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"Recycling rice straw as a type of agricultural solid waste"

Alternatives of using rice straw in Building construction as a tool to protect the environment in Egypt.

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Abstract

The research aims to develop alternatives of using rice straw in construction as a tool to preserve the environment in Egypt. where the rice straw is one of the types of solid agricultural waste, which is produced in Egypt in large quantities, as a result of the lack of strategy by the State for how to collect rice straw from farmers to recycling to benefit from them. Farmers burn it, which causes the formation of a black cloud annually in Egypt and resulting environmental problems and health damage. Therefore, it was necessary to research how to get rid of rice straw by making use of it in recycling and using it in different ways in construction work in order to maximize the economic return from it as well as to preserve the environment in Egypt. The research paper deals with alternatives to benefiting from rice straw, and these alternatives can be considered as a methodology or framework that the government may benefit from in addressing the environmental problem facing the country annually.

Keywords: Solid Waste, Solid Waste Agricultural, recycling rice straw, rice straw bales, sustainable construction.

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1. Introduction

Rice straw is the most agricultural solid waste available in Egypt, which it's burning causes the formation of the black cloud annually and resulting environmental damage. Therefore, it was necessary to think about how to benefit from rice straw in construction work through its recycling and use in the manufacture of various building materials from bricks and materials Filler for walls and internal partitions. where the research deals with a study of those alternatives that can be used by the Egyptian government in the recycling of agricultural waste, and therefore work on collecting rice straw bales from farmers instead of burning them in the fields and thus can contribute to benefiting from those wastes economically and contribute to preserving The environment and the health of citizens in Egypt.

1.1 *Research problem*

The problem is summed up in the annual burning of rice straw that causes the formation of a black cloud and the resulting environmental and health damages to citizens, as the lack of a methodology by the state to benefit from it as an industrial raw material, this leads to farmers burning rice straw in the fields.

1.2 *Research objective*

Develop a set of alternatives to take advantage of rice straw as a raw material for construction, with the aim of working on recycling rice straw as a agricultural solid waste to get rid of it in a clean way and to maximize the economic return from it, and thus contribute to protecting the environment.

2- Research Structure

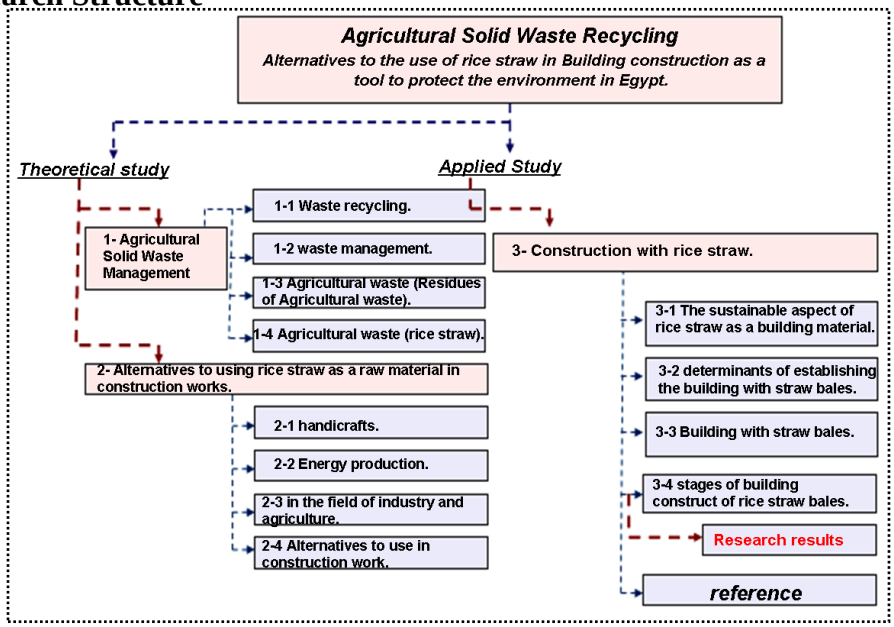


Fig. 1: The Research structure (**Source:** Author).

3. Agricultural solid waste management.

3.1 waste recycling:

Recycling wastes is the entry of the material through a system that enables it to be used again, and the material resulting from this process is considered less harmful to the environment and energy consuming, and **fig. (2)** Shows the degrees and methods of waste recycling **(The waste hierarchy)** to achieve maximum benefit from the product and reduce the amount of waste, and there are some definitions related to waste recycling, including **[9]:**

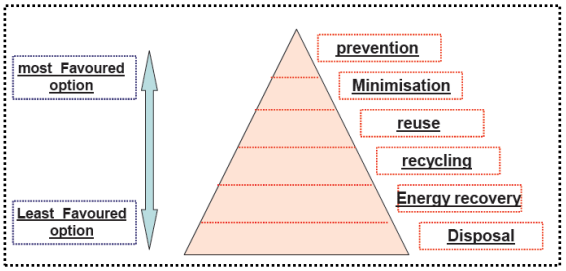


Fig. 2: Degrees of waste recycling (**Source:** ref. [9]).

3.1.1 Re-use: is the use of the element more than once, and the element may be used again in the same job or used in another job **[9].**

3.1.2 Recycling: It is the dismantling of the element used in raw materials to obtain new elements **[9].**

3.1.3 Advantages and disadvantages of the waste recycling process:

The waste recycling process has some advantages and disadvantages, as shown in **Table (1).** Among its advantages are contributing to the disposal of waste, reducing environmental pollution, saving energy and raw materials, obtaining a new product with a lower cost, in addition to preserving some of the most valuable elements, and among the disadvantages of waste recycling Obtaining dangerous materials, it may increase the cost of the new product because it needs cleaning, transportation and labor, it takes some time to complete the recycling process, which affects other tasks **[10].**

Table (1): Advantages and disadvantages of waste recycling (**Source:** Author).

Advantages of waste recycling		Disadvantages of recycling waste	
1	It reduces waste and environmental pollution to achieve the idea of sustainable development.	1	Recycling may affect cost as it requires cleaning and transportation.
2	Save the energy involved and raw materials.	2	Some materials are hazardous and inefficient in energy when recycled.
3	Reduce the need to dispose of waste and protect the built environment	3	Reusable materials require durability
4	Creating job opportunities for young people and low-income people	4	Preparing materials for reuse may take some time, which harms consumers and costs investors
5	The new product is less costly to the consumer	5	In some cases, the process of reusing building materials encounters some obstacles, such as the high cost of labor,
6	Preserving some of the oldest and most important elements		

3.2 Waste Management:

Waste management is an element of sustainable development that reduces the impact of human activities on public health, the environment and urbanization. Waste management includes the process (collection, classification, cleaning, transportation, product planning and possibilities of use, recycling and reuse of waste or the process of disposal according to the cost study), and the previous steps are governed by a set of environmental, economic and health laws. Waste management includes different materials (gaseous, liquid and solid) and the different methods that suit each of them, whether from residential, commercial or industrial sources. As for hazardous waste, it is the responsibility of the places of generation **[1].**

3.3 Types and sources of solid waste:

There are many types of solid waste, including industrial and agricultural solid waste, municipal solid waste, and waste resulting from building and construction works.

Among the solid waste sources are:

3.3.1 Industrial waste:

Such as cement dust produced during the cement industry, blast furnace slag for iron production, construction industry waste (the construction industry produces a large amount of solid waste such as broken bricks and concrete and surplus aggregates and iron) **[1].**

3.3.2 Agricultural waste:

The problem of the accumulation of solid agricultural waste (Agricultural waste) in the fields and sides of water drains is a real environmental problem, where various pests of rodents and insects are produced. On agricultural roads and the spread of many chest diseases (in a study by the Ministry of Environment in 2003, it was found that the burning of agricultural waste in the months of October and November of each year is responsible for 42% of the black cloud phenomenon, while car exhaust and industrial radiation are responsible for 23% of the phenomenon, garbage burning is responsible by 12%), and the importance of the causes of acute episodes of air pollution (black cloud) varies according to the location of the pollution and the time of occurrence. Therefore, forecasting these episodes is a great challenge, especially when expected changes in weather conditions or pollution sources occur **[2].**

3.3.2.1 Benefits of using agricultural waste:

The reuse of agricultural waste (Benefits of using residues) is an important pillar for the self-development of the local community because of its economic, environmental and technological benefits as follows **[2]:**

A- Economic benefits:

Agricultural waste represents an annual waste of valuable wealth. The use of agricultural waste raises the economic return from agriculture, as it allows the farmer to sell not only the basic product, but also the by-products of agriculture, and its cost is reduced to just the cost of transporting it from the site of its existence and circulation to the site of its manufacture or use. It is therefore far from the fluctuations of the national and global market.

B- Environmental benefits:

Several environmental studies have proven that burning agricultural residues causes economic problems such as soil erosion and a lack of soil vital activity, and consequently a lack of yield. The use of agricultural waste protects the local environment (Environment) from the risks resulting from leaving it and not using it (mites - rodents - diseases - parasites).

It also protects the local environment from the risks resulting from wrong disposal methods such as open burning. Burning agricultural waste leads to an annual increase in carbon dioxide (carbon dioxide resulting from burning 1 ton of straw reaches 56 thousand tons), and this results in many health problems. And the spread of chest and respiratory diseases and allergies **[3].**

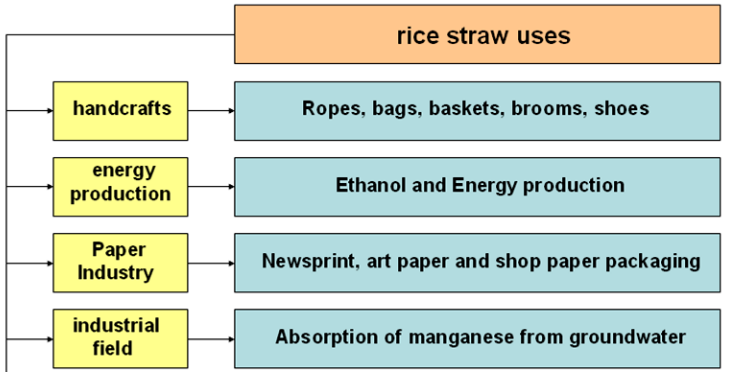
C- Technological (technical) benefits:

Agricultural waste represents a basis for a new industrial wealth starting from the countryside and desert communities, and an opportunity to build self-scientific and technological capabilities in important industrial fields in Egypt. The use of agricultural residues is the best alternative for cutting, transporting and processing wood worldwide, and some agricultural residues were used for many industrial purposes such as paper, construction, and others.

4. Alternatives of using rice straw.

4.1 Alternatives of burning rice straw:

The largest country in rice cultivation, such as Southeast Asian countries and the United States of America, does not suffer from other rice straw problems. Many economic industries to raise the economic return from agriculture depend on methods and techniques for many handicrafts, paper and energy production, agricultural, industrial and engineering fields, in the field of construction, architecture, etc. **Fig. (3).**



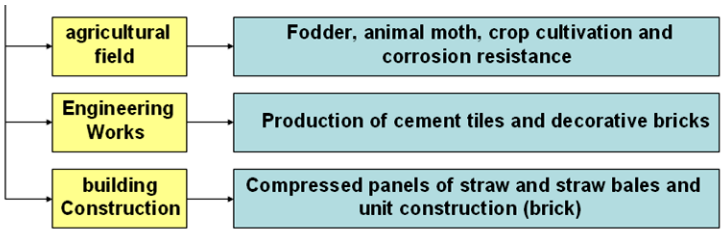


Fig. 3: Rice straw uses (**Source**: Author).

4.1.1 Handmade Industries:

Straw is included in many handmade industries that find great demand for its distinction and beauty, such as ropes, bags, baskets, brooms, sandals, shoes, cushions, seats and other handicrafts.

4.1.2 Energy production:

Converting waste into energy technology is considered one of the most environmentally friendly technologies in the field of waste recycling. And it has been possible in many global cities to establish factories to use rice straw as a direct combustion agricultural waste to produce ethanol (direct combustion). And generate energy (Energy production), and convert to gas (Gasification), Figure (4) shows the steps for converting rice straw into gas and producing energy **[11].**

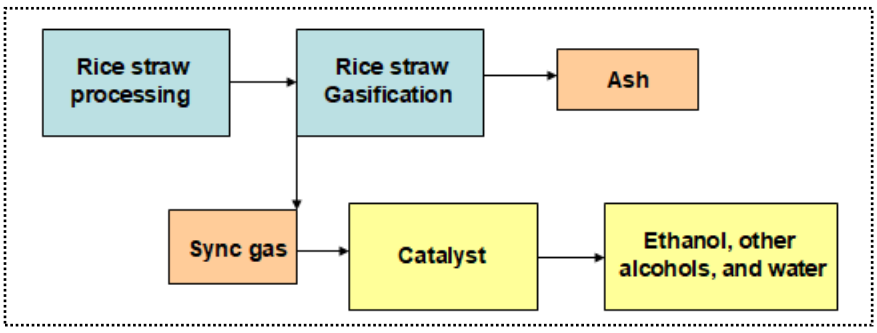


Fig. 4: Steps to convert rice straw into gas, and produce energy (**Source**: Author).

In Egypt, fuel gas was produced from rice straw in cooperation with the Ministries of Petroleum, Agriculture and Military Production, the Arab Organization for Industrialization and within the framework of Egyptian-Chinese cooperation. Egypt was able to benefit from the Chinese experience through the Agricultural Research Center in Sichuan State – Chengdu **[12].**

The straw-to-gas conversion technology includes the following stages: pressed straw storage (15 thousand tons), straw shredding unit, straw burning unit up to 1500 ° C, resulting gases control unit, Wet Scrubber filter, gas tank (nitrogen gas 41% gas Carbon monoxide 27% methane 13% hydrocarbons 4% other gases 15%) **[12].**

The modus operandi of the gas conversion unit: collecting gases after burning and filtering, experimenting with gas according to the color of the flame, allowing gas to pass into the tank. The tank operates in a method of gas storage above the water surface. The tank cover rises according to the volume of gas. The measurement mark determines the fullness of the tank (350 m3 of gas). And when the gas is consumed, the incinerator is restarted to pump new quantities of gas, the gas network for delivery to the stations, where (Natural Gas) is establishing a network to feed 300 homes, and 100% Egyptian gas was manufactured in the military factories, where this gas does not need a regulator or a control dial (Instead of buying the Chinese stove, which costs 80%, the military factories and the Arab Organization for Industrialization manufactured a lighter that will be used to operate bread ovens and in the future brick and pot factories) **[12].**

4.1.3 In paper industry:

The paper industry has spread from agricultural waste such as rice straw many years ago, where the straw is processed and the rice straw pulp is mixed with some other materials to produce paper, which is exactly what happens when the cellulose material resulting from the wood industry (which represents 95% of the cellulosic raw materials used) can be produced. Many types of paper, such as newsprint, paper for art purposes, paper packaging for shops, and in Egypt there is a paper factory (RakTA) that uses about 5-7% of the available rice straw in the manufacture of paper (3 tons of straw = a ton of paper), The paper pulp industry in Egypt has been remarkably successful, but this industry results in some wastes that have a bad impact on the environment, such as black liquid and waste water. The waste has been used in the manufacture of some types of cement bricks and balustrades in an attempt to find an economic value for recycling in addition to reducing the rates Pollution from the paper industry **[13].**

4.1.4 In industry field:

Rice straw was used to absorb manganese from groundwater, and rice straw was chosen for its application as a leading material in the absorption process because of its stable chemical

composition, high mechanical strength, and inability to water, in addition to its low cost **[4].**

4.1.5 In agriculture field:

Currently, rice straw is used in the production of non-traditional animal feed (Animal Feed), after treating it to raise its nutritional value (using urea and injecting with ammonia). In Egypt, the protocol signed between the Ministry of Environment and Agriculture was implemented to take advantage of rice straw by converting it into industrial organic fertilizers (compost-fertilizer), to fertilize agricultural land **[5].**

• Rice straw is used as a butterfly for animal bedding, as it contributes to absorbing moisture.

• Rice straw is also used as a preventer of weeds in the soil.

• Cultivation of some crops on rice straw bales.

4.1.6 In engineering works field:

Rice straw can be used for erosion control on construction sites and highways, and for soil protection. It can be used as bales or loose straw, or as wattles and blankets (in California, about 7,500 tons of rice straw are used annually in the form of bales and loose straw to combat erosion) **[5].**

• Utilizing rice straw waste and cement kiln dust waste in the production of new quality reinforced cement tiles (Al-Mazaiko), according to Egyptian Standard No. 269 for the year 2003.

• Rice straw is used in the manufacture of ceramic bricks.

4.2 In construction and architecture field:

Rice straw can be used in the field of construction in several ways, including the construction with a unit made of straw (brick), pressed straw sheets of different thicknesses, in addition to the construction with straw bales, which is related to the current study, and Figure (5) shows the different methods of straw construction.

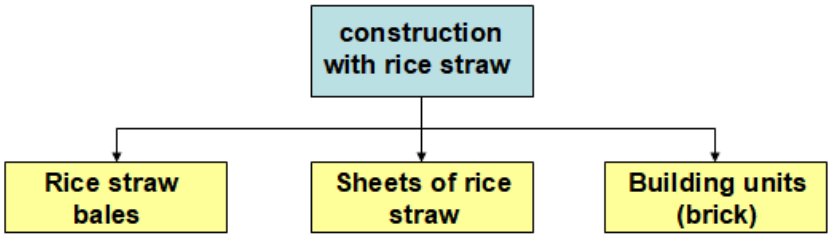


Fig. 5: Different methods to construction with rice straw (**Source:** Author).

• Production of building units (bricks):

Rice straw can be mixed with other materials using unconventional technology to produce various products such as Bricks, Roofing Tiles, and these products are characterized by light weight and heat insulation **[5].**

4.2.1 Production of straw panels:

Some companies in North America have produced building panels of compressed straw of different sizes to be used for many purposes, including **[6]:**

4.2.1.1 Compressed straw sheets:

The production of compressed agricultural fiber CAF began in Sweden in 1935 by (Theodor Dieden), then the commercial product was developed in Britain under the name Stramit by (Torsten Mossesson) in 1940 and since then many companies have used this product around the world. The world has been built about 250,000 buildings using these panels **[6].**

All products for this technology use an important property of straw, which is the adhesion of straw fibers together when pressed under a high temperature of about (390 F or 200 C) without any adhesives . where the resin melts into the straw somehow, but there are some objections to this, as the heat makes the straw weak, but if the material cools, the fibers remain in place, and these panels can be used as external walls in buildings, and a number of houses have been implemented in this way **[6].**

The stramit panels range from 50 to 100 mm and are covered with sheets of heavyweight brown paper. They are mainly used for internal partitions, internal partitions (for bathrooms, kitchens, offices and schools), where there are places for electrical connections and panel connections to each other, and is also used for doors and light ceilings.

Straw boards have been used in the construction of some modern buildings to achieve environmental sustainability, enjoy a healthy and comfortable environment, build a strong and cohesive society, take advantage of the properties of straw in thermal insulation, and reduce energy consumption. The design came to express the maximum benefit from natural lighting. **Fig. (6)** shows how to install straw compressed panels in the foundations of the building **[6].**

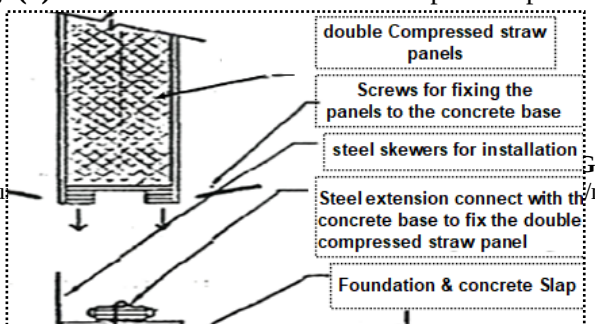


Fig. 6: The method of installing compressed straw panels in the foundations of the building. (**Source:** ref. [6]).

4.2.1.2 Thin Straw panels:

Some companies in California have produced thin panel pressed straw (thin panel) which is characterized by light weight, high density and thickness ranges between 1-4 inches for use in the walls of prefabricated buildings, and these panels have durability and good insulation properties (R14) alternative to using other insulating materials. Companies are planning to produce thin sheets for furniture, which is more weather-resistant, non-toxic (formaldehyde-free), and does not radiate pollutants to the environment during manufacturing and after installation **[6].**

4.2.1.3 Bales of straw to build an acoustic wall:

Rice straw is a suitable material for creating acoustic barriers (Straw bale sound walls) along highways and around residential communities, to reduce noise pollution and as safe and durable barriers in addition to the property of absorbing heat **[6].**

4.3 Construction with straw bales:

It is the direct method of using straw in construction, and straw has been used for many centuries by builders who knew its structural integrity and straw is simply a tube of cellulose (tubes are among the strongest structural forms). The straw was initially used to strengthen the mud and protect it from cracking, and in the late 19th century construction was carried out using new building blocks (rectangular bundles of straw) with the invention of the baler in the form of bales. The method of building with straw bales has returned to be taken more seriously, and is likely in the long run to be more important for the construction sectors, whether using straw as a building material or building products from straw. The consumed quantity of local rice straw used in Egypt in all the previous fields can be calculated as in **Table (2) [6].**

Table (4): The consumed quantity of local rice straw used in Egypt in all fields (**Source:** ref. [5]).

field of use	rice straw uses		The consumed quantity of local rice straw
	under studying	actual application	
handcrafts		•	3500 tons
power/gas output		•	15000 tons
Paper Industry		•	13000 tons
Adsorption of manganese from ground water	•		-
unconventional feed		•	8000 tons
Industrial organic fertilizer		•	25000 tons
floor covering for animal husbandry		•	7000 tons
Inhibitor the growth of weeds in the soil	•		-
Cultivation of some crops		•	10000 tons
Corrosion control on construction sites and highways			-
reinforced cement tiles	•		
ceramic bricks industry	•		
Production of building units (bricks)	•		
Production of straw panels			
Create with straw bales			

total consumption			**81500 tons = about 25% of the quantity produced**

Although there are several researches to find economical uses for rice straw, the main objective of which is to reduce or eliminate burning, but the beneficial uses actually applied to rice straw in Egypt are about 25% of the produced quantity, which is a very small percentage indicating that the amount of straw available is much more than Local uses [5].

By using rice straw in construction, most degrees of waste recycling can be achieved. It is re-use and reducing its quantity, as shown in **Fig. (7),** which achieves the goals of sustainability.

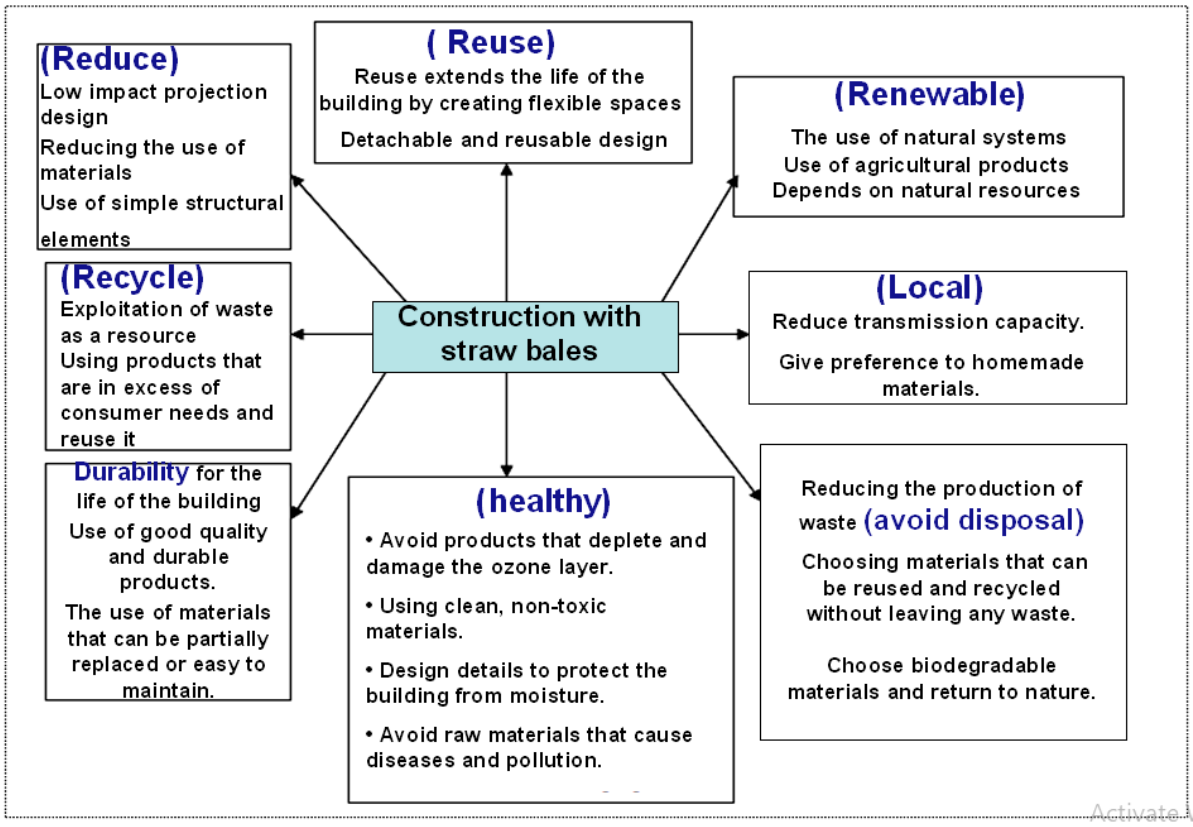


Fig. 7: Recycling and using rice straw in construction achieves the goals of sustainability (**Source:** Author).

5. Construction with rice straw bales.

The construction with straw bales as one of the agricultural solid waste is one of the alternatives to making use of rice straw as a direct way to use straw in construction. It is also considered one of the government's encouragement for farmers to eliminate the problem of straw burning and the resulting serious environmental and health problems.

5.1 The sustainable aspect of rice straw as a building material:

The building is part of the local ecosystem, and when construction begins, the project must be evaluated from the perspective of its environmental impact, where all precautions are taken to protect the local environment, and to preserve the components of the natural environment (trees, water, natural plants, valleys) and the results of the evaluation affect the design of the building Its activity and method of construction **[6].**

5.2 Sustainable Buildings:

They are those buildings that are designed and constructed with available building methods and materials and do not negatively affect the environment and the health of users, builders and future generations. Sustainable Buildings deals with many considerations, including land use, impact on the site and the surrounding environment, energy and water depletion, waste disposal, And the study of assessing the environmental impact of buildings and their building materials, and sustainable construction aims to reduce dependence on non-renewable energy, appropriate methods of waste disposal and management of its recycling, the design of the building that will keep it continuous in the long term, in addition to the use of appropriate local building materials that achieve sustainability **[6].**

5.3 Sustainable Building Materials:

Sustainable building materials are those materials used in construction that achive environmental, technological, social and economic standards, so that they are local and natural as much as possible, and their use does not lead to a negative impact on health aspects, is not characterized by toxicity, and is renewable, durable and recyclable. Low energy consumption, low wastage, socially acceptable, and be appropriate in terms of cost **[6].**

Rice straw is considered a sustainable building material because of its advantages through the three dimensions of environmental, social and economic, **Fig. (8),** It is represented in being a local material that is renewable annually and as one of the agricultural wastes to protect the environment from pollution by using it in the construction and coordination of the site and then returning to nature again. And because of its excellent insulating properties, fire and insect resistance properties, low energy content, low cost, durability, and aesthetic properties **[6].**

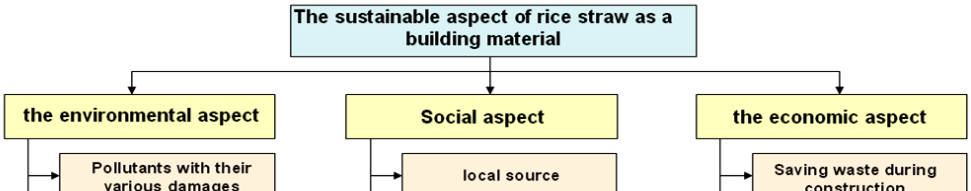


Fig. 8: The sustainable aspect of rice straw (**Source**: Author).

5.4 Construction with rice straw bales:

Rice straw is one of the most available agricultural wastes in Egypt, which is burned and causes environmental pollution. From here, we explain a complete model for the exploitation of rice straw as an alternative building material, and it is included in the manufacture of a new quality of bricks, and its components include sand and straw in addition to cement, to form a distinguished brick globally that contributes to preventing Pollution, and achieving a double benefit in the use of waste materials from rice straw, which has become one of the causes of environmental pollution and the spread of the black cloud, which opens the way for small industries based on brick-making in villages and cities, absorbing the energies of youth, and pursuing urbanization with less expensive and higher productivity building materials **[14].**

5.4.1 Brick Industry from rice straw:

The brick-making experiments, which reached, were implemented through the manufacture of about 250 experimental mixtures with different proportions of sand, gravel, rice straw and cement to choose the best mixture for manufacturing bricks with the standard dimensions in length, width and height, which are 12, 25 and 6 centimeters, and making successive choices to determine the specification of the new brick while comparing it with Common or well-known types of bricks in the local market.

The brick industry in other international experiments focused on using the product of rice straw fire, some curing additives for cement to produce special mixtures of concrete, but the Egyptian brick can be used extensively in erecting blocks and building bricks with the use of biological reactions to convert rice straw into organic compounds that are formed for the manufacture of blocks Hollow or building bricks, and these experiments have already been successfully applied using rice straw to construct building units of cement, gypsum and clay.

5.4.2 Construction system with straw bales:

There are many construction methods with straw bales, including: load-bearing walls, Lightweight frame reinforced load-bearing walls, structural walls, hybrid system and mortar bales, and each of these methods has its advantages and disadvantages in terms of ease of construction, need for manpower, and the area of possible openings...etc , **fig. (9) & (10).**

Fig. (9) & (10): Construction with rice straw (**Source**: **[14]).**

5.4.2.1 Bearing walls:

In the case of using straw bales as bearing walls (load-bearing straw bale construction), the bales are stacked and piled inside the walls, and the weight of the roof is supported directly on them, and a number of houses built in this way still exist today.

The outer surface of the bales in the load-bearing wall system is an important part that helps in transferring the loads and helps in this by stacking the bales, the used layer of whiteness, as well as the wire mesh that helps to hold the bales together and may be placed on all sides. The use of wire mesh depends on the expected moisture content on the surface of the bales wall, as this may lead to a crack in the surface of the used white.

The load-bearing walls system is characterized by the low use of timber, and it is recommended to design simple square or rectangular projections to distribute the roof load evenly on all walls. The buildings are usually limited to one floor and a few windows and doors, and bales are stacked on a poured concrete base with a height of 150 mm, and some construction prefers three-link bales. Because they are wider than double-linked bales, the

walls are more stable, and the wooden frames of windows and doors are installed above the rows of bales **[14].**

5.4.2.2 Load-bearing walls supported with Lightweight frame:

The straw bales load-bearing wall method supported by a lightweight frame, is characterized by Retaining the advantages of the construction method with load-bearing walls, but it is characterized by the possibility of building the roof before the walls to protect from the weather during the process of raising the wall.

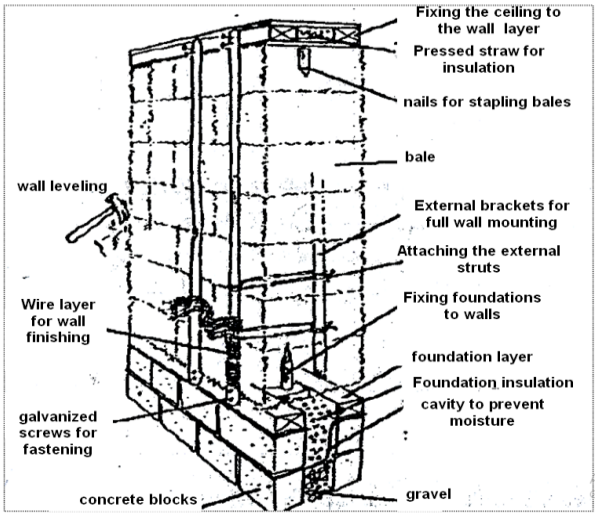


Fig. 11: Bales stapling inside light-weight frame-reinforced load-bearing walls (**Source**: **[14]).**

Lightweight wooden frames are used that require temporary fixation until the bales settle in their places, but straw represents the main aspect of stabilizing the construction to a greater degree than wood, and it works with wood to carry the weight of the floors and the roof. The wooden columns are placed in the corners and sides of the door and window openings only. One of the disadvantages of this system is that it is more complex than the load-bearing walls system.

5.4.2.3 SKeleton walls:

Structural walls (in-fall straw-bale construction), (post and beam), (timber frame) a structure consisting of a beam and column made of wood, iron or concrete), the ceiling anchors and is designed to comply with earthquake code and construction safety and straw bales are used as a material Fluid between the columns bearing the finish of the walls from the inside and outside.

928,

Fig. 12 & 13: The wooden structure of the building, straw bales as a filler (**Source**: **[14]).**

The need to reinforce the bale walls is reduced and the bales can be stacked on the edge, and the design becomes more flexible to create irregular and trussed roofs, multi-storey buildings (multiple stories) height of one and a half or two floors, and compound horizontal plans can be designed, different glass openings in multiple places.

5.4.2.4 Hybrid System:

While there are many differences between the two previous construction systems, Texas designer Pliney Fisk created a hybrid system that uses elements of the previous two systems, such as building three walls that carry loads and a fourth that is a frame to allow for more glass. This system was tested for structural performance in Canada in the 1980s. Produce a very solid wall system but the thermal performance is not good due to the heat conduction through the point of the mortar **[14].**

5.4.2.5 bales of mortar:

Mortared bearing walls or structural mortar bales, placed between straw bales is a mortar consisting of Portland cement and sand and when dry, the building remains cohesive. This method has been developed in Canada, and it has a building code. The bales are finished inside and out to protect the bales from climatic factors and have an attractive shape **[14].**

5.4.2.6 replacing parts of buildings:

Straw bales are used to replacing parts of old buildings (retrofits of existing buildings) Thermally inefficient, such as stone block buildings, (cinder block), cement buildings (cement), metal buildings, wood-framed building and brick buildings (adobe structures) to increase their efficiency depending on the high insulation ability of straw bales.

Table (5): Explains the advantages and disadvantages of construction systems for walls of straw bales (**Source**: Author).

Walls of straw bales	Advantages	Disadvantages
bearing walls	- Possibility of construction and low cost. - Ease and for non-professionals in construction and design. - Multiple projections from one room to more, according to marital status. - Diversity of curved and circular projections, etc. Construction speed.	- The need to keep straw bales dry during the construction process until it is finished, and this may be difficult for the large building or in the case of slow construction. - The area of window and door openings shall not exceed 50% of the wall area. - The maximum height of the unsupported wall is 6 m
bearing walls reinforced with Lightweight frame	- The possibility of constructing the roof before the walls to protect against the weather. - Gives greater stability to windows and doors. - Reducing the amount of timber compared to traditional construction.	- More complicated than the method of construction with load-bearing walls. - It requires more technology to design the building.
Skeleton walls	- The roof can be built before the walls to protect against the weather. - It gives greater stability to windows and doors than the load-bearing walls method. - Creating a large living space.	- More complex than the previous system in the design of the building. - Requires a high level of skill to build the structure. - Use of a large amount of wood.
Hybrid system (combining load-bearing and structural walls)	- Combines load-bearing and structural advantages, possibility of construction and low cost.	- Use of a large amount of wood. - Experience in design and construction is required.

	- Diversity of projections in shape and area. - The roof can be built before the walls to protect against the weather. - Creating a large living space. - Larger window and door space.	
bales of mortar	- Solid structure with an attractive shape	- needs more building workers and uses a quantity of cement and is exposed to moisture to use the cement on the straw directly

5.5 stages of straw baling construction:

The techniques used in the construction of straw bales are related to the urgent need to reduce the cost, materials and energy used, and the construction elements of the straw bale house can be arranged from bottom to top as follows **[15].**

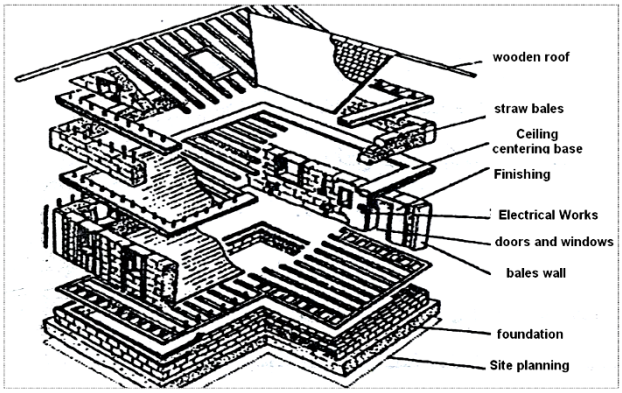


Fig. 14: Construction elements for straw bale house from bottom to top (**Source**: **[15]).**

5.5.1 Construction of the foundations:

It is necessary that the design of the foundations (footing) for the buildings of straw bales Compatible with the technical specifications and engineering requirements that achieve the safety and safety of the building as follows **[15] :-**

1- The width of the foundations is proportional to the thickness of the bale wall (the minimum width of the foundations is the width of the bale they are carrying in addition to the thickness of the finishing).

2- Foundations bear the weight of the bale wall plus live and dead loads (a straw bale wall requires foundations of the same bearing capacity as a normal masonry wall, although a straw bale wall has a lower weight).

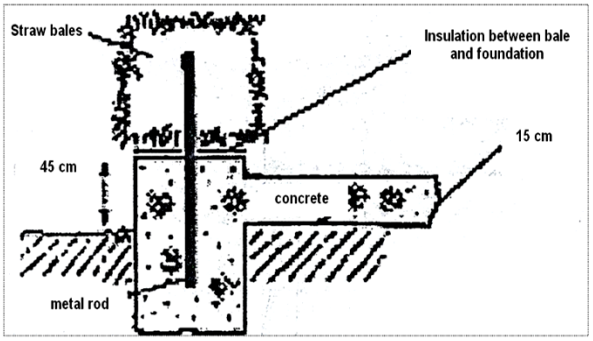
3- The foundation wall (which holds the bale walls) extends in the facade with a distance of not less than 10 cm above the ground from all points to protect the bales from moisture, ground water and rain.

4- Appropriate materials are placed on top of the foundations such as (roofing felt/asphalt/emulsion/plastic/galvanized metal flashing/ sealer) to protect the bales from moisture and insects.

5- Stapling the first row of bales by placing (Rebar Pins) in the foundations, which is in the form of (1-shaped), two per bale, and in order to be stable in the foundations, they must be placed at a depth of 15 cm (at least) and extend outside the foundations by 30 cm (at least) **Fig. (15).**

5.5.1.1 Foundation types for straw bale building:

There are many types of foundations for a straw bale building, including concrete foundations, rammed earth foundations, stone foundations, post or pier foundations, and car tire foundations for each type. Of the foundations its advantages and disadvantages.



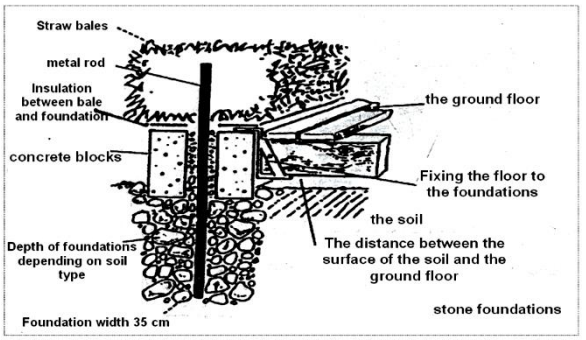
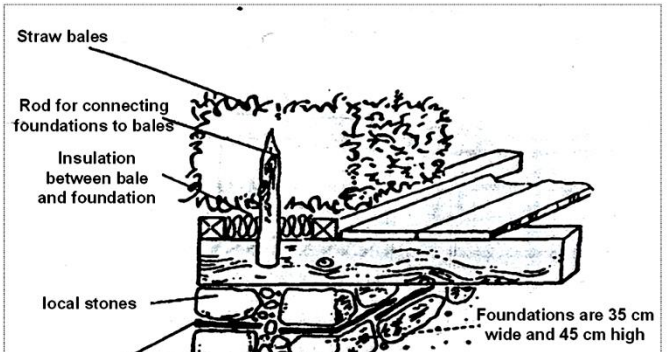


Fig. 15: straw bales concrete foundations **Fig. 16:** straw bales stone foundations (**Source**: **[15]**).



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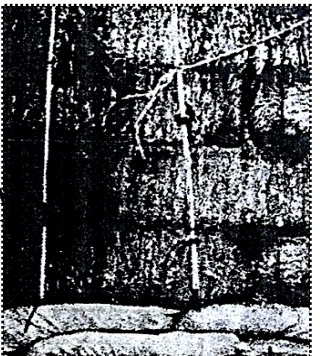


Fig. 17: straw bales stone foundations

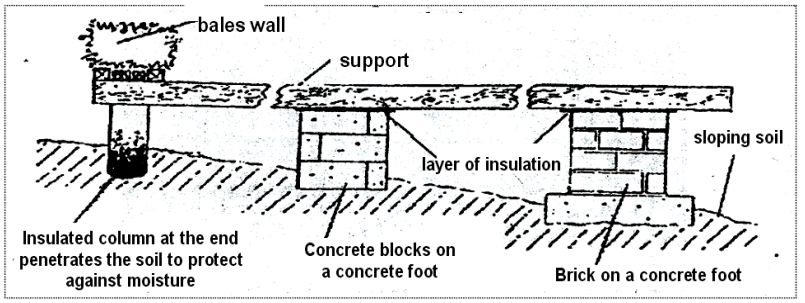
Fig. 18: Foundations consisting of bags filled with natural soil (**Source**: **[15]**).

- **Foundations consisting of bags filled with natural soil.**

A trench for the foundations is excavated and polypropylene bags filled with natural soil materials (fracture concrete, stones and gravel) are stacked on top of each other and stapled with wood panels to create a wall on which the bales rest.

- **The wells foundations.**

- **Foundations of car tires.**



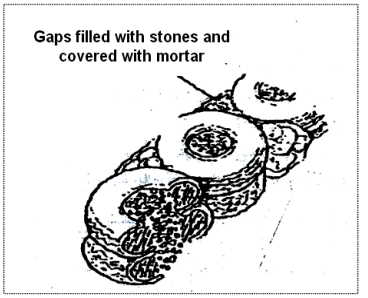


Fig. 19: An overview of foundation options that include low cost and alternative methods

Fig. 20: Foundations of car tires (**Source**: **[15]**).

5.5.1.2 Advantages and disadvantages of the different types of foundations for a straw bale building:

Table (6):.Advantages and disadvantages of the different types of foundations (**Source**: Author).

Foundation types	Advantages	Disadvantages
Stone foundation	- Consists of natural materials. - Possibility to use recycled stone - Good looking - Ease of construction with no previous experience. - The possibility of reusing it in case of demolition in other projects.	- Work requires a longer period of time - The cost increases in the absence of stone compared to other types of foundations. - The cost increases if labor is used compared to other types of foundations.
Wells foundations.	- It is suitable for similar sites because it pours easily at different heights of the earth by increasing the height of the well. - The cost is reduced if a series of wells are used. - Low impact on the environment. - Relatively easy to build -The possibility of reuse in case of demolition in other projects.	Determine the choice of design in some cases.
concrete foundations	- A common and usual method of construction. - There are no problems if carried out according to building rules. - Fast and can be done mechanically, especially on construction sites	-Not looking good. - Its creation is difficult. - You need a design that may exceed the goal of the required building. - Its cost is high. - Expensive for the environment because it needs cement with large energy in production and transportation and does not decompose naturally.

Car Tire Foundations	**- Easy to create, no previous knowledge required.** **- Its cost is very low.** **- You do not need to use insulation because the tires themselves are impermeable to water.**	**- Its cost increases when labor is used.** **- After the building is demolished, it cannot be used again.** **- Not good looking and can be finished externally.**

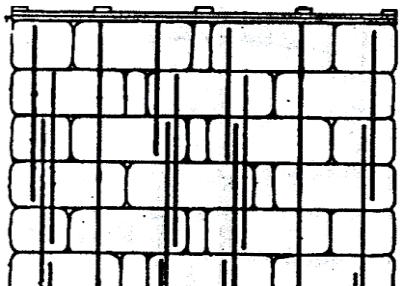
5.5.2 Construction of walls:

Wall Construction in straw buildings can be done in one of the following ways. Either as a wall filler in structural buildings, or straw bale is a load-bearing element in load-bearing wall buildings.

5.5.2.1 Construction of load-bearing walls:

In the case of for load bearing walls, the bales contribute to transferring the load from the ceiling to the foundations, where the bale stacking is on one base, and the whole bales are placed in the corners of the wall using a running bond and directed towards the center of the wall, which produces a stronger wall, more stable.

Stapled bale pinning to increase the resistance of the walls to wind and earthquakes. The first row of bales are connected to the foundations using vertical reinforced rods with a diameter of not less than 1.2 cm. They are placed within the foundations with a depth of no less than 15 cm and extend at the top of the foundations and penetrate the bales with a distance of not less than 30 cm. At the end of the wall or corners, when necessary, bars for each bale at least, and their place is determined on the central line of the bale wall, and the distance between them does not exceed 30 cm. The next rows of bales are stapled to the first row using wood or iron bars. As for window frames, door frames are installed and fixed to the foundations before stacking the bales. As for window frames, they are installed during construction and fixed with bars connected to the foundations



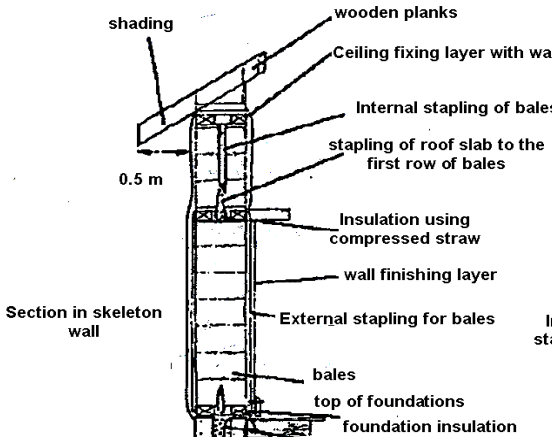


Fig. 21: The method of stapling and stacking straw bales bearing and section in skeleton wall (**Source**: **[16]**).

Fig. 22: Section of straw bale wall

5.5.2.2 Construction of walls in structural buildings:

In the case of structural buildings (for framed construction), this case uses straw bales as external and internal filler walls in concrete, wooden or metal structures . The structure and the beams can be constructed outside the site, and the roof can be constructed before stacking the bales to be a protection for the bales during construction. **Fig. (19)** shows two sections in two walls of a straw bale building, one of which is bearing wall and the other skeleton wall.

5.5.2.3 The inner walls of the straw bale building:

The no bale walls that adjoin the bale walls are connected with it in several ways, including:

1- Wooden dowels with a diameter of not less than 2.5 cm and sufficient length to be able to penetrate the bale with a distance of not less than 30 cm. They are placed through hollow holes in the wall stud axes, and are separated to enable one dowel to be connected to each bale.

2- Pointed wooden stakes, their dimensions are 10 x 50 cm, and their length is not less than 30 cm. They pierce the rows of bales with the pointed end.

3- Stitching or fixing the connection wall with the bale wall using steel nut, steel or plywood washer with an area of not less than 15 cm and thickness of not less than 6 mm for iron, 12 mm for wood from at least three places.

4- Brick ties using mortar and fixed to the bale wall using one of the two previous methods.

5.5.3 Flooring:

There are many types of floors used in straw bale buildings, whether in load-bearing or structural, and they can be:

1- Wood floor.

2- (Adobe) it is a mixture of straw and clay that is poured in place, then polished and left to dry. The straw is used to bind the mixture and to prevent cracking. When the floor dries, it is oiled with linseed oil, and it can be colored with dyes.

3- Tiles (dry-set pavers) where the floor area is filled with sand to the required level and then the tiles are arranged in a specific pattern and fine sand is sprinkled between the cracks.

4- Concrete floors, which are the most common floor, as it is faster to build, durable and moderately priced.

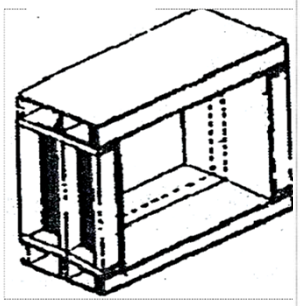
5- In all cases, it is required to use moisture insulation under the floor to prevent the transfer of moisture to the building.

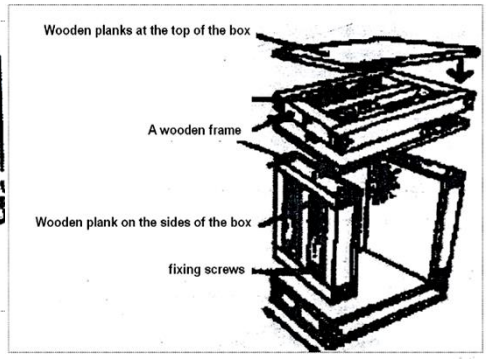
5.5.4 processing of openings (windows and doors):

1- All openings in the bale-carrying walls shall be separated from the outer corners by a distance not less than the length of the bale.

2- The openings in the outer walls of the bale do not exceed 50% of the total area of the walls, depending on the internal dimensions and the location of the wall, which gives resistance to vertical loads.

3- The load of the wall or ceiling above the openings must be transferred to the foundations using the structural window and door frames.





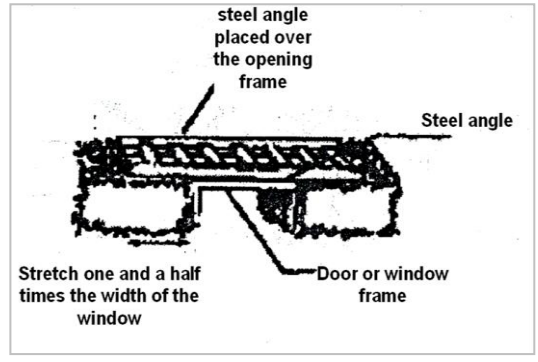
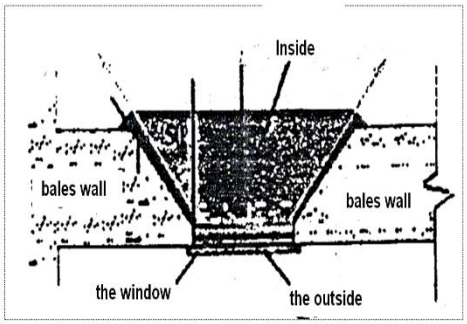


Fig. 23 & Fig. 24: Structural box frames for doors and windows **Fig. 25:** Steel angle above the openings frame, the length of which is at least twice the width of the opening (**Source**: **[16]**).

In the case of load-bearing walls, reinforced box frames are used to place the window or door, and to help transfer the load of the ceiling. As for the structural walls, all the loads from the ceiling are carried on the used structural structure, and window and door frames carry only the load of bales over the frame, so wooden frames are used to transport the loads they are exposed to. . In the case of load-bearing walls, the door frames are fixed to the foundations before stacking the bales. As for the window frames, they are installed during the construction of the wall and are fixed with the reinforcement bars of the foundations. Box frames for doors and windows are fixed in the bale walls using wooden or metal staples with a diameter of not less than 2.5 cm. These staves penetrate the sides and top of the frame at a distance of not less than 30 cm inside the bales, with a distance of not more than 90 cm from each other, at least 2 for each side From the frame, and in some cases it is possible to use an iron angle (Lintel) that is centered on top of the frame of the openings and extends to lie over the bales for a distance of not less than half of the adjacent bale on both sides as a means of increasing the support of the openings and transferring the load to the foundations **[16].**

5.5.5 choosing the openings and their locations:

Choosing the shape and location of the openings affects heat gain or loss, glare, overlooking, privacy and causes thickening of the bale walls. The design of the openings is very important so that they do not become dark caves. **Figure (26)** illustrates the design of one of the openings to direct the light to many directions inside the straw bale building. The openings (doors and windows) of the straw bale building are well insulated so that they are not exposed to rain and lead to rotting of the bales **[16].**



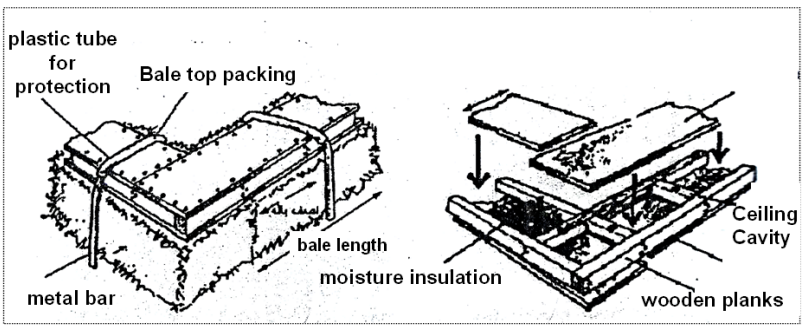


Fig. 26: The slope angle of the opening inward is 45 degrees to allow the maximum amount of light to enter **Fig. 27:** Components of the roof anchor layer on the top of the bales wall (**Source**: **[16]**).

5.5.6 Types of roofs:

There are many roofs that can be used in the straw bales building:-

In the case of load bearing structures, there are restrictions on choosing the type of roof. The most common roof is a roof that slopes down on all sides and the load of the roof is

distributed over the four walls, protecting the walls from rain and sun, and it is the best choice for resisting high wind loads.

In structural walls (non-load bearing structures), there are various types of roofs depending on the budget, required protection, character and function, such as: -

1- Flat roof: It is used in warm climates, It tends to have a slight tendency to keep rain away from the walls of the bale, and is characterized by ease of construction, and low cost, but its disadvantage is that it tends to leak, especially during periods of heavy rain, but it is necessary to carry out regular maintenance.

2- Shed roof: It is a horizontal level roof inclined in one direction from one side of the building to the other. It is characterized by ease of construction, low cost, and gives the opportunity to enter light from windows, and protect the building from moisture and sun.

3- The truss roof: It is the most popular traditional roof that leans on both sides, and is characterized by the relative ease of construction. It is an economical alternative. It gives an opportunity for a role or half a role as a place for an upper floor and places for openings, and beautifying the facade, but one of its disadvantages is to leave two sides of the house exposed to rain. And the sun can be treated by creating an exposure to shading under the main roof.

4- Planted roof: the design ranges from simple to complex, and it can be isolated and planted with local plants and herbs, and it needs regular maintenance and calculations to treat those loads.

5- Domes and vaults with straw bales: The roof of a straw bale building can be safely constructed using straw bale vaults & domes. Numerous structural tests have been carried out on the domes and vaults constructed with straw bales, and a number of straw baling structures have been constructing in the form of vaulting.

5.5.7 Sanitary and electrical works:

5.5.7.1 Electrical Works:

The electrical cables are placed in a conduit (metal or small plastic) between the cracks of the bales and the electrical points are fixed in the wooden pegs. The pipes that pass through the walls are surrounded by a plastic sheath to prevent condensation entering the bales, and the exits are fixed with wooden stakes securely with a minimum of 30 cm inside the bales **[17].**

5.5.7.2 Heating:

Heating pipes are installed under the concrete floor.

5.5.7.3 pluming:

Gas or water pipes are placed inside the bale walls in a continuous sheathed pipe to prevent leakage inside the wall, and the pipes that appear on the bale walls are insulated using suitable anti-moisture **[17].**

5-5-8 Wall finishes:

It is necessary to protect the internal and external surfaces of straw bale walls from flame damage and exposure to moisture, and insects by using appropriate finishes, while bale walls adjacent to bathrooms and showers are protected using a moisture barrier **[17].**

5-6 Economic bases and determinants:

The economic bases and determinants include the possibility of repetitive units, weight and size of units, number of floors, construction time, construction cost, financing, durability and life expectancy of the building.

5-6-1 Repetitive unit:

The construction with straw bales is still experimental, and because of the simplicity of the construction, it can accept a large number of different designs for different facilities, including school classrooms, private homes, studios, garages, and others.

5-6-2 Weight and Size of Units:

The weight of the unit depends on the shape of the design, its area and the number of bales used, and it is possible to obtain a variety of spaces from the straw bale buildings that may start with one room with an area of 30 square meters, and may reach areas of 90, 145 square meters, ..etc.

5-6-3 Number of floors and construction time:

The floors of the straw bale building do not exceed one floor if the straw bales are used as load-bearing walls, but in the structural walls it may reach three floors.

Construction time: The construction with straw bales is characterized by the speed of construction, as it may reach only a week, depending on the area of the building and the method of construction used.

5-6-4 Construction cost with straw bales:

Straw is considered a surplus product of agricultural residues. The average cost of obtaining bales from the field is 7 pounds, and the cost of pressing and transporting the bales

is 10 pounds (varies with the difference in transportation distance). The cost varies when constructing and installing a straw bale house. ,The cost of constructing and installing a straw bale building is equal to the traditional building of the same size and finishing for the same location in the following items: internal walls, floors, ceilings, electrical wiring, plumbing, lighting, heating and cooling systems, foundations, windows and doors, and there are some expenses that increase The cost of a straw bale building such as the cost of the designer and obtaining permits, site preparation expenses per square meter, excavation work, land cost and road access cost.

But its cost can be reduced by about 80% of the cost of the traditional building in the case of participation in the construction by self-efforts due to the simplicity of the construction method. The most important cost in the straw bale house is to reduce the energy used in the long run as a result of the efficiency in insulation. The following are some of the expenses for the cost of the straw bale building including:-

Concrete used, structure (in the case of structural walls), carpentry cost (doors and windows), sanitary works, these four categories represent 45% of the total cost, followed by interior and exterior finishing, electrical works, floors, bathroom and kitchen insulation, and ceilings ranging in percentage The cost is 33% of the total construction cost, so the total of the nine high-cost categories amounts to 87% of the total cost of the building. The previous categories are not all required by all builders, but the designer can find more than one way to reduce this cost.

5-6-5 Lifespan (Durability):

The secret to the durability of straw bale buildings lies in the quality, design, details, good construction, and maintenance. If this is achieved, straw bale buildings can last hundreds of years.

5-6-6 Foundations and operational determinants:

It includes the quality of the construction and the installation of the straw baling building, the construction stages, the labor, the materials used, and the equipment used in the Construction.

5-6-7 Quality of construction and installation of the bales building:

The success of the structure depends on the proper treatment of the connections (the attached area between the parts of the building) and the type of the connection is determined according to the location of the link from the building and the type of forces affecting it (joints between the foundations and the first row of the bale, connections between the bales and some of them, and the connection of the bale wall to the ceiling) in order to give the strength and

durability necessary for continuity Work of building to transfer the loades to which it is exposed.

5-6-8 stages of construction:

The success of the facility depends on the integrity and sequence of the construction stages, including foundations - walls - treatment of openings (windows and doors) - ceilings - floors - finishing.

5-6-9 the labors:

The rates of labor cost compared to other fields of activities are among the high rates in the field of construction and construction, and in the case of the participation of the beneficiary individuals, this reduces the total cost of the facility.

5-6-10 Materials used:

One of the important factors is the use of bales and building materials available locally in the establishment of the facility, in addition to knowing the extent to which these materials can cope with weather conditions, erosion factors and the various uses of the building.

5-6-11 Equipment and tools used in construction:

The construction of straw bales does not require heavy equipment as used in other construction systems, and may need cranes to lift the bales and put them in their specified places, as well as some simple tools for leveling and finishing the bales.

5-6-12 Management System:

The process of organizing and planning site construction operations is one of the most important factors that help in the smooth running and organization of work and thus to provide the total cost of construction , and the preparation of implementation programs is one of the most important basics required by the work of implementing any building , so a general plan must be developed through which the site resources can be exploited from materials And work efficiently on time.

6- Result:

The research recommended a methodology to take advantage of rice straw in construction work by putting different alternatives in front of the designer to take advantage of straw bales in all the different building elements in order to reduce farmers' disposal of rice straw by burning and the consequent formation of the black cloud and the resulting environmental problems and negative effects, in addition to develop a scientific methodology

to benefit from the outputs of rice straw and directing it in construction works contributes on the one hand to preserving the environment in addition to maximizing the economic return and benefiting from rice straw as a sustainable building material.

References

Arabic References

1- إعادة تدوير واستخدام المخلفات الصلبة فى صناعة التشييد "ندوة جامعة عين شمس فى خدمة المجتمع وتنمية البيئة من 11-13 مايو 2014.

2- مؤتمر تكنولوجيا اعادة تدوير المخلفات فى صناعة البناء – القاهرة – 11 يونيو 2015.

3- "استخدام البواقى الزراعية فى الصناعة – نموذج لدور الجامعة فى تنمية المجتمع" ندوة جامعة عين شمس فى خدمة المجتمع مايو 2015.

4- مها مصطفى الشافعى ، (استخدام قش الأرز فى ادمصاص المنجنيز من المياه الجوفية)، مؤتمر تكنولوجيا إعادة تدوير المخلفات فى صناعة البناء – 11 يونيو 2016.

5- رئاسة مجلس الوزراء ، اللائحة التنفيذية لقانون البيئة الصادر بالقانون رقم 4 لسنة 1994 م ، قرار رقم 338 لسنة 1995 م . وزارة الدولة لشئون البيئة ، المخلفات الصلبة ، 2013 م ، القاهرة .

6- نرمين مختار محمد، العمارة وتدوير المخلفات قش الأرز كأحد الحلول لتصميم مساكن اقتصادية صديقة للبيئة فى مصر، رسالة دكتوراه ، جامعة القاهرة ، 2008 م

7- فريد ، واقع الأوضاع البيئية فى مصر (لا مركزية إتخاذ القرار من خلال التخطيط بالمشاركة لتحسين الأوضاع البيئية) ، 2012 م .

8- الهيئة العامة للتخطيط العمرانى ، المخطط الإستراتيجى بعيد المدى للتنمية العمرانية لتحقيق التنمية المستدامة بإقليم القاهرة الكبرى بجمهورية مصر العربية (التقرير النهائى) ، الصفحات 230 ، 231

English References

[9] - Re-use.Avaliable At: http://en.wikipedia.org/wiki/Re-use

[10] - waste management. Available at : http :// en . wikipedia. Org / wiki / waste _ management

[11] - Ethanol and power production Uses of Rice Straw. Available at: http://www.calrice.org/downloads/a5b5_ethanol.Pdf

[12] - http://www.eeaa.gov.eg/arabic/main/env_recycling_rice.asp/ Rice straw recycling - production of gas from rice straw

[13]- Paper and Packaging Materials Uess of Rice Straw. Available At http:www.calrice.org/downloads/a5b4_paper.pdf.

[14]- Aguilar , Ortega , Campos , Gonzalez & El – Halwagi , Optimal planning for the sustainable utilization of municipal solid waste , 2018 , p. 2608 .

[15]- Tian, Gao , Hao , Zhu & Qiu Atmospheri pollution problems and control proposals associated with solid waste management in china : A review , 2018 , p 149 .

[16]- coml. McHugh,Bailingout: AnAnalysis of Straw Bale houses, and the provision of Mortgages and insurance for these houses in the UK,2020.

[17] - Catherine Wanek, the New Straw bale Home, 2016.