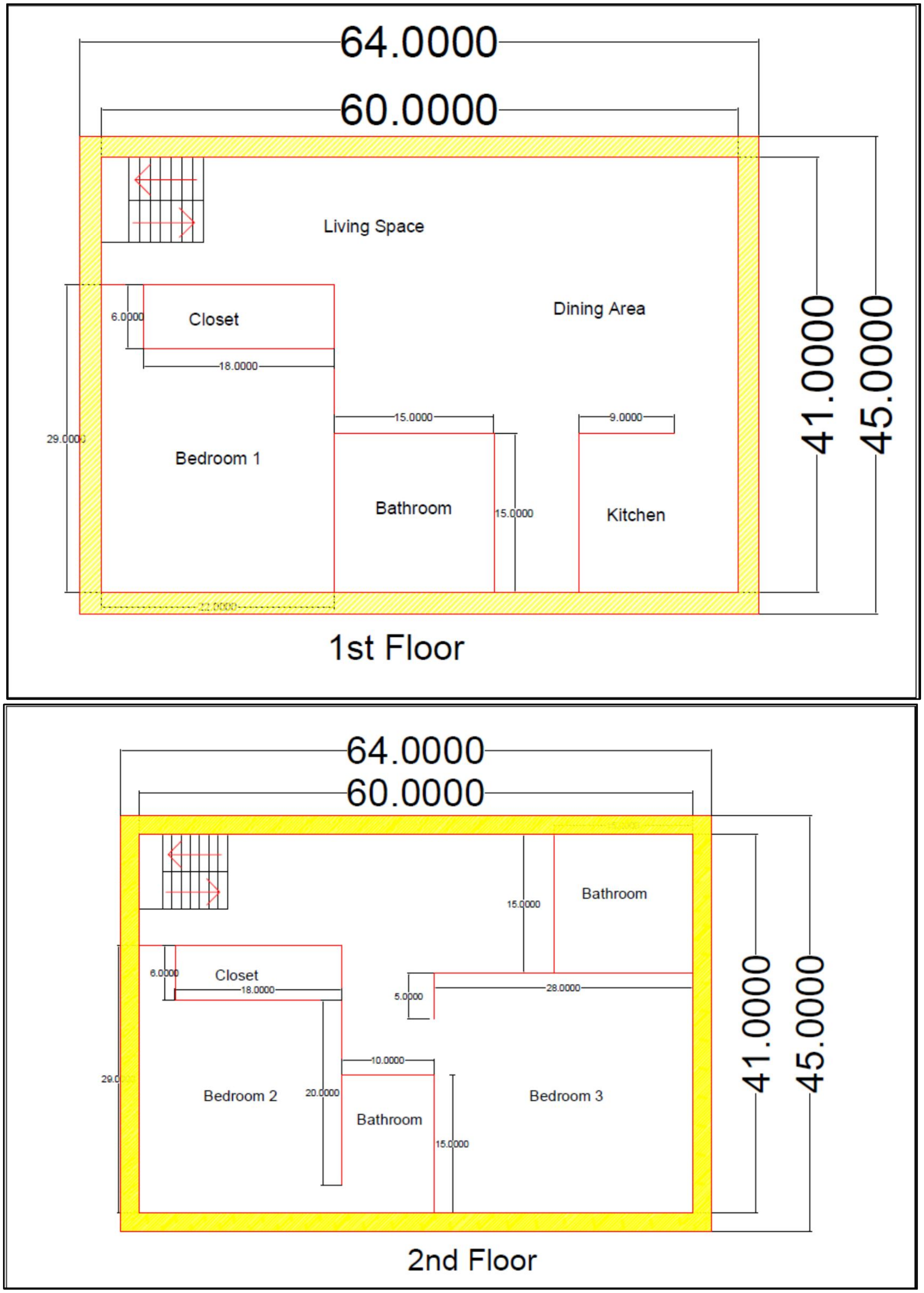


Figure 7.3 Floor Plan Layout of Straw-Bale Home Design

At such a point in the development of the LCA it was necessary to determine values for straw bales. A fully completed LCA for the Timber and Steel housing options was accomplished, but in order to draw comparison to a straw-bale housing option, data was required to be entered for the exterior wall options. In addition to varying exterior wall building materials, the column and beam selection would vary according. The decision was made for all other assemblies to mirror those selected for the timber housing option. As the results from Figure 6.20 were presented in the Survey portion of this document, the preferred building material to complement straw is timber, and therefore would be most likely to be utilized in a real world building scenario. Therefore, the task at hand was to determine performance measurements for straw bales.

It was determined that certain performance measurements could be established through the methodologies detailed within TRACI and the four divisions of an LCA as defined the EPA's Life Cycle Assessment: Principle and Practice. As specified within the "inner-workings" of the EcoCalculator, Athena places the highest importance upon Fossil Fuel Consumption and Global Warming potential, as those are the most directly connected to the building sector. Through consultation with an LCA expert, it was determined that the performance measures of Global Warming, Fossil Fuel Consumption, and Weighted Resource Use could be developed, while remaining measures were either too complex for determination or produced negligible values.

Consideration was given as to whether it would be advisable to determine aquatic eutrophication values. Defined as the estimated amount of water-nutrifying substance that can lead to proliferation of photosynthetic aquatic species, eutrophication is measured in mass units of Nitrogen equivalents forming. It is known that nitrogen fertilizer is the limiting nutrient in a freshwater system. Ultimately it was determined that bales may or may not receive fertilizer treatment, but such a determination was not placed upon the ultimate selection to utilize the straw bales as a building material. Essentially the treatment of fertilizer was determined to be out of the scope of this project's LCA.

Acidification Potential is defined as the estimated amount of acid-forming chemicals created, and is measured in moles of hydrogen ions (H+). For the creation of straw bales there was not a significant production of acidification potential. Similarly, the following three performance measures were also considered to produce null values.

- Human Health Respiratory Effect Potential, defined as the estimated amount of airborne particles that can lead to respiratory disease, measured in mass units of 2.5 micron particulate matter.
- Ozone Depletion Potential, defined as the estimated amount of ozone-depleting substances such as CFC's, and is measured as CFC-11 equivalents.
- Smog Potential is the estimated amount of chemicals that could produce photochemical smog and ground-level ozone when exposed to sunlight. Measured in mass units of ethylene equivalents.

The ability to determine the Global Warming potential was based upon research and assumptions regarding agricultural harvesting equipment, and the associated fuel consumption. The agricultural material is harvested in bushels, and ultimately is related to the number of bales to be utilized on one straw-bale home. Once such a final value was determined in **tonnes of CO_2** equivalent, the Fossil Fuel Consumption could be derived in terms of **MJ**. Lastly the Material Resource Use is simply the total weight, kg., of the building material, straw, as compared to the total square footage of the home. The calculations and assumptions that yielded performance measure values are detailed below. The functional unit that was considered for the development of such performance measurements was one house.

<u>Global Warming Potential</u>

Assumptions: 6000 acre field; harvest straw/acre = 200 bushels/acre; 1 bushel, bu.= 80 dry lbs. of straw; combine fuel tank = 210 gallons; fuel consumption = 315 acres/1 tank

Calculation:

Fuel consumption: $\frac{\text{315 acres per harvest}}{\text{1 tank}} = \frac{\text{315 acres}}{\text{210 gallon}} = 1.5$ acres/gallon

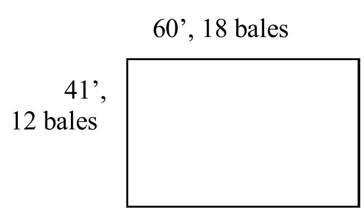
Straw Harvest: $\frac{\text{200 bu.}}{\text{acre}} * \frac{\text{1.5 acres}}{\text{1 gallon}} = \frac{\text{300 bu.}}{\text{gallon}}$

300 bushels harvested per 1 gallon of diesel

1 bu. = 80 dry lbs. → 300 bu.= 24,000 lbs.

Assume: 1 straw bale ~ 60 lbs. and average home ~ 2438 sq. ft. □ 41'x 60'

average bale size ~ 40" l x 12" h = 3.33' x 1'



Bales per Home: 12 bales *w* (18 bales stacked) + 18 bales *l* (18 bales stacked) = 540 bales/ home

Accounting for openings (doors, windows, etc.) say **450 bales / home**

$$450 \text{ bales} * \frac{60 \text{ lbs.}}{1 \text{ bale}} = 27{,}000 \text{ lbs. of straw per home}$$

Recall: 1 gallon diesel = 300 bushel = 24,000 lbs.

$$\frac{27{,}000 \text{ lbs.}}{24{,}000 \text{ lbs.}} = \textbf{1.125 gal. diesel required to create bales for 1 home}$$

From the Intergovernmental Panel on Climate Change (IPCC):
CO_2 emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12) = 10,084 grams = 10.1 kg./gallon

Therefore: 1.125 gallon diesel * 10.1 kg./gallon = 11.3625 kg. CO_2 emissions
1000 kg. = 1 metric ton (tonnes)
11.3625 = 0.0113625 tonnes of CO_2 equivalent

This value is doubled as the impact is assessed from the tractor use during both fertilizing and harvesting

Global Warming Potential = 0.022725 tonnes of CO_2 equivalent per house

Fossil Fuel Consumption

Assumptions: 1.125 gallon diesel/ home; 1 gallon = 129,500 btu

$$\frac{1.125 \text{ gallon}}{\text{home}} * \frac{129{,}500 \text{ btu}}{\text{gallon}} = \frac{145{,}688 \text{ btu}}{\text{home}}$$

Conversion Factor:
145,688 btu * .001055056 = 154 MJ

Fossil Fuel Consumption = 154 MJ per functional unit

Material Resource Use

Value is based upon kg. straw/ total sq. ft. of home
Conversion Factor:
1 lb. = 0.45359 kg.

$$27{,}000 \text{ lbs. straw/ home} * \frac{0.45359 \text{ kg.}}{\text{lb.}} = 12{,}247 \text{ kg. straw/ home}$$

12,247 kg./ 2880 sq. ft. = **4.252 kg/ ft^2**

As mentioned the EcoCalculator does not allow for the addition of new assemblies, so an additional Excel spreadsheet recreated the appearance and supplied data of the EcoCalculator in order to implement the calculated straw-bale performance measurements and complete the LCA for the housing option. After the creation of the final spreadsheet, all necessary information was presented through databases or determined through established LCA methodologies in order to complete the LCA for all three housing options. The following section details the final results produced through the life cycle assessment.

7.6 LCA Results

Upon the completion of building material selections and desired assembly square footage based on home design, the EcoCalculator provided tabular and graphic depictions of the results. Tables 7.3-7.5 below detail the tabular output of the Environmental Impact Summaries for the three housing options. As has been noted, Athena regarded Fossil Fuel Consumption and Global Warming Potential as the key performance measurements as they are appropriately highlighted in pink.

Steel

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Weighted Resource Use (tonnes) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Respiratory Effects Potential (kg PM2.5 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg NOx eq) TOTAL
Foundations & Footings	2,460	65,743	8	74	2,613	18	1,646	18	26
Columns & Beams	2,460	22,466	1	3	490	3	1,051	0	1
Intermediate Floors	4,920	285,514	19	52	12,818	59	18,306	1	215
Exterior Walls	4,040	551,296	38	124	20,670	103	18,629	10	249
Windows	540	523,316	44	40	65,203	505	13,050	127	296
Interior Walls	2,600	105,918	6	12	2,031	27	1,999	1	12
Roof	2,460	728,234	43	89	13,104	101	19,388	1	70
TOTALS		2,282,486	158	395	116,930	816	74,069	158	870

Table 7.3 Environmental Impact Summary - Steel

Timber

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Weighted Resource Use (tonnes) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Respiratory Effects Potential (kg PM2.5 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg NOx eq) TOTAL
Foundations & Footings	2,460	65,743	8	74	2,613	18	1,646	18	26
Columns & Beams	2,460	4,761	0	2	108	1	122	0	1
Intermediate Floors	4,920	140,687	7	46	13,449	54	15,792	1	295
Exterior Walls	4,040	527,647	37	147	20,375	110	19,012	10	200
Windows	540	221,498	21	41	20,379	209	6,457	35	110
Interior Walls	2,600	76,112	3	15	1,482	24	757	1	11
Roof	2,460	580,317	31	77	11,751	86	15,275	1	104
TOTALS		1,616,766	107	403	70,158	502	59,060	66	747

Table 7.4 Environmental Impact Summary - Timber

Straw Bale

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Weighted Resource Use (tonnes) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Respiratory Effects Potential (kg PM2.5 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg NOx eq) TOTAL
Foundations & Footings	2,880	75,902	9	86	3,011	21	1,892	21	30
Columns & Beams	2,880	4,494	0	2	103	0	125	0	1
Intermediate Floors	5,760	164,736	8	54	15,725	63	18,488	1	345
Exterior Walls	4,360	667,080	0.10	19	0	0	0	0	0
Windows	540	221,498	21	41	20,379	209	6,457	35	110
Interior Walls	2,600	76,112	3	15	1,482	24	757	1	11
Roof	2,880	679,395	37	92	13,973	102	18,162	1	124
TOTALS		1,889,218	78	309	54,672	419	45,882	59	621

Table 7.5 Environmental Impact Summary – Straw Bale

In order to supplement the tabular outputs, as well as provide an additional viewpoint for analysis of results, the EcoCalculator displays pie charts for each performance measurements. The pie chart provides divisions based upon the percentage for each assembly type as compared to the total impact of that performance measurement. A more feasible means of comparison between the assembly types for the three housing types are provided by bar charts. Figures 7.4 to 7.6 below display the applicable performance measurement results in the supplementary format.

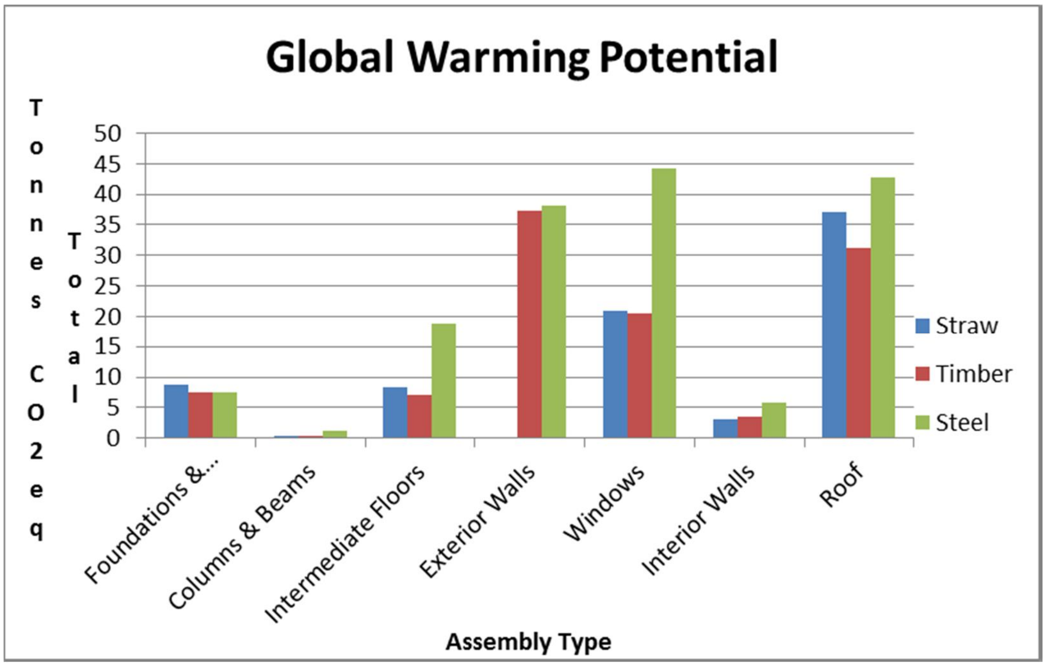


Figure 7.4 Global Warming Potential Comparison

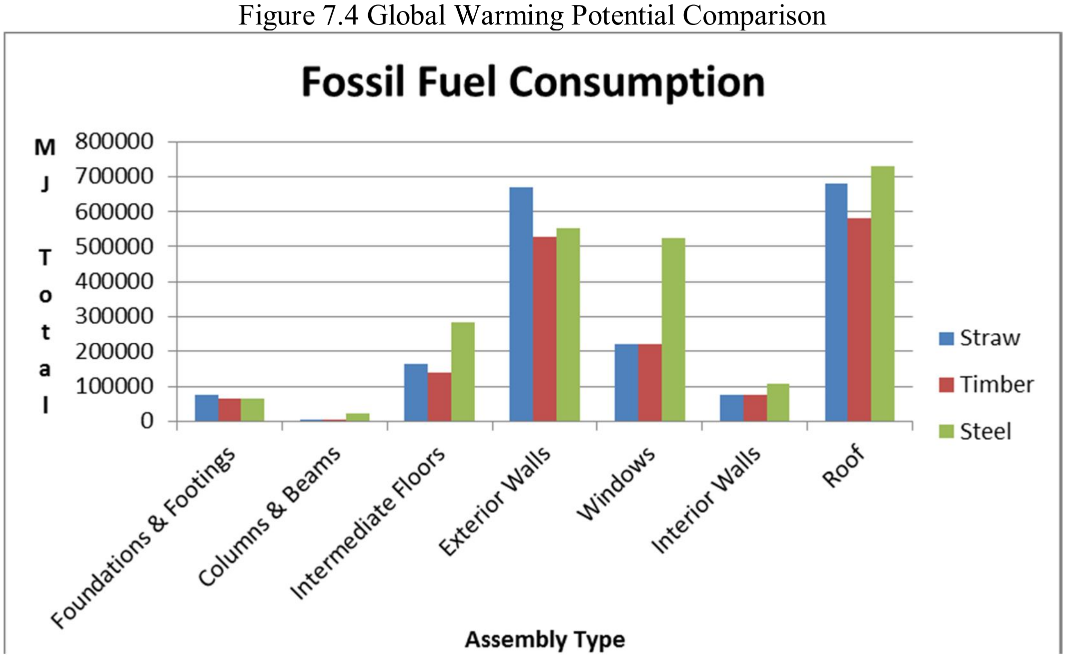


Figure 7.5 Fossil Fuel Consumption Comparison

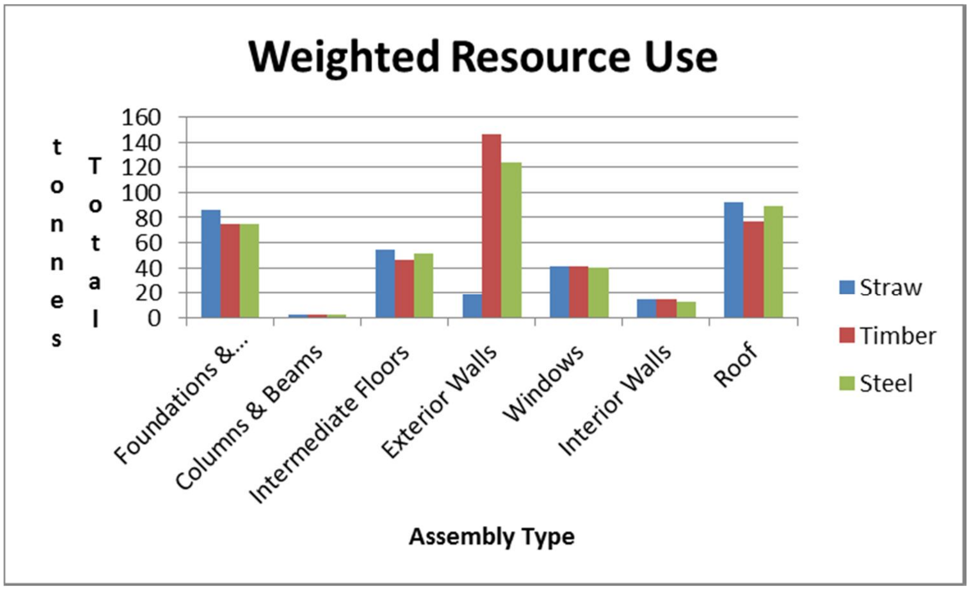


Figure 7.6 Weighted Resource Use Comparison

Upon review of the results it becomes evident that in many cases, the steel housing option causes the maximum environmental detriment. A primary focus on the results should be based upon the exterior walls assembly, as that is the assembly most directly impacted by the use of straw bales. Also, it must be considered that the use of straw created an increased requirement on the quantities of many of the material assemblies. Only the Weighted Resource Use takes into account the impact of a material based upon the size of the whole building. The Weighted Resource Use is attributed to the greater dimensions and mass of a straw bale as opposed to stud construction. Though this may provide more of an environmental detriment solely based on this category, the great mass of straw bale creates thermal mass and is associated with lessened energy requirements for heating and cooling loads. In certain cases, straw provides a greater environmental detriment as opposed to other material selections. For example, the Fossil Fuel Consumption of the exterior walls composed of straw bales exceeds the total MJ production of the other options. Based upon the calculations provided, the sole creation of this value is based upon the diesel required during agricultural production of the straw, and therefore the associated Megajoules required.

It is essential to understand the conclusions of an LCA are solely providing an evaluation of embodied energy. As evident from the surveys of experienced professionals, considerations of operational energy are one of the primary advantages of the utilization of straw bales. When evaluating the straw-bale housing option in comparison the timber and steel options, an advocate of the straw-bale industry would likely be pleased with the results display in the outcome of the LCA.

7.7 Cost Considerations

While the LCA was able to successfully evaluate various environmental stressors based upon diverse housing options, it did not account for monetary differences. As was stated as a goal of this project, both environmental and economic impacts of the utilization of straw bale as a building material was to be investigated. As evident from surveying experienced professionals, it is common to purchase several hundred straw bales at a time for a cost of $3.00/bale. In the design performed for the LCA, approximately 450 bales would be required to build a home that is 2880 sq. ft. Using the commonly mentioned cost of $3.00/ bale, the bales required to build the walls would cost approximately $1,350. Such a value is worthy of comparison to the timber and steel housing options in order to determine how upfront material costs differ.

In order to remain consistent with the assembly selected for exterior walls within the EcoCalculator, the timber housing option employed Wood Studs 2x6 that were spaced 16" on center, then covered by oriented strand board, OSB and insulated with R-20 cavity insulation. Referencing current prices from Lowe's, 19/32"x4x9 OSB sheathing is priced at $9.97/board, wood studs 2x6x10 are $4.98, and 9-Pack 93"L x 23"W x 6.5"D R-19 Fiberglass Insulation Batts are $55.85. Considering a home that is 60'x41', that would encompass 11 oriented strand boards in the width direction, and 15 boards in length. The following calculations detail the derivation of material costs.

(15+15+11+11)*2 stories = 104 boards

104 boards @ $9.97/board = **$1036.88**

Similarly, the dimensions of the home would require 45 studs in the long direction, and 30 studs in the wide direction. The calculations below derive the material costs for studs.

(45+45+30+30) * 2 stories = 300 studs

300 studs @ $4.98/stud (timber) = **$1494.00**

The designed home would require a total of 8 packages of R-19 insulation batts to cover the length of the home, and 6 packages to cover the width dimension.

(4+4+3+3) * 2 stories = 28 packages of R-19 insulation batts

28 packages * $55.85 = **$1563.80**

Total costs = $1036.88 +$1494.00 + $1563.80 ~ $4095 for timber wall assembly

The assembly selected within the EcoCalculator for exterior walls of the steel housing option employed steel studs 1-5/8 x 3-5/8 that were spaced 16” on center, then covered by oriented strand board, OSB, and insulated with R-13 cavity insulation. Referencing current prices from Lowe’s, steels studs 2x4x10 are $5.65, 11-Pack 93"L x 15"W x 3.5"D R-13 Fiberglass Insulation Batts are $40.49, and the previously information regarding OSB sheathing would still apply.

Due to the insulation for R-13 being offered in packs of 11 with dimensions that differed from the timber example, the designed home would require a total of 10 packages of R-13 insulation batts to cover the length of the home, and 6 packages to cover the width dimension. The following calculations detail the derivation of material costs.

(5+5+3+3) * 2 stories = 32 packages of R-13 insulation batts

32 packages * $40.49 = **$1295.68**

(45+45+30+30) * 2 stories = 300 studs

300 studs @ $5.65/stud (steel) = **$1695.00**

Total costs = $1295.68 +$1695.00 + $ 1036.88 ~ $4088 for steel wall assembly

Chapter 8

SUMMARY AND FUTURE WORK

8.1 Summary and Conclusion

The work included within this document attempted to build upon the existing knowledge base within the straw-bale industry. While the advantages and opportunities presented by the selection of straw as a building material are well documented, the intention was to supplement such information in order to advance the industry. Specifically, the determination of the factors that are presently hindering the growth of the industry was conducted. With the advent of the straw-bale construction method in North America traced back to the 19th Century, and a revival of the industry in the 1980s, the current status of the industry appears to have reached a somewhat stagnant level. As the awareness of green technology, materials and construction methods has reached nearly every level of society, there are now more than ever a myriad of other options that straw-bale construction is essentially competing against. Through the methods utilized within this document, two surveys allowed for an objective evaluation of such factors that may be inhibiting the industry. Additionally, the goal was to determine the economic and environmental consequences associated with the selection of straw bale in comparison to common materials. In order to supplement the viewpoints shared by the respondents, a Life Cycle Assessment was utilized to quantify such impacts.

Analysis of the surveys allowed for an understanding of the size, budget, and classification of the types of firms that are involved or may be interested in gaining a further involvement within the industry. Additionally, the types and preferences of materials that are commonly utilized with straw bales were established. The surveys further offered the opportunity to discover what aspects of straw-bale projects were difficult or unexpected, as well as the specific benefits that were achieved. Conversely, an understanding as to why other professionals may be weary of the industry was developed.

Through the utilization of databases that provided widely accepted values of performance measurements of environmental stressors, an LCA was completed for two common housing options, as well as a straw-bale option. Additionally an evaluation of upfront and construction cost considerations was conducted. As a result, it was proven that with regards to embodied energy as well as what may be considered embodied costs, straw bales provide a very viable option as a building material.

Regardless of whether the professionals have experience on a straw-bale project, or do not even intend to become involved with the industry, all respondents placed a high importance on taking measures to ensure that their projects are viewed to be sustainable. As long as there remains an industry wide steadfast intention to design greener buildings, the straw-bale construction methods will remain a feasible option. Provided that the firms involved within the straw-bale industry can overcome the factors that are hindering the advancement and widespread use of the material and proper marketing techniques are addressed, the construction method may very well become a common practice.

8.2 Future Work

Future work of various natures relative to topics covered within this project could be performed as an enhancement to the conclusions and methods that have been established. Based upon the results and opinions expressed by the professionals surveyed, a new survey may be composed for release at a future time to monitor the advancement of the straw-bale industry. In future investigations, a determination as to specifically why many professionals do not believe the public would be tolerant of a straw-bale project could become a very constructive discovery. Additionally, an interdisciplinary involvement with professionals skilled in developing marketing campaigns could be coupled with the conclusions drawn within this survey. As the focus of this exploratory study was to evaluate the factors that are hindering the advancement of the straw-bale industry, future work could provide the creation of marketing tools to allow the industry to advance beyond such hindrances.

While the completion of the LCA provided a valuable asset to objectively evaluate environmental stressors of various construction building and material options with regard to embodied energy, future operational energy modeling comparison would be a beneficial endeavor. While it has been established through anecdotal evidence that straw bales provide owner's with many energy saving advantages, building energy modeling would provide a means to quantify and demonstrate such values.

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APPENDIX

Athena

To ensure fair comparisons between assemblies, the following assumptions were made:

■*Results are presented on a per unit area basis (e.g., per square foot), but the underlying the Impact Estimator analyses were done on a whole building basis and actually took into account much larger quantities, such as 1,000 linear feet of wall of a defined height with an assumed window–to–wall ratio.*
■*Installation for all assemblies was assumed to utilize components and loadings typical for central areas of the United States.*
■*It was assumed that all assemblies would be used in "owner occupied office buildings" (in the Commercial version) or "single family residences" (in the Residential version) with a 60-year lifespan; building type and ownership assumptions affect the maintenance and repair/replacement schedules of relevant building envelope materials (e.g., roofing membranes, claddings and window systems).*
■*Other specific assumptions covered factors such as:*
◦*concrete strength and fly ash content;*
◦*gypsum board type and thickness with latex paint;*
◦*live load for all intermediate floors, columns and beams, and roofs;*
◦*bay sizes;*
◦*column heights;*
◦*external wall thicknesses depending on construction system;*
◦*stud size/strength and spacing; and*
◦*sheathing and decking materials.*
■*Results are presented on a per unit area basis (e.g., per square foot), but the Impact Estimator software actually took into account much larger quantities, such as 1,000 linear feet of wall.*
■*Installation for all assemblies was assumed to utilize components and loadings typical for central areas of the United States.*
■*It was assumed that all assemblies would be used in "owner occupied office buildings" with a 60-year lifespan – which affects the maintenance and repair/replacement schedules of relevant building envelope materials (e.g., roofing membranes, claddings and window systems).*
■*Other specific assumptions covered factors such as:*
•*Window-to-wall ratio*
•*Concrete strength and fly ash content*
•*Gypsum board type and thickness with latex paint*
•*Live load for all intermediate floors, columns and beams, and roofs*
•*Bay sizes*
•*Column heights*
•*External wall thicknesses depending on construction system*
•*Stud size/strength and spacing*
•*Sheathing and decking materials*

<u>Assembly Definitions & Assumptions</u>

The ATHENA® EcoCalculator results reflect the assumptions inherent within the ATHENA® Impact Estimator for buildings. However, the Impact Estimator offers additional options for many of the assemblies and the basic approach to developing EcoCalculator results was to select assumptions that would be fair in terms of assembly comparisons. These essential underlying assumptions are described below. Users wishing to explore other supported options can do so using the Impact Estimator .

Global Assumptions

•In the development of specific LCA results using the Impact Estimator, one must define quantities of assemblies, such as the length of an exterior wall. The results are presented on a per unit area (such as per square foot) basis, but the base Estimator runs used large quantities, such as 1000 linear feet of wall. This was performed to reduce the effect of end conditions, such as the additional stud at the end of a wall or the perimeter columns in a beam and column assembly.
•The Impact Estimator does not yet include all the required information for all materials or assemblies within the defined list. For materials within assemblies that are not currently supported by the Estimator, assumptions were made to approximate their environmental impact from first principles. For this version, estimated embodied effects were developed for EIFS cladding, precast concrete cladding, welded wide flange (WWF) steel columns, structural Insulated panel walls (SIPs), and Glulam and LVL columns.
•We assumed that all assemblies would be installed in either low- or highrise office buildings, using components and loadings typical for central areas of the United States (i.e., no unique seismic loadings were considered), but with a differentiation between northern and southern climates for the purposes of properly defining assemblies in terms of thermal performance.
•The Impact Estimator requires a definition of building type, ownership and expected life. This affects the maintenance schedule and repair / replacement of certain building assemblies. For the purposes of the EcoCalculator, we assumed an "owner occupied office" building type with a 60–year life for both high and low-rise buildings.
•The life cycle stages included in the LCA results include resource extraction, resource transportation, building product manufacturing and component manufacturing (components incorporate two or more building products), transportation from manufacturing plant to building site by various modes, on-site construction, maintenance and replacement of components over a sixty year period and end-of-life (demolition) effects.
•The building exterior walls were assumed to have 40% windows by area, with all windows having low E glass.
•All concrete (except floor topping) was assumed to be 4000 psi (30 MPa).
•All cast-in-place concrete was assumed to contain 25% fly ash in place of Portland cement; although this is not necessarily typical, it was considered more appropriate to use an environmentally beneficial formulation.
•All concrete masonry was assumed to contain 0% fly ash, while precast concrete was assumed to contain 10% silica fume in place of Portland cement.
•All gypsum board was assumed to be 5/8" thick regular gypsum board with latex paint.
•The live load for all intermediate floors, columns and beams was set at 75 psf (3.6 kPa). The live load for roofs was set at 45 psf (2.4 kPa).
•All wood structural panels (WSP) used data for oriented strand board (OSB).
•All structural composite lumber (SCL) used data for LVL beams.
•All vapor barriers were assumed to be 6 mil PET.

Column and Beam Assumptions
•Bay sizes were set at 30 feet by 30 feet for the purpose of assessing columns and beams.
•Column heights were set at 10 feet.

Exterior Wall Assumptions
•Concrete masonry exterior walls were assumed to be 8" thick and ICF exterior walls were assumed to be 8" in total thickness.
•Cast-in-place concrete and concrete tilt-up walls were assumed to be 6" thick.
•Wood studs were assumed to be kiln dried, 2x4 or 2x6 depending on the climate zone
•Steel studs were assumed to be 20 gauge, 1 5/8" x 3 5/8".
•Precast cladding was 4" thick, with 5,000 psi concrete.
•Stucco was assumed to be Portland cement based traditional stucco with steel mesh reinforcement.
•All rigid insulation was assumed to be extruded polystyrene, 4" thick in the northern climate zone and 2" in the southern region.
•All batt insulation in exterior walls was assumed to be fiberglass, 8" thick in the northern climate zone and 4" thick in the southern region.

Interior Wall Assumptions

•Interior concrete masonry walls were assumed to be 6" thick.
•Wood studs were assumed to be 2x4, kiln dried.
•Steel studs were assumed to be 25 gauge, 1 5/8" x 3 5/8"

Floor and Roof Assumptions
•Floor and roof decking was assumed to be 5/8" OSB.
•Wood-I joists incorporated ½" thick OSB webs, and 2.5" x 1.5" LVL flanges.
•Steel joists were assumed to be 1 5/8" x 10", 16 Gauge, and 16" on center.
•All rigid insulation in roof assemblies was assumed to extruded polystyrene, 8" thick in the northern climate zone and 4" in the southern region
•All batt insulation in roof assemblies was assumed to be fiberglass, 9.5" thick in the northern climate zone and 5.5" in the southern region.
Impact Measure Definitions
Embodied primary energy is reported in Mega-Joules (MJ). Embodied energy includes all non-renewable energy, direct and indirect, used to transform or transport raw materials into products and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources. (For example, natural gas used as a raw material in the production of various plastic (polymer) resins.) In addition, the measure captures the pre-combustion (indirect) energy use associated with processing, transporting, converting and delivering fuel and energy.

Global Warming Potential (GWP) is a reference measure. Carbon dioxide is the common reference standard for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a "CO2 equivalence effect" which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide. This effect has a time horizon due to the atmospheric reactivity or stability of the various contributing gases over time. The International Panel on Climate Change (2001) 100-year time horizon figures have been used here as a basis for the equivalence index:

CO2 Equivalent kg = CO2 kg + (CH4 kg x 23) + (N2O kg x 300)

The air and water pollution measures are similarly intended to capture the pollution or human health effects of groups of substances emitted at various life cycle stages. In this case we used the commonly recognized and accepted critical volume method to estimate the volume of ambient air or water that would be required to dilute contaminants to acceptable levels, where acceptability is defined by the most stringent standards (e.g., drinking water standards). The ATHENA® Impact Estimator software calculates and reports these critical volume measures based on the worst offender–that is, the substance requiring the largest volume of air and water to achieve dilution to acceptable levels. The hypothesis is that the same volume of air or water can contain a number of pollutants.

The final measure is an ecologically weighted measure of resource use, using weights developed in the mid 1990s through a survey of Canadian resource extraction and environmental experts, none of whom were at the time working for an industry involved in the production of any of the six resources studied. The expert panel was asked to weigh the relative effects of extraction in terms of four dimensions: the extensiveness of the area typically impacted; the intensiveness of the typical extraction activity; the significance of the areas typically impacted; and the duration of impacts in terms of the time that it typically takes for an impacted area to return to a level of reasonable ecological balance and productivity. The resulting weights range from 1 for aggregates extraction (used to normalize the results) to 3.25 for timber harvesting in coastal British Columbia rain forests. All other resources used in products have since been given a weighting of 1 until a more comprehensive survey can be undertaken.

With regard to the air and water pollution measures, it is worth noting that critical volume approaches were well recognized in the LCA literature at least through the 1990s. Those measures still stand today as an indicator of toxic flows that can have human and ecosystem health effects. Given the uncertainties associated with other measures, and the lack of international agreement on many of the otherwise accepted measures, we still feel that these two measures have value and should be retained until more robust measures can be supported. Like the other measures used in the Impact Estimator, a 'less is better' approach governs their relevance and interpretation.

The weighted resource use measure was not included in the original assembly analysis because, as noted in the first *briefing paper, we were concerned about its Canadian focus and age. However, in view of the concerns expressed by some subcommittee members over the lack of a land use measure, we have included this measure. It comes as close as any other measure to getting at the relevant endpoints given that we are dealing with generic, or representative, LCI data.*

Survey SB

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http://SurveySB.questionpro.com Customize | View All Questions | Print / Options

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INTRO

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Dear Building Professional,

I cordially invite you to participate in this survey associated with my graduate research through the University of Cincinnati College of Engineering and Applied Science. I am pursuing my Master of Science in Civil Engineering and my thesis topic involves the development of the straw-bale construction industry. Thorough literature research has proven that straw-bale as a building material provides many advantages, as well as cost savings, yet in much of North America the industry is widely unknown.

The survey that you are invited to participate in is part of a research project whose objective is to increase the awareness of straw-bale construction benefits and practices. Additionally, the goal is to provide information and marketing tools useful to firms who wish to become involved in utilizing this type of building material and construction practice. Your participation will help in achieving this objective. You have specifically been chosen with your proven experience and association to straw-bale building. We share a common interest in expanding the industry, and I want to express how highly I respect your opinions and shared experiences. The results of this survey will be published and emailed to all participants.

Your survey responses will be strictly confidential and data from this research will be reported only in the aggregate. Your information will be coded and will remain confidential. If you have questions at any time about the survey or the procedures, please feel free to contact me by email. I am very appreciative of your valuable time.

Thank you,

Sean McIntosh
Civil Engineering Graduate Student
College of Engineering and Applied Science
University of Cincinnati
Cincinnati, OH
Phone: 859-380-0098
mcintosp@gmail.com

Add New Question | Add/Update Logic | Separator | PageBreak

Page Break

Q1

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Company Information

Which of the following best describes the type of company you work for?

- ○ General contractor/construction manager
- ● Developer-Builder
- ○ Developer
- ○ Subcontractor
- ○ Engineering Firm
- ○ Architecture Firm
- ○ Other

Add New Question | Add/Update Logic | Separator | PageBreak

Q3

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How many salaried employees does your company employ?

- ● <5
- ○ 6-10
- ○ 11-25
- ○ 26-50
- ○ If over 50, approximately how many?

Add New Question | Add/Update Logic | Separator | PageBreak

Q4

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What was the estimated revenue of your company in 2009?

- ○ <$250,000
- ○ $250,000-$500,000
- ○ $500,000-$1 million
- ○ $1 - $10 million
- ○ $10 – 50 million
- ○ $50-$100 million
- ○ $100-$150 million
- ○ $150 million +

Add New Question | Add/Update Logic | Separator | PageBreak

Q5

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What is the average construction budget on a project your company completes?

- ○ <$100,000
- ○ $100,000-$500,000
- ○ $500,000-$1 million
- ○ $1-$5 million
- ○ $5-$25 million
- ○ $25-$50 million
- ○ $50 million +

Add New Question | Add/Update Logic | Separator PageBreak

Q6

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NOTE: For all questions that follow, please consider straw-bale building materials to include both straw bales as well as compressed straw building panels.

Frequency of Straw-Bale Construction

Please indicate the number of construction projects where your company employed straw-bale as a building material.

- 0
- 1
- 2-5
- 6-10
- 11-20
- If over 20, approximately how many?

Add New Question | Add/Update Logic | Separator PageBreak

Q7

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Of your current projects, please indicate the % of construction projects that your company is involved with that is employing straw-bale as a building material.

- 0-10%
- 10%-30%
- 30%-50%
- 50%-75%
- 75%-100%

Add New Question | Add/Update Logic | Separator PageBreak

Q8

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Materials and Experiences

On your company's projects that employ straw-bale as a building material, please indicate the method for which it was used.

- For structural purposes only
- For insulation purposes only
- As a combination of structural and insulation purposes
- As a building block bonded by mortar

Add New Question | Add/Update Logic | Separator PageBreak

Q9

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On your company's projects that employ straw-bale as a building material, please indicate

if the other materials were used, as well as the "typical" frequency of use.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Adobe											
Other natural plaster (non adobe)											
Natural paints/finishes											
Gypsum											
Steel framing											
Timber Framing											
Roof Truss											
Compressed Straw Building Panels											
Other											

Add New Question Add/Update Logic Separator PageBreak

Q10

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If your company has experience on projects that have employed compressed straw building panels, please briefly state your opinion of the material, as well as any problems encountered.

Add New Question Add/Update Logic Separator PageBreak

Q11

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On your company's projects that employ straw-bale as a building material, please indicate which of the following were used as the agricultural fiber that the straw bales were composed of, as well as the "typical" frequency of use.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Bagasse											
Cereal Straw											
Cornstalks											
Cotton Stalks											
Kenaf											
Rice husks											
Rice straw											
Other											

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Q12

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Market Drivers

Please select the factors that are the principle reasons for implementing straw-bale as a building material on your projects. (Please select 3 or less)

- LEED certification
- State regulations
- Owner's request
- Tax incentives
- Community perception
- Company policy
- Providing affordable housing
- Economic (cheaper material)
- Environmental (ecological responsibility)
- For marketing purposes
- New endeavor/broaden skill set
- Other

Add New Question | Add/Update Logic | Separator | PageBreak

Q13

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Problems Encountered While Employing Straw-Bale Construction

Please select the problems that you have encountered when involved with a straw-bale construction project. (Please select 4 or less)

- No problems
- Documentation for LEED certification
- Training subcontractors
- Training piece workers
- Training temporary laborers
- Familiarity with the material (by those involved with the construction)
- Familiarity with the material (by the client, public, etc.)
- Lack of good/reliable straw-bale firms or builders out there
- Time associated with engaging in new building process
- Please describe any other problems that you have encountered while using straw-bale construction.

Add New Question | Add/Update Logic | Separator | PageBreak

Q14

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Please briefly document any aspects of a project involving straw-bale building materials that particularly surprised you.

Add New Question | Add/Update Logic | Separator | PageBreak

Q15

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Best Strategies for Straw-Bale Construction

Please select the practices below that have helped you the most when employing straw-bale as a construction building material. (Please select 4 or less)

- ☐ Establishing goals early on
- ☐ Prior experience with the material and building techniques
- ☐ Have your labor foreman supervise all straw-bale construction phases
- ☐ Having language in the subcontracts regarding straw-bale construction
- ☐ Orientation meetings before subs start working
- ☐ Providing information with your companies marketing
- ☐ Building in a geographic region with other visible straw-bale projects
- ☐ Working with subs that have experience in straw-bale building
- ☐ Incentive programs for subs to engage in new techniques
- ☐ Having someone else (a third party) provide all training
- ☐ Please describe any other practices that have worked well for you in increasing the efficiency and ease of construction.

Add New Question | Add/Update Logic | Separator | PageBreak

Q16

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On most of your company's straw-bale projects, those employees involved with the construction process include which of the following. (Please select 4 or less)

- ☐ Salaried employees
- ☐ Hourly Employees
- ☐ Subcontractors
- ☐ Volunteers
- ☐ Charitable Organization
- ☐ If volunteers or charitable organizations were involved, what percentage of your straw-bale projects have included this?

Add New Question | Add/Update Logic | Separator | PageBreak

Q17

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Please indicate how much you agree or disagree with the following statements.

The success of straw-bale construction relies upon having hourly employees educated on the straw-bale building construction process.

- ○ Strongly Agree
- ○ Agree
- ○ Neutral
- ○ Disagree
- ○ Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q18

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On most of your company's current projects, hourly employees are educated on the straw-bale building construction process.

- ○ Strongly Agree (Applies to all jobs)
- ○ Agree (Applies to most jobs)
- ○ Neutral

- Disagree (Rarely occurs)
- Strongly Disagree (Never occurs)

Add New Question | Add/Update Logic | Separator | PageBreak

Q19

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Types of Construction

This section attempts to determine if the success of straw-bale construction is impacted by the type of construction being built.

Please indicate how much you agree or disagree with the following statement.

The type of structural system greatly affects the ease of straw-bale construction.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q20

Edit | Delete | Copy | ReOrder | Settings | Preview

Of the options listed, please rate the "relative ease" of construction when the following structural systems are used on a straw-bale building project. (Use the rating of 1 to 5 with 1 being the most difficult, 3 neutral, and 5 being the easiest)

	1	2	3	4	5
Stacked straw-bales support all loading	☐	☐	☐	☐	☐
Straw-bales bonded with mortar	☐	☐	☐	☐	☐
Straw-bales within timber framework	☐	☐	☐	☐	☐
Straw-bales within steel framework	☐	☐	☐	☐	☐
Straw-bales within concrete framework	☐	☐	☐	☐	☐

Add New Question | Add/Update Logic | Separator | PageBreak

Q21

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Incentives

Please indicate how much you agree or disagree with the following statement.

Contractors will save a project money by utilizing straw-bale and strawboard materials.

- Strongly Agree
- Agree

- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q22

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Relative to a building utilizing traditional building materials, owners of a straw-bale building will experience energy savings throughout their period of ownership.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q23

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Relative to a building utilizing traditional materials, a straw-bale building will yield a reduction in carbon-based greenhouse gas emissions.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q24

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Relative to a building utilizing traditional materials, a straw-bale building will have a lessened fire risk.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q25

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Relative to a building utilizing traditional materials, a straw-bale building will yield provide the same level of structural integrity.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator PageBreak

Q26

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Relative to a building utilizing traditional materials, a straw-bale building will provide sufficient weatherproofing.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator PageBreak

Q27

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ReOrder | Settings | Preview

Relative to a building utilizing traditional materials, a straw-bale building will provide less of a concern regarding the "sick building syndrome".

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator PageBreak

Q28

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ReOrder | Settings | Preview

Geographic Impacts

Please indicate how much you agree or disagree with the following statements:

The success of a straw-bale construction project is dependent on the region of the country where the project is located.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator PageBreak

Q29

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ReOrder | Settings | Preview

The perception of straw-bale construction as a feasible building method is the same in all locations across North America.

- Strongly Agree
- Agree
- Neutral
- Disagree

Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q30

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Company Policy

Please indicate how much you agree or disagree with the following statements:

The success of a straw-bale construction project relies heavily on having company policies that require straw-bale or straw board materials to be utilized on all projects.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q31

Edit | Delete | Copy | ReOrder | Settings | Preview

Your company currently has a policy that requires the utilization of straw based materials on all projects.

- Yes
- No

Add New Question | Add/Update Logic | Separator | PageBreak

Q32

Edit | Delete | Copy | ReOrder | Settings | Preview

Procurement Practices

Please indicate how much you agree or disagree with the following statements:

It is beneficial to go into an interview/negotiation with a potential owner/developer with straw-bale costs figured into my bid and disclose this to the owner as a potential advantage.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q33

Edit | Delete | Copy | ReOrder | Settings | Preview

The project delivery system (hard bid, negotiated contract, etc.) greatly impacts the ability to have a successful straw-bale construction project.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Add New Question Add/Update Logic Separator PageBreak

Q34

Edit Delete Copy ReOrder Settings Preview

Of the options listed, please rate the "relative ease" of a straw-bale construction project based on the different delivery systems. (Use the rating of 1 to 5 with 1 being the most difficult, 3 neutral, and 5 being the easiest)

	1	2	3	4	5
Hard bid (low bid general contract)	☐	☐	☐	☐	☐
Negotiated contract	☐	☐	☐	☐	☐
Construction Management	☐	☐	☐	☐	☐
Design Build	☐	☐	☐	☐	☐

Add New Question Add/Update Logic Separator PageBreak

Q35

Edit Delete Copy ReOrder Settings Preview

Timing

Please indicate how much you agree or disagree with the following statement:

The success of a straw-bale construction project depends on when the decision is made to utilize the building material as opposed to traditional materials.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q36

Edit Delete Copy ReOrder Settings Preview

When is the best time to decide to implement straw-bale as a building material on a project?

- Design period
- Bid time
- Preconstruction meetings
- Before any on-site work takes place
- Anytime before you go vertical

Add New Question Add/Update Logic Separator PageBreak

Q37

Edit Delete Copy
ReOrder Settings Preview

On the projects that you are involved with, when is the decision to implement a straw bales as a building material usually made?

- Design period
- Bid time
- Pre-construction meetings
- Before any on-site work takes place
- Anytime before you go vertical

Add New Question | Add/Update Logic | Separator PageBreak

Q38

Edit Delete Copy
ReOrder Settings Preview

Cost

How do you usually purchase straw bales?

- Procured on your own land/crops
- $/bale directly from the field
- $/bale delivered
- $/bale from a factory
- $/compressed straw-panel from factory
- Other

Add New Question | Add/Update Logic | Separator PageBreak

Q39

Edit Delete Copy
ReOrder Settings Preview

Please indicate how much you agree or disagree with the following statement:

It is easier and more cost effective to dispose of straw than to reuse it as a building material.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator PageBreak

Q40

Edit Delete Copy
ReOrder Settings Preview

On a typical project, please indicate the price and quantity that you are paying for straw-bale building materials.

Add New Question | Add/Update Logic | Separator PageBreak

Q42

Edit Delete Copy
ReOrder Settings Preview

Project Size

Please indicate how much you agree or disagree with the following statement:

The size of the project impacts the success of using straw-bale as a building material.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Add New Question Add/Update Logic Separator PageBreak

Q43

Edit Delete Copy
ReOrder Settings Preview

Please rate the "relative ease" of using straw-bale on the following sizes of projects. (Use the rating of 1 to 5 with 1 being the most difficult, 3 neutral, and 5 being the easiest)

	1	2	3	4	5
<$100,000	☐	☐	☐	☐	☐
$100,000-$500,000	☐	☐	☐	☐	☐
$500,000-$1 million	☐	☐	☐	☐	☐
$1-$5 million	☐	☐	☐	☐	☐
$5-$25 million	☐	☐	☐	☐	☐
$25-$50 million	☐	☐	☐	☐	☐
$50 million +	☐	☐	☐	☐	☐

Add New Question Add/Update Logic Separator PageBreak

Q44

Edit Delete Copy
ReOrder Settings Preview

Future Trends

Please indicate how much you agree or disagree with the following statements:

Straw-bale construction is a fad that will not become a standard practice that lasts over time.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q45

Edit Delete Copy
ReOrder Settings Preview

The practice of straw-bale construction will get easier as time passes and the method becomes more prevalent.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q46

Edit Delete Copy ReOrder Settings Preview

Respondent Contact Information

Please provide your contact information so that we may send our final conclusions.

In what state/province do you primarily conduct business?

- Alabama
- Alaska
- Alberta
- Arizona
- Arkansas
- British Columbia
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Manitoba
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Ohio
- Oklahoma

- Ontario
- Oregon
- Pennsylvania
- Quebec
- Rhode Island
- Saskatchewan
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- Washington DC
- West Virginia
- Wisconsin
- Wyoming

Add New Question | Add/Update Logic | Separator | PageBreak

Q48
Edit | Delete | Copy | ReOrder | Settings | Preview

Your Name

Add New Question | Add/Update Logic | Separator | PageBreak

Q48
Edit | Delete | Copy | ReOrder | Settings | Preview

Company Name

Add New Question | Add/Update Logic | Separator | PageBreak

Q49
Edit | Delete | Copy | ReOrder | Settings | Preview

Email Address

Add New Question | Add/Update Logic | Separator | PageBreak

Edit Footer | Thank You Page

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- Global Options

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- Security
- Finish Options
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Survey Options
- Images/Multimedia

Connector
- Salesforce.com CRM

http://SurveyNE.questionpro.com Customize | View All Questions | Print / Options

Edit Header | Images/Multimedia

SURVEY NE

INTRO

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Dear Building Professional,

I cordially invite you to participate in this survey associated with my graduate research through the University of Cincinnati College of Engineering and Applied Science. I am pursuing my Master of Science in Civil Engineering and my thesis topic involves the development of the straw-bale construction industry. Thorough literature research has proven that straw-bale as a building material provides many advantages, as well as cost savings, yet in much of North America the industry is widely unknown.

The survey that you are invited to participate in is part of a research project whose objective is to increase the awareness of straw-bale construction benefits and practices. Additionally, the goal is to provide information and marketing tools useful to firms who wish to become involved in utilizing this type of building material and construction practice. Your participation will help in achieving this objective. You have specifically been chosen with your proven expertise in green home building, and your opinions are invaluable. The results of this survey will be published and emailed to all participants.

Your survey responses will be strictly confidential and data from this research will be reported only in the aggregate. Your information will be coded and will remain confidential. If you have questions at any time about the survey or the procedures, please feel free to contact me by email. I am very appreciative of your valuable time.

Thank you,

Sean McIntosh
Civil Engineering Graduate Student
College of Engineering and Applied Science
University of Cincinnati
Cincinnati, OH
Phone: 859-380-0098
mcintosp@gmail.com

Add New Question | Add/Update Logic | Separator | PageBreak

Page Break

Q1

Edit | Delete | Copy
ReOrder | Settings | Preview

COMPANY INFORMATION

Which of the following best describes the type of company you work for?

- General contractor/construction manager
- Developer-Builder
- Developer
- Subcontractor
- Engineering Firm
- Architecture Firm
- Other

Add New Question | Add/Update Logic | Separator | PageBreak

Q2

Edit | Delete | Copy
ReOrder | Settings | Preview

How many salaried employees does your company employ?

- <5
- 6-10
- 11-25
- 26-50
- 50+
- If over 50, approximately how many?

Add New Question | Add/Update Logic | Separator | PageBreak

Q3

Edit | Delete | Copy
ReOrder | Settings | Preview

What was the estimated revenue of your company in 2009?

- <$250,000
- $250,000-$500,000
- $500,000-$1 million
- $1 - $10 million
- $10 – 50 million
- $50-$100 million
- $100-$150 million
- $150 million +

Add New Question | Add/Update Logic | Separator | PageBreak

Q4

Edit | Delete | Copy
ReOrder | Settings | Preview

What is the average construction budget on a project your company completes?

- <$100,000
- $100,000-$500,000
- $500,000-$1 million
- $1-$5 million
- $5-$25 million
- $25-$50 million
- $50 million+

Separator

Add New Question | Add/Update Logic | PageBreak

Q5

Edit | Delete | Copy | ReOrder | Settings | Preview

Frequency of Straw-Bale Construction

Please indicate the number of construction projects where your company employed straw-bale as a building material.

- 0
- 1
- 2-5
- 6-10
- 11-20
- 20+

Add New Question | Add/Update Logic | Separator | PageBreak

Q6

Edit | Delete | Copy | ReOrder | Settings | Preview

Green Construction Projects

In your opinion, in order to remain competitive in the industry, it is necessary to be educated and regularly practice "green" construction techniques.

- Yes
- No

Add New Question | Add/Update Logic | Separator | PageBreak

Q7

Edit | Delete | Copy | ReOrder | Settings | Preview

Please select the factors that are the principle incentives for implementing "green" construction practices in your projects.(Please select 4 or less)

- We do not consider "green" construction practices necessary
- We practice "green" construction, but do no identify with a particular incentive
- LEED certification
- State regulations
- Owner's request
- Tax incentives
- Community perception
- Company policy
- Marketing purposes
- New endeavor/broaden skill set
- It is the responsible thing to do
- Other

Add New Question | Add/Update Logic | Separator | PageBreak

Q8

Edit | Delete | Copy

ReOrder Settings Preview

Of the NEW projects that your company starts, how many would you consider take significant steps to be viewed as a "green" project.

- 0-10%
- 10%-30%
- 30%-50%
- 50%-75%
- 75%-100%

Add New Question Add/Update Logic Separator PageBreak

Q9

Edit Delete Copy
ReOrder Settings Preview

Perception

Please indicate how much you agree or disagree with the following statements:

Overall there will be a positive public perception of a project that uses straw-bale building materials.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q11

Edit Delete Copy
ReOrder Settings Preview

Straw-bale building materials will contribute positively to a project that is focusing on sustainable practices.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q12

Edit Delete Copy
ReOrder Settings Preview

Straw-bale building has a perception of being a "hippie" endeavor that sheds an unprofessional light on the industry.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q13

Edit Delete Copy
ReOrder Settings Preview

Geographic Impacts

Please indicate how much you agree or disagree with the following statements:

The success of a straw-bale construction project is dependent on the region of the country where the project is located.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q14

Edit Delete Copy
ReOrder Settings Preview

Straw-bale construction is utilized equally throughout North America.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q15

Edit Delete Copy
ReOrder Settings Preview

The perception of straw-bale construction as a feasible building method is the same in all locations across North America.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question Add/Update Logic Separator PageBreak

Q16

Edit Delete Copy
ReOrder Settings Preview

Company Policy

Please indicate how much you agree or disagree with the following statements:

Your company frequently conducts employee training and education on sustainable/innovative/alternative practices.

- Strongly Agree
- Agree
- Neutral
- Disagree

Strongly Disagree

Add New Question

Add/Update Logic

Separator
PageBreak

Q17

Edit Delete Copy
ReOrder Settings Preview

Your company would consider becoming educated on straw-bale construction to be a beneficial endeavor in order to remain competitive in the industry.

Yes
No

Add New Question

Add/Update Logic

Separator
PageBreak

Q18

Edit Delete Copy
ReOrder Settings Preview

Cost

Please indicate how much you agree or disagree with the following statement:

It is easier and more cost effective to dispose of straw than to reuse it as a building material.

Strongly Agree
Agree
Neutral
Disagree
Strongly Disagree

Add New Question

Add/Update Logic

Separator
PageBreak

Q19

Edit Delete Copy
ReOrder Settings Preview

Project Size

Please indicate how much you agree or disagree with the following statement:

The size of the project impacts the success of using straw-bale as a building material.

Strongly Agree
Agree
Neutral
Disagree
Strongly disagree

Add New Question

Add/Update Logic

Separator
PageBreak

Q20

Edit Delete Copy
ReOrder Settings Preview

Future Trends

Please indicate how much you agree or disagree with the following statements:

Straw-bale construction is a fad that will not become a standard practice that lasts over time.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q21

Edit | Delete | Copy | ReOrder | Settings | Preview

The practice of straw-bale construction will get easier as time passes and the method becomes more prevalent.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Add New Question | Add/Update Logic | Separator | PageBreak

Q22

Edit | Delete | Copy | ReOrder | Settings | Preview

Respondent Contact Information

In what state/province do you primarily conduct business?

- Alabama
- Alaska
- Alberta
- Arizona
- Arkansas
- British Columbia
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Manitoba
- Michigan

- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
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- Pennsylvania
- Rhode Island
- Saskatchewan
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- Washington DC
- West Virginia
- Wisconsin
- Wyoming

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Q23

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Your Name

Add New Question Add/Update Logic Separator PageBreak

Q24

Edit Delete Copy ReOrder Settings Preview

Company Name

Add New Question Add/Update Logic Separator PageBreak

Q25

Edit Delete Copy ReOrder Settings Preview

Email Address

Add New Question

Add/Update Logic

Separator

PageBreak

Edit Footer

Thank You Page

Email Sent to Task Members

Dear Task Group Members,

I'm sending this to those task group members who have worked with strawbale, hempcrete, or other *unprocessed* agricultural fiber technology. I need your help.

In drafting the standard, I found it useful to classify agricultural fiber based building products into two categories:

1. *processed fiber products* - These are products that use agricultural materials processed into particles or fiber and substituted for wood fibers in products already covered by ASTM such as panel products, wood-plastic composites, fiber-cement board, cellulose insulation, etc.
2. *unprocessed fiber products* - These include primarily strawbale, hempcrete, but also products like stramit, agriboard, stak block, etc. Products that use whole stems with minimal processing.

I've finished drafting the Terminology and Classification sections, and now I'm writing the sections on how to specify the properties and performance of these products. For processed fiber products, it's relatively straight forward, one can use existing ASTM (or other body) wood standards, one just has to account for the differences between the agricultural fibers vs. the wood fibers.

But for unprocessed fiber products, the task is much more ornery. There is as yet no mention of these types of products in any US standards, so we basically have a clean slate on how to approach them. Now the question is: What do we want standards to do for us? Certainly, we don't want standards to make us jump through expensive hoops and have to do a million tests on these products. My philosophy on this is: "Minimize burden, maximize benefit." So my question to you all is how do you think standards could help with these products? (BTW, a stand alone straw bale specification will follow down the road.) Our standard guide introduces these materials into ASTM and addresses general issues for this material class. Who do you think would use it? Would it be used primarily to get these materials into building codes? To help specify these materials for projects? Are there other uses?