Straw Bale is Future House Building Material

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Abstract - Egypt is rapidly developing its economy. The economics of the government identify the building industry as a vital engine of economic growth. The rising need of housing for the growing rural and urban population is a pressing issue. To maintain rapid rates of economic growth in the 21st century it is important to put strategy for housing to meet the needs of the rural and urban population. Straw bale construction has considerably good insulation and can be a promising building alternative that meets housing needs and energy efficient goals of Egypt. Also the use of straw in building will solve the problem of pollution caused by burning of straw, which produces carbon mono oxide CO. Enough straw is already produced in Egypt, it reaches 33 million ton every year and its burning produces 1.65 million ton of CO. In addition that straw bale building has a low impact on the environment. So choosing straw bale construction has many advantages-for people and the planet. This paper discusses building resource efficient and energy conserving homes without sacrificing affordability, quality or beauty.

Key Words - Nebraska-style - Post-and-beam – Straw panel

1. Introduction
Each year grain farmers battle with the remains of their harvest, straw. Straw doesn't decompose very rapidly and becomes a burden for the farmers. The burning of straw produces CO. Enough straw is already produced in Egypt, it reaches 33 million ton every year and its burning produces 1.65 million ton of CO, for that many efforts were directed to find alternatives to burning of straw.
One of these alternatives is using straw bales in building. Straw has been used as a building material by ancient Egyptian in their tombs. Straw bale was first used after that by the settlers of the sand hills region of Nebraska. The rise in the popularity and use of cement led to its virtual extinction.
Then, in the late 1970's, Judy Knox and Matts Myihman rediscovered some of those early houses and pioneered straw bale revival.
The use of straw bale in building will not only solve the problem of straw as a waste but also will help in building houses having significantly low impact on the environment without sacrificing most of comforts we have been accustomed to having. Such buildings will be of low cost and because of the high insulating ability of straw it can be used in the desert where the climate is harsh. [1]

2. Definition
Straw bale building has at its heart the humble bale of straw. Straw is the baled up dead plant stems of a grain crop, (including wheat, oats, barley, rye, rice and hemp), once the seed head has been harvested from the plant. It has virtually all its seed heads removed, and contains no leaves or flowers. [2]
It is a fairly inert material, with a similar chemical make-up to wood. It is quite difficult to make it decompose. Straw is composed of cellulose, hemicelluloses, lignin, and silica. It breaks down in soil and 'waste' straw can be used as mulch. Different grasses have slightly different qualities, for instance rice straw has a significant amount of silica, which adds density and resistance to decomposition. [3]
3. Why straw bale building?

Apart from the most important environmental issues there are plenty more good reasons to choose straw bales as your favorite building material. The benefits of building with bales include:

3.1- Energy Efficiency
One of the leading reasons to choose straw bales over other building materials is their high level of energy-efficiency. This is due to the exceptional insulating properties of the bales.

<table>
<thead>
<tr>
<th>CONSTRUCTION</th>
<th>R- VALUE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional wall system</td>
<td>2.0 to 3.5</td>
<td>depending on climatic conditions, building code regulations, building material and type of insulation</td>
</tr>
<tr>
<td>Straw bale walls</td>
<td>5.5 to 8.5</td>
<td>depending on widths, type, quality and density of straw bales and on how the bales are stacked</td>
</tr>
</tbody>
</table>

Combined with a well-designed passive solar system straw bale houses require very little energy to keep warm in winter and cool in summer.

3.2- Healthy Choice
Straw bales are a healthy choice. They do not contain the paints, chemicals, glues and toxins Combined with clay and lime renders and natural paints or oxides to finish the structure, straw bale walls can breathe and provide a natural, fresh and healthy living environment. The thick walls seal out noise. [6]

3.3- Cost Advantage
Straw bale is a low cost material. At best, the bale walls can reduce your overall budget by 5 to 10 %. But you'll be getting more than twice the insulation value and great aesthetic potential, and savings in energy costs will stay with you for the life of the buildings. Heating costs can be reduced by up to 75% annually compared with modern style housing. [7]

3.4- Structural capabilities
Research has shown that structural load bearing straw bale walls can withstand loads of more than 48,826 kg/m². In the load-bearing straw bale method, walls of up to 3 stories have been constructed, with infill walls, in post and beam type structures; the straw does not take weight anyway. [8]

Fig.1- Straw bale wall can withstand great loads. Wall up to 3 stories can be constructed
3.5- Comfort, Creativity & Aesthetics
Straw bale buildings have their own unique feel and character. The thickness of the walls provides a feel of calm, safety and comfort. Deep window seats, alcoves, niches, and subtle curves are creative features.

3.6- Resistance against termites and pests
Walls built with tightly pressed straw bales provide fewer spaces for pests to live in than conventional timber frame houses do. Also, because clean and dry straw has very little nutritional substance, it is unable to support a pest population for long itself if the render is well applied, contains no or only very fine cracks and is well maintained, the risk of any pest infestation into your walls is very low. However, normal precautions against termite infestation, as used with any other construction technique, should be followed to protect the vulnerable components of your building from termites. [6]

3.7- Fire resistance
Straw bales are tightly packed and covered with a skin of cement render. Fire can’t burn without oxygen, and the dense walls provide a nearly airless environment, so the fire resistance of compacted straw is very good. A test of a plastered wall panel showed a two-hour fire resistance, and an unplastered bale wall had a 30-minute resistance. [3]

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>FIRE RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-rendered straw bale</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Rendered straw bale</td>
<td>2 hours</td>
</tr>
<tr>
<td>Timber framed and cladded building</td>
<td>8 minutes</td>
</tr>
</tbody>
</table>

3.8- Moisture effect
Straw bale walls should not exceed moisture content of 15%. Protecting your bale walls with an appropriate foundation, generous roof overhangs, intact & well maintained guttering, porches and verandahs and suitable render materials are the most effective ways to avoid direct rain exposure, splash back, and resulting moisture damage to the walls. Well applied, intact, properly maintained and breathable render will also protect the straw bales from moisture damage. [6]

Fig.2- The rocks at the bottom exterior of this home are a decorative way to protect the earth plastered straw bale walls from rain splash.
3.9- Maintenance
Maintenance is possible, and is very easy. Wedges of the bales can be pulled out quite easily. Hazel pins can be cut through if necessary and fresh straw wedges can be packed tightly back to fill the gap. [5]

4. Straw bale in construction
The most direct way to use straw in building is through straw-bale construction. During grain harvest, a baler compresses straw into rectangular bales tied with either two or three wires or poly propylene strings.

Fig. 3- Typical two- and three-string bale dimensions.

4.1- Methods of construction using straw bale
There are three main methods to build with straw bale

Fig. 4- Methods of straw bale construction.
### Table 3- A Comparative analysis of straw bale construction methods

<table>
<thead>
<tr>
<th>NO</th>
<th>TYPE</th>
<th>LOAD BEARING</th>
<th>LIGHT-WEIGHT FRAME</th>
<th>IN-FILL METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Construction Method</td>
<td>Bales are placed together like giant building blocks, pinned to the foundations and to each other with coppiced hazel, and have a wooden roof plate on top which is fastened to the foundations and the bales with coppiced hazel and strapping, and the roof is constructed in the usual manner on top of the roof plate.</td>
<td>It uses a timber framework that is so light-weight that it cannot stand up alone, it requires temporary bracing and/or the use of a crow props to give it stability until the straw is in place.</td>
<td>Posts and beams are constructed of timber or steel to form the structural frame work the roof is then added and finally straw bales in-fill the frame work.</td>
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<tr>
<td></td>
<td></td>
<td><img src="image" alt="Fig. 5- Building with Nebraska-style" /></td>
<td><img src="image" alt="Fig. 6-Light-weight frame wall" /></td>
<td><img src="image" alt="Fig. 7- Building made with post and beam construction" /></td>
</tr>
<tr>
<td>2</td>
<td>Building Style</td>
<td>Designs from one room to two-storey homes can be created using a simple, step by step approach. Curves and circles are easy to achieve, for little extra cost.</td>
<td>Building up to three floors can be made.</td>
<td>Any number of floors can be constructed since the weight is supported in the frame. In conjunction with a steel frame, can create large warehouse space (and gives an even temperature throughout the year).</td>
</tr>
<tr>
<td></td>
<td></td>
<td><img src="image" alt="Fig. 8- Section through a load bearing wall Nebraska-style" /></td>
<td><img src="image" alt="Fig. 9- Light - weight frame wall" /></td>
<td><img src="image" alt="Fig. 10- The weight of the roof is carried by steel framework." /></td>
</tr>
<tr>
<td>3</td>
<td>Load Distribution</td>
<td>The bales themselves take the weight of the roof - there is no other structural framework.</td>
<td>The straw is an essential part of the structural integrity of the building, more so than the timber, and it works together with the timber to carry the load of floors and roof.</td>
<td>The weight of the roof is carried by a wood, steel, or concrete framework, and the bales are simply infill insulation blocks between the posts.</td>
</tr>
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<td>4</td>
<td>Amount of support Materials Needed</td>
<td>Minimal use of timber</td>
<td>Vastly reduces the amount of timber required compared to the more traditional post and beam method.</td>
<td>It requires substantially more timber than a load bearing design,</td>
</tr>
<tr>
<td>5</td>
<td>Stability and size of openings</td>
<td>Low stability for windows and doors in the wall. Openings for windows and doors must not exceed 50% of the wall surface area in any wall</td>
<td>Provides greater stability for window and door frames than in the load bearing style</td>
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</tr>
<tr>
<td>6</td>
<td>Subjection to wetting</td>
<td>The straw must be kept dry throughout the whole building process until it is plastered. This can be very difficult on a large building, or one that is being constructed slowly. As the roof is placed at the top after the walls</td>
<td>The roof can be constructed before the straw is placed providing secure weather protection.</td>
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</tr>
<tr>
<td>7</td>
<td>Speed of construction</td>
<td>Fast</td>
<td>Take more time than load bearing method</td>
<td>Take more time than load bearing method</td>
</tr>
<tr>
<td>8</td>
<td>Need of Skills</td>
<td>No skills are needed. Easy for non-professionals to design, following readily comprehensible basic principles</td>
<td>Greater technical ability is required to make the structure stable whilst the straw is being placed</td>
<td>This method requires a high level of carpentry skill</td>
</tr>
</tbody>
</table>
4.2- Other forms of straw used in construction

4.2.1- Straw-clay building
A pancake-like batter of clay and water stirred into the loose straw produces a straw-reinforced clay mud. In the past, this mixture was packed into a double-sided wood form between the posts.

![Fig.13- Brick making with straw and clay mixture - New Gourna.](image)

4.2.2.- Pressed straw panels
Straw is compacted under certain temperatures. The resulting panels are 100 percent straw that can be used to build pre-fabricated structures, not only walls, but also roofs and floors. [4]

![Fig.14- Processing straw into panels](image)

5- Case study

*[New straw bale house at Solar Haven - Mexico]*

5.1- Features

- Two bedrooms
- One and a half bathrooms
- Living room and dining area
- Enclosed kitchen
- Wheelchair accessible - doors 3’ wide
- All natural, nontoxic materials used (mostly recycled)
- Square footage: interior (1025), exterior (1188) - not including 36” roof overhangs
5.2- Design and Construction Details
"Load-bearing" straw bale design; adobe earthen floors, earth and lime plastering on walls (internal and external), conventional gable roof (prefab metal trusses with purlins and 26 gague R-profile metal roofing), 30” overhangs, recycled cotton batt insulation in attic space (R-32), radiant foil installed underneath purlins.

5.3- How to build it?

5.3.1- Trench and rebarring for the footer

Fig.16- First step of foundation to build the straw bale house

a) Trench and rebarring for the footer
b) The trench is filled with concrete, the poured footer is two feet wide
5.3.2- Completed double stem walls.
The space in between the walls and all cells in the blocks still must be filled with concrete.

Fig.17- Second step of foundation to build the straw bale house
a) Completed double stem walls and filling in between,
b) Section of foundation

5.3.3- Raising the door (bucks) onto the foundation

Fig.18- Third step of foundation to build the straw bale house,
a) The finished foundation walls to build up a floor
b) Compacting the fill dirt with a gasoline powered tamper.

Fig.19- Raising the door onto the foundation.
5.3.4  Straw bale wall rising

Fig. 20 - Wall construction method
a) The barn raising tradition of old comes alive again
b) Attempting to line up a bale exactly over an all thread rod before lowering it onto the wall.

Fig. 21 - Placing the roof plate on the top of the wall
a) A bale raising tripod makes lifting the bales into position and lowering them
b) Wall and roof plate are finished and ready to receive the pre-manufactured metal trusses.

Fig. 22 - Plan and section showing the roof plate
5.3.5- Straw bale house with the roof finished

![Fig.23-Roof finishing](image)

a) Coating the roof
b) Section of straw bale building
c) The roof finished, the bare straw walls await their first coat of adobe earthen plaster.

5.3.6- Finishing Elements (windows)

![Fig.24- Finishing elements](image)

a) Window frames were constructed to fit used windows already purchased, then the straw bale walls were built around them. Insulation of the actual windows was very quick
b) Section of box frame for window
c) The rough plumbing of the drains for sinks, toilets, and tub/shower.

5.3.7- Thermal insulation

![Fig.25- Process of interior roof insulation](image)

a) A radiant foil barrier installed underneath the metal roof sheets will reflect out 95% of the radiant energy
b) Recycled natural cotton fiber insulation was installed in the attic space to a depth of 10 inches (R-32). This material consists of left-over scraps from the making of blue jeans.
5.3.8- Coating the straw bale wall

Fig. 26- Plastering of walls  

a) A clay slip is sprayed on the bales in preparation for the first coat of earthen plaster. A standard sheetrock texture gun is being used.

b) During first plastering the base or scratch coat of plaster consisting of high clay content soil, a little dirt from our yard, chopped straw, lime, and water was applied.

Fig. 27- Decoration of doors and windows  

a) & b) Colored bottles are being placed over doors and windows - "stained glass on a budget". They are mortared in with a mixture of cement, sand, and peat moss known as "Tufa Stone" which can be easily sculpted and molded around the bottles.

5.3.9- The final outer shape

Fig. 28- The outside has now been fully plastered with a base coat of adobe earthen plaster.
5.3.10- Interior finishing

Straw bale walls shot with lime stucco and ferrous sulfate coloring

Fig.29- A pure lime stucco (stabilized with cement) was shot professionally on all interior wall surfaces of our straw bale house. Ferrous sulfate, a common garden fertilizer/additive, was added to the mixture for coloring (turning the plaster a light tan instead of brilliant white).

5.3.11- Finishing floor

Fig.30- pre-manufactured adobe blocks to make the floor

5.3.12- Partitioning of the interior space

Fig.31- Our first wall partition was built with the usual 2’ x 4’ wood frame, but the usual fiberglass insulation and sheetrock was not used. Rather the wall cavity was filled with a mixture of clay and straw, And then covered and sealed with hand applied lime plaster [9]
6- Conclusion and Recommendations

6.1- Conclusion
1. Instead of being unwanted and difficult to dispose of, rice straw would become a valuable commodity to be harvested for profit.
2. Plastered straw-bale construction creates long lasting, super insulated (generally R-40 and R-50); fire-resistant housing at per-square-foot costs less than those of traditional methods. The energy savings for space cooling and/or heating continue to accrue for the life of the structure
3. The emissions from eventual burning or decomposition of the straw are postponed.
4. Straw is produced by photosynthesis, a natural, non-polluting process fueled by solar energy.
5. Straw is an annually renewable agricultural residue often considered a waste product. So it is environmentally friendly
6. The major physical components of an ideal passive solar design would include adequate thermal mass (to store and release heat of a 24-hour cycle) and an insulating exterior wrap to reduce heat loss to the outside. In straw bale construction, proper placement of high mass materials like stucco, mud plaster, brick, concrete, tile, adobe or rammed earth in the interior of the structure would provide the thermal mass, while the thick, highly insulative walls would greatly reduce heat loss by conduction. Straw bales on the outside, earth on the inside- we win, the planet wins.

6.2- Recommendations
1. It is obvious that straw bale buildings are efficient in achieving comfort in a harsh weather resembling the climate of new urban areas in Egypt as Sinai and Toshkie so we recommend that the construction of structures and building in these areas to be made using straw bales to provide comfort with minimum costs and at the same time minimize the pollution caused by the incineration of straw.
2. We recommend also that architects, advisors and contractors who see its value in terms of cost effectives, sustainability, ease of insulation and energy efficiency to make further examinations on straw bales to include it in Egyptian building codes to live happily in healthy environment and enjoy a comfortable life.

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