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## Review Article

# STRAW BALE CONSTRUCTION A REVOLUTIONARY BUILDING MATERIAL IN LOW COST HOUSING FOR RURAL AREAS

\***Monika Shekhar Gupta**

Amity School of Architecture and Planning, Amity University, (M.P.), India

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### ABSTRACT

The paper deals with the study of a low cost agro waste construction material i.e. Strawbale. The cost of construction materials is increasing incrementally. It is essential to find functional substitutes for conventional building materials in the construction industry. In view of the importance of saving of energy and conservation of resources, efficient recycling of all these agro wastes is now a global concern requiring extensive R&D work towards exploring newer applications and maximizing use of existing technologies for a sustainable and environmentally sound management. More details on the availability of agro wastes of all kinds from different sources, their present utilization and recycling potentials for safe, sound and substantial development are summarized and discussed in this paper.

In this emerging world where the rising need of housing is increasing day by day due to tremendous growing of rural and urban population has been a pressuring issue. Without compromising affordability, quality and maintaining the component of earth system has been a challenging task where Straw Bale can be one of the promising building material that meet the overall housing need and energy efficient goal of most of the developing countries like India, Nepal, Bhutan etc where agriculture act as the backbone of development. India being one of the largest countries for production of straw but most of those is considered as waste and limited are only used for productive type but if we can utilize them for construction in the form of straw bale then staying in good house won't be limited to dream for people. It also includes the study of aids to maintain the quality of living standard of people because straw house fulfills serviceability and helps to maintain the environmental quality. Straw is getting lots of preference in many countries because it is cost effective with high health value, Aesthetics value, thermal performance, Fire resistance, light weight and eco friendly in nature. It also has good response against earthquake so it can be constructed in earthquake prone areas as well. So, profound research and awareness regarding straw bale construction should be enhanced in developing countries land agriculture countries like India for effective implementation of straw bale house.

## INTRODUCTION

This paper revolves around the study of Straw bale which is simply a compressed bundle of straw which is arranged in square, rectangular or round shape attached with wire or twines. Straw is the dry stems of cereal grains left after the seed heads have been removed. Bale density varies according to the type of grains, moisture level and degree of compaction provided by the baler. The dimension of straw bale can vary as per circumstance but the standard size can be 900mm x 450mm x 350mm / 584mm x 1168mm x 400mm. Straw bales are light which means a straw bale wall weights 65% less than an equivalent brick wall and 62% less than concrete block wall. Straw is a natural fiber which we get as a byproduct from the agriculture.

\* **Corresponding author: Monika Shekhar Gupta,**  
Amity School of Architecture and Planning, Amity University, (M.P.),  
India.

It is the plant structure between the root crown and the grain head which is composed of cellulose, hemicellulose, lignin and silica. It is being produced by the process of photosynthesis, a natural and non-polluting process by solar energy. We can get this from wheat, rice, oats, hops, barley. Among this rice straw is the toughest one due to high silica content. It is an annually renewable agricultural residue which is being produced in ample amount in most of the countries. It is also considered as the waste product and is being wasted by burning or any other way which is having impact on the environment directly or indirectly. It is being produced by the collaboration of environment so use of this in construction would be obviously an environmental friendly and would have a lot of merits for our quality of life. Burning of the straw leads to black clouds which cause serious chronic chest diseases and carbon evolved from it would affect the quality of environment.

Straw which is produced has become one of the head ache for the farmers as it won't decay easily. The world largest straw producing countries like China, India and other agricultural country have not been able to utilize it for productive work up till now. In India it is used for paper factory for production of papers and some other purposes but this is not enough for proper utilization and still these country are wasting in ample amount. The use of straw for the construction has been commenced long back. Straw bales were first used by the settlers of the sand hills region of Nebraska. In 1890's Nebraska commenced this straw bale for building buildings, churches, schools, officials and grocery stores. In those times they focus in stability of bale wall system, structural stability, plastering and moisture control. So, straw bale construction has been a boom for the economic environmental building alternative are summarized and discussed in this paper.

## ANALYSIS OF STRAWBALE CONSTRUCTION

### The direct cost saving

A saving of approximately 10 % in the direct cost of the walls is achieved when building with straw bales. The tremendous increase in the cost of steel and cement indicates the great variance between the foundations used under the masonry brick unit, while the straw bale unit foundation has an approximate saving of 50%. Saving in the roofing system of the straw bale unit exceeds 50% of the total direct cost. This is over and above the indirect cost saving in energy consumption achieved from reducing the amounts of producing reinforcing steel and cement as raw materials which are used in the traditional ways of building.

Tribes and tribal governments are very different from cities and counties, because so much more of the housing on an Indian reservation is income, public assistance housing, because that's the population. Cities don't have programmatic control over all the residential buildings in their jurisdiction the way tribes do or the way tribes can. Tribes have a greater opportunity to really make a difference; tribes can programmatically address their housing needs and address their unemployment needs and at the same time address their energy needs. If we could meet the present need for new homes and replace a good deal of the existing Indian housing in the next 20 or 30 years with energy efficient homes, these reservations would hum as models, as islands of sustainability, as shining stars of passive and efficient survivability.

The materials and construction technology for low cost housing remain very much bound with the locally available materials. By adopting new appropriate and innovative technologies for utilizing alternative to basic building materials like brick, cement, is an effective, efficient and economic manner. One of the best approaches is to use agriculture waste to meet the growing requirement of the building material. Utilization of agro-industrial wastes assumes a high priority in producing the resources of building materials.

Agriculture is the most economic activity of India and other developing countries. There has been a vast expansion in agro-industrial field in recent years which makes the sustainable increase in the volume of agricultural residues of different types.

Thus, the current shortages of wood and other building materials for ever rising the housing requirements have created a great interest in these agro-wastes. Groundnut husk, jute fibre, rice husk, rice staw, rice bale, saw dust, and coconut fibre and other fibrous material have been identified as most economically important wastes for building industry. It is estimated that in India nearly 700 million tonnes of organic waste is generated annually which is either burned or land filled. The large amount of the agro waste generated from the market area has created major environmental problems. Earthworms have ability to convert organic waste into valuable resources containing plant nutrients and organic matter, which are essential for maintaining soil productivity.

Presently in India, about 960 million tonnes of solid waste is being generated annually as by-products during industrial, mining, municipal, agricultural and other processes. Of this 350 million tonnes are organic wastes from agricultural sources; 290 million tonnes are inorganic waste of industrial and mining sectors and 4.5 million tonnes are hazardous in nature. Globally 998 tonnes of agricultural waste is produced in a year. To safeguard the environment, efforts are being made for recycling different wastes and utilize them in value added applications. 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:

### Energy Efficient

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. 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. 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. - Value of Construction materials

Conventional wall system 2.0 to 3.5 depending on climatic conditions, building code regulations, building material and type of insulation Straw bale walls 5.5 to 8.5 depending on widths, type, quality and density of straw bales and on how the bales are stacked Combined with a well-designed passive solar system straw bale houses require very little energy to keep warm in winter and cool in summer.

### Healthy Choice

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### Structurally Sound

Research has shown that structural load bearing straw bale walls can withstand loads of more than 48,826 kg/m<sup>2</sup>.

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. Wall up to 3 stories can be constructed.

### Comfort, Creativity and 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. 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 in 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.

### 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.

### Moisture effect

Straw bale walls should not exceed moisture content of 15%. Protecting your bale walls with an appropriate foundation, generous 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.

### 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.

### Finishes

Straw-bale walls are most typically plastered on the outside with lime, clay, or cement and lime mix. Inside surfaces are typically lime, clay or plaster board (gypsum). Structural analysis has shown that the straw-bale/stucco assembly behaves much like a sandwich panel, with the rigid stucco skins initially bearing most of the load and adding considerable strength to the wall.

### Low Embodied Energy

The thick walls (typically 21 to 26 inches (530 mm) when plastered), result in deeper window and door "reveals", similar to stone and adobe buildings.

Since the bales are irregular and may be shaped easily, they are readily adaptable to curved designs, and when plastered, tend toward a relaxed, imperfect texture and shape. If flat, straight walls are desired, this can be achieved, as well, by the application of more plaster. Straw is very low in embodied energy (Embodied energy is the total amount of energy which is consumed in the manufacture and transportation of a product, in this case, building materials.) compared to cement, steel or wood.

### Passive solar

Passive temperature control refers to buildings designed to maximize the heating and cooling effects of the environment around them. They are called passive because there are none (or few) parts of the design that require energy to operate.

### Resistance to pests

Straw bales are thick and dense enough to keep out many kinds of pests. As well, the outer layer of plaster makes them unattractive or impenetrable to animals and insects. Finally, because straw contains little nutrient value to most animals and insects, it does not attract pests. Plastered surface with no openings prevent the structure from infestation.

### Flexible

Straw is a flexible material and requires us to work with it somewhat differently than if it was rigid. Accurate measurement and precision is impossible and unnecessary with straw, but working without these aids can be worrying to the novice, and threatening if you're already used to 20th century building techniques. It is very important to make this clear at the outset. Rushing the process, and working alone or competitively can mean that an adjoining section of wall is distorted and pushed out of shape – a section that someone else has spent time and care in getting right. It's as much a personal learning process as it is learning a new building technique.

- Holds itself up, be self-supporting and resist tipping.
- Keep out the wind; inhibiting air/moisture infiltration.
- Resist heat transfer (insulation)
- Reduce water intrusion and migration, store and transfer moisture within the wall.
- Keep the assembly from buckling, under a compressive load.
- Keep the assembly from deflecting in a strong wind.
- Keep the assembly from bursting apart in an earthquake, when pushed and pulled from all directions.
- Hold the plaster at least while it's curing.
- Keep the plaster from cracking after it is cured, from shrinkage or movement.
- Transfer and absorb loads to and from the plaster.
- Support the plaster skins from buckling.
- Support the roof load (compression).
- Reduce damage or failure from high winds (ductility).
- Reduce damage or failure from earthquakes (ductility).
- Stop bullets and/or flying debris.

### 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.

Size of bale (in mm) 900 x 450 x 350/ 584 x 1168 x 400  
 Modulus of Elasticity 1379 KPa  
 Compressive Stresses More than 482.7 KPa

Structural bale-suitable for one to two storied building. It is also known as Nebraska style and is considered as the first technique of construction. The entire load is being beared by the straw in this case so it is also known as load bearing method. In this case door should not exceed 50% of wall surface. In this process roof of the building is constructed at last. This is the original method of building, pioneered by the Nebraskan settlers in the USA. In this method, the bales themselves take the weight of the roof - there is no other structural framework. They 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. The roof plate 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. Windows and doors are placed inside structural box frames, which are pinned into the bales as the walls go up. This is the simplest method and the most fun way of building - it requires little previous knowledge of wall construction and is very accessible. Owner-builders tend to prefer this method because of its simplicity, ease of design, minimal use of timber, and the opportunity it affords for a modern day wall raising. The potential for empowerment through working together on a shared project is one of the main differences between this type of building and any other.

Considerations for strawbale construction that should be followed without failure:

- 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.
- Openings for windows and doors must not exceed 50% of the wall surface area in any wall.
- Maximum unsupported (unbraced) wall length is 6m (20').

#### TYPES OF STRAW BALE CONSTRUCTION

##### Light-weight frame and load bearing

Suitable up till three floor. It is also known as timber framework method in which firstly timber framework is prepared and in those frame only straw is installed. In this timber would be an additional material or any other framework material. In this frame should be provided for doors and windows. In this roof should be constructed at first only.

One of the most important design features of a load bearing straw bale house is to distribute the loads as evenly as possible around the whole building. Never use point loads. Timber posts are located at corners and either side of window and door openings only, and are designed such that the timber wall plate at first floor and/or roof level can be slotted down into them once the straw is in place allowing for compression on the bales. Compression of the straw bale infill walls is essential for stability. To increase stability, the bales are pinned externally and the pins are secured onto the base and wall plate of the

framework once all the settlement of the walls is complete. It is constructed in such a way that the wall plate and roof are kept 100mm above the finished straw wall height whilst the wall is being built allowing for compressive settlement of the straw wall once the bracing and props are removed.

##### Advantages

- The roof can be constructed before the straw is placed providing secure weather protection.
- Framework and posts can be constructed off site.
- Provides greater stability for window and door frames than in the load bearing style.
- Vastly reduces the amount of timber required compared to the more traditional post and beam method.

##### Disadvantages

- It is more complicated than the Nebraskan style to construct.
- Greater technical ability is required to make the structure stable whilst the straw is being placed.

##### Post and beam or timber frame also called infill

Non structural bale-More than three storied. It is also known as in fill method. In this building with post and beams are made with timber or steel. In this weight is supported by the frame. Wood, Steel or concrete framework and the bales are simply infill insulator blocks between the posts. It gives great stability and cost is also high in compare to others. In this also roof should be constructing at first. In this way, as per the accessibility we can select any one way of construction which encompass ancient till modern way of construction. If our budget is low than selection of Nebraska style of construction is more preferable than others. In this method, 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 preferred option for architects, as the structural concepts are not innovative and rely on an already established method of building, therefore the risk associated with an experimental technique is minimized. There is no need to satisfy oneself of the capacity of the bales to take the weight of the roof, since the framework does this. This method requires a high level of carpentry skill and uses substantially more timber than a load bearing design, which has significant cost and environmental implications.

##### Advantages

- The roof can be constructed before the straw is placed, giving secure weather protection.
- Framework and posts can be constructed off site.
- Provides greater stability for window frames than in the load bearing style.

##### Disadvantages

- It is more complicated than the Nebraskan style to construct.
- It requires a high level of carpentry skill (or metalwork experience in the case of a steel frame) to construct the frames.
- It uses a large amount of timber.

## Conclusion

Instead of being unwanted and difficult to dispose of, rice straw would become a valuable commodity to be harvested for profit. 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.

The emissions from eventual burning or decomposition of the straw are postponed. Straw is produced by photosynthesis, a natural, non-polluting process fueled by solar energy. Straw is an annually renewable agricultural residue often considered a waste product. So it is environmentally friendly. 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.

In this study describes briefly the utilization, applications of agro-wastes in construction industry. Agriculture is the most important economic activity of India and so in other developing countries. There has been a rapidly increase in the agro industrial field in last two decades which has caused substantial increases in the volume of agricultural residues of different types. In current shortage of wood and other building materials for ever rising increased housing requirements have created great interest in those agro-wastes. These agro waste materials reduced building cost. Utilization of agricultural wastes helps in environmental prevention and prevention of agriculture land.

## Recommendations

- It is obvious that straw bale buildings are efficient in achieving comfort in a harsh weather resembling the climate of new urban areas in India 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.
- I recommend also that architects, advisors and contractors who see its value in terms of cost effectiveness, sustainability, ease of insulation and energy efficiency to make further examinations on straw bales to include it in Indian building codes to live happily in healthy environment and enjoy a comfortable life of economics of the system.

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