Straw Bale

Straw has been used as a building material for centuries, for both thatch roofing and also mixed with earth in cob and wattle and daub walls. Straw bales were first used for building over a century ago by settlers in Nebraska, USA, shortly after the invention of baling machines.

Straw is derived from grasses and is regarded as a renewable building material since its primary energy input is solar and it can be grown and harvested.

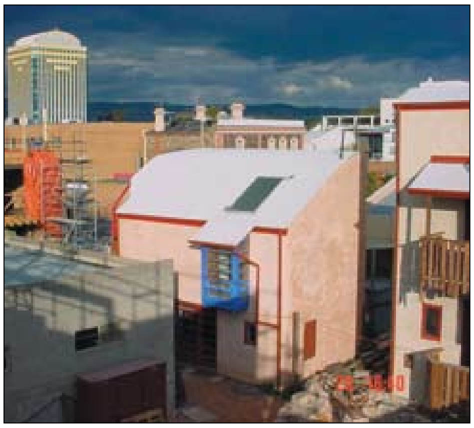
Straw is the springy tubular stalk of grasses like wheat and rice that are high in tensile strength. It is not hay, which is used for feeding livestock and includes the grain head. Straw is composed of cellulose, hemicellulose, lignins, and silica. It breaks down in soil and waste straw can be used as mulch. Different grasses have slightly different qualities, for instance rice straw has a significant amount of silica, which adds density and resistance to decomposition.

Straw bale walls are surprisingly resistant to fire, vermin and decay. Australian straw bales have two strings (American how-to books often show 3-string bales) and are typically 900mm long x 450mm wide and between 350 and 400mm high and weigh 16 to 20 kg.

PERFORMANCE SUMMARY

Appearance

Finished straw bale walls are invariably rendered with cement or earth so that the straw is not visible. The final appearance of rendered straw bale can be very smooth and almost indistinguishable from rendered blockwork, or it can be more expressive and textural. There is a project in London, England, for instance, that made straw bales visible in the completed construction by placing them behind corrugated acrylic cladding.



Straw bales in the city. There is no location that straw bale building cannot adapt to.

Structural capability

The structural capacity of straw bale construction is surprisingly good. In the load-bearing ('Nebraska' style) straw bale method, walls of up to three storeys have been constructed, but straw bale construction commonly uses a frame for the building structure. Most buildings require a frame of timber or steel to comply with current building codes. [See: 5.5 Construction Systems]

There are now several examples of multi-storey buildings in framed straw bale construction, including three houses with two storeys of straw bale wall in the City of Adelaide.

Thermal mass

Straw bales themselves have very low thermal mass, being composed, by volume, mostly of air. However, the cement and earth renders typically used on straw bales results in finished walls having some appreciable thermal mass in the thin masonry 'skins' either side of the insulated straw core. With the use of earthen renders a thick render skin of up to 75mm can be achieved, providing significant thermal mass. [See: 4.9 Thermal Mass]

Insulation

Straw bales demonstrate excellent insulative properties, in fact possibly the most cost effective thermal insulation available. [See: 4.7 Insulation]

Inch for inch, or centimetre for centimetre, straw has a similar insulation value to fibreglass batts. The insulation value of a straw bale wall greatly exceeds that of any conventional construction. All straw bale buildings demonstrate excellent insulation characteristics and the design goal in any structure must be to complement the insulation performance with the performance of the rest of the building. Thus, it is essential to insulate roofs and windows to maintain the overall performance of a straw bale building. [See: 4.10 Glazing]

Sound insulation

Straw bales also provide the most cost-effective sound insulation available. Dollar for dollar, the overall insulation value of a straw bale wall greatly exceeds that of any conventional construction.

The effect of sound insulation contributes to the livability of this kind of construction and can be quite marked. Even walking into the space created by an unfinished straw bale structure, one can appreciate the quietness and hear the difference compared with conventional buildings. [See: 2.7 Noise Control]

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. Conclusive evidence of its good fire resisting performance can be found in laboratory fire tests conducted at the Richmond Field Station in 1997 by students at University of California Berkeley. These rated a straw-bale wall at two hours. Straw bale homes survived Californian bush fires that destroyed conventional structures. [See: 3.5 Bushfires]

A fire that was started in the Whyalla Buddhist's straw bale building did not take hold, as it would have in a conventional structure, and the damage caused was repaired and the cost covered by insurance. Tests undertaken on behalf of AUSBALE and the South Australian fire authority in July 2002 on rendered straw bales (earth, lime and cement) resulted in a two hour fire rating. These tests are likely to be used to establish a formal value of fire resistance for building approval purposes nationwide.

Straw bales can burn but the potential for fire to take hold can be minimized. It is important to try and cap walls by continuing render over the top of the bales and plates so that an inadvertent flue effect does not support combustion by bringing in air to fuel the fire.

Straw bale structures are likely to attract interest. Sometimes that interest is not positive and it is wise to maintain vigilance during construction and to ensure that loose straw and sawdust or other combustibles are not left in or around the structure at any time. Some trades use fire, such as oxy cutters and welders. Special care should be taken to manage activities that are of high fire risk.

A low cost owner built straw bale home in the country.

Vermin resistance

A completed wall has excellent resistance to vermin, but it is important to prevent infestation of mice during construction when the bales are relatively unprotected. In virtually all straw bale construction any exposed straw is coated with plaster or render which is usually adequate to keep animals out, and if they do manage to get inside, densely packed straw makes it hard for them to navigate through the space. During construction, consider using traps and baits to ensure the finished structure is sound and vermin-free.

Durability and moisture resistance

Provided the straw is reasonably well protected and is not allowed to become waterlogged it can last many years with moderate maintenance. Indeed, it is reasonable to expect that straw bale buildings can have a lifetime of 100 years or more.

The most detrimental factor affecting straw bale wall durability is long term or repeated exposure to water. Given enough moisture and two to three weeks, the fungi in bales produce enzymes that break down straw cellulose. But for this to occur the straw moisture content must be high (above 20 per cent by weight). Straw bale walls should not exceed a moisture content of 15 per cent. Reasonable and sensible precautions against water penetration during construction, such as covering otherwise unprotected walls with tarpaulines, make it unlikely that water damage will be a problem in most building programs. The best way to prevent rot in a finished structure is to create a breathable straw bale wall and the success and survival of historic structures in Nebraska and Alabama demonstrate the durability of straw bale structures in climates with variable moisture and temperature.

Toxicity and breathability

The natural materials of straw bale construction are safe and biodegradable, unlike conventional construction, which is replete with artificial materials and toxic fumes. No toxic fumes are released when straw burns and there is no toxic end to the straw bale construction cycle. Straw bale walls have good breathability allowing air to slowly permeate the structure without moisture penetration. Earthen and some earth-lime renders may allow walls to 'breathe' better than cement render, especially compared with renders that have a high cement to sand ratio.

Environmental impacts

Straw is a waste product, it cannot be used for feed, like hay, and much of it is burned at the end of the season. Using straw for building reduces air pollution and stores carbon. The straw left over from building can be used as mulch so that, overall, there is minimal waste from using the material. **[See: 5.3 Waste Minimisation]**

With grasses able to grow on almost any land, there is a high level of renewable material content in straw bales. They are biodegradable and have a growing cycle of one year. To be truly sustainable in the long term, straw would need to be grown in such a way that it maintained the soil quality and ecological integrity of its provenance. **[See: 5.4 Biodiversity Off-site]**

The fertilisers and pesticides often used as part of industrial farming practices increase the overall environmental impact of straw, as does the use of twine made from petroleum products.

Straw bales are inherently low in embodied energy but most are produced by fossil-fueled machinery, they are tied together by plastic twine and may end up being transported over hundreds of kilometres. This can add significant amounts of embodied energy to what is a fundamentally low energy material. Straw bale walls are often laid on concrete footings that add further to the intrinsic energy cost of their construction.

Using straw for building stores carbon that would otherwise be released. The greenhouse gas emissions associated with straw bales is very low. One tonne of concrete requires more than 50 times the amount of energy in its manufacture than straw. **[See: 5.1 Material Use Introduction]**

Buildability, availability and cost

Straw bale construction rates highly for buildability because it can be very straightforward and is well suited to workshop and volunteer based building programs. As a result there have been many volunteer and workshop-based bale-raisings overseas and around Australia. There is a very active and informed international network of straw balers that constantly explores ways to improve and quantify bale building technology. In 2002 a non-profit association Ausbale was formed. Its members can provide excellent access to the best information available in straw bale building techniques and performance.

The general availability of straw bales is good, with many settled parts of Australia being within an hour or so of wheat or rice straw supplies. Straw bale is a low cost material but requires labor-intensive construction techniques. Straw bale construction can be very low cost provided the labour input is also low cost. Projects that can guarantee some volunteer or workshop-based construction can guarantee cost savings. Straw bale cost savings can be used to offset other costs. In South Australia, a large, detached dwelling, with a high standard of fittings and finishes and built entirely via conventional building contractual arrangements, cost the same as if it were in double brick, but had a much better, cost saving thermal performance.

Ladder frame being filled with pea gravel prior to frame and bale placement.

TYPICAL DOMESTIC CONSTRUCTION

Construction process

The various straw bale construction methods are all variations on ways of achieving good compression of the bales to minimise settlement and movement.

Bales should be well compacted and have a moisture content not exceeding 15 per cent and below 10 per cent is preferable. Straw bales should not get wet inside but wetting the sides should not be a problem. Straw does not wick water into itself like concrete. If rain is driven into the sides of bales, the natural movement of air or wind around the bales is able to dry them out and this cycle of wetting and drying does not damage the bale.

Whilst footings are being prepared, work can proceed on other aspects of the building. Construction can be speeded up by making frames and 'bucks' in advance of site works.

The vertical and horizontal stability of straw bale walls generally needs to be guaranteed by tying bales to structural frames or pinning between bales and structural elements, however there is a growing consensus that the extensive use of reinforced steel bars and excessive pinning that characterised early straw bale construction is not necessary and as a result modern straw baling practice is more material and resource efficient.

Bales are laid like giant bricks and, as with bricks, it is preferable to interlock the bales for a stronger and more stable wall, whether or not it is load-bearing.

Typical details

All structural design should be prepared by a competent person and may require preparation or checking by a qualified engineer. Qualified professionals, architects and designers provide years of experience and access to intellectual property that has the potential to save house builders time and money as well as help ensure environmental performance.

Footings

A straw bale wall requires footings with a similar load carrying capacity to that required for a masonry wall, although a straw wall is generally much lighter (one mud brick weighs about the same as a straw bale). The footings used are usually concrete strips or slabs to make compliance with engineering and building codes easier. There have been successful experiments with rubble trench and rubber tyre footings and there are several straw bale buildings in Australia built on piers, bearers and joists. As with mud bricks, the non-load bearing option means a roof structure can be raised in advance of the walls to provide a protected environment for building works. [See: 5.7 Mud Brick]

Ladder frame bottom compression plates being bolted to concrete slab through ant-cap damp course showing recycled irrigation hose for sleeving high tensile wire through pea gravel base.

Framed construction provides more design freedom for wall and opening placement – in the example a large two storey bay structure with a partly cantilevered floor construction can be easily achieved that would not be possible in the same way in a load bearing straw bale structure.

Load bearing walls

The earliest straw bale buildings of over a century ago were load bearing. Australian straw bale experts recommend a maximum wall height of 2.5m when using standard sized bales. Bales for load bearing construction should ideally have tighter strings than normal.

Load-bearing straw bale construction employs relatively simple techniques that are forgiving to novice builders and yet have sufficient flexibility to allow the creation of design features such as curved walls. Its limitations are that openings for windows and doors should not exceed 50 per cent of any given wall surface area and the maximum unbraced wall length is about 6m.

Bales should be laid like bricks in a 'running bond'. Corners should allow for at least a full bale return in each direction to assist in providing strength and stability. After the walls are laid they have to be pre-compressed before taking any structural loads. There are a variety of methods for achieving this but the most popular and practical method is grippling.

Grippling involves running 2.5mm high tensile fencing wire vertically around the bale walls every 450mm. The wires are run through a bottom 'plate' (generally a ladder –frame timber structure secured to the footings) and over a top plate (which may be similar or as simple as a plank of wood). The gripples are proprietary soft metal clamps that hold the wires in tension. They were invented for fencing use and are readily available with the associated specialist tools through fencing suppliers.

Early experiments in bale building involved excessive vertical reinforcement to tie bales to footings and to each other. Good results with better economy in materials can be achieved without reinforced steel bars and the vertical spiking of bales is largely unnecessary when the wire and grippling method is used.

Like giant bricks, straw bales need to be cut to fit into wall lengths, the fewer cuts the better. Walls should be designed in straw bale length modules and heights should be calculated from working out straw bale dimensions and allowing for compression of 50-75mm per single storey height of bales.

Slicing a bale requires that it is first ‘sewn’ at the desired finished length, then the original twine is cut. The idea is to produce two short bales with the same compression as the original, held by new sets of twine. The cutting and trimming of bales can be done with hand tools, but the most popular and effective method is to use a chain saw with a blade length of at least 400mm.

The middle plate and vertical compression wires can be seen in this detail of a timber framed three storey straw bale townhouse.

Frames

Although it is possible to build strong and effective single storey straw bale structures, it is often easier to ensure Code compliance and predictable engineering outcomes if the straw bale walls are constructed as in-fill elements between load bearing frames. Non-load bearing straw bale walls are very similar to load bearing but are generally more complex and have to be connected to the frames within which they sit. The frames allow more freedom in the design and placement of openings and a running bond is not as essential as it is with load bearing walls. Pre-compression is still necessary to avoid future problems with settling of the bales over time.

Framework and posts can be constructed off-site and the frame can allow a roof to be constructed in advance of the wall raising, providing shelter during the wall construction process.

Joints and connections

Straw bale walls can be joined to almost any construction provided attention is paid to flashing details. When one material joins another there must always be care taken to ensure that there is no passage for moisture penetration and that any differential movement is accommodated. A competent architect or designer can assist greatly in this regard.

The roof timbers or steel members can spring from the columns (particularly in the case of steel) or bear on wallplates. It is recommended that roofs have considerable overhang in order to provide some protection to walls from driving rain. In more sheltered areas this requirement is less vital, but care must be taken to provide a good quality render and waterproofing finish.

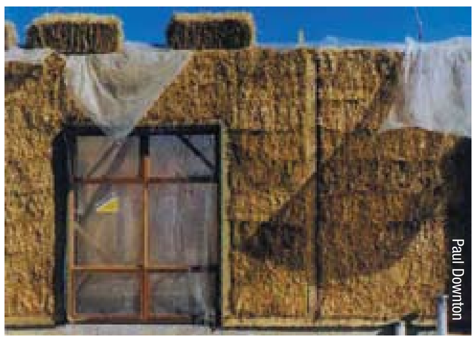
Fixings

It is possible to fix substantial loads to load bearing and non-load bearing straw bale walls by forming clamps made from planks of timber on either side of the bales, tied through the wall with high tensile wire and tensioned by grippling or twisting. Other methods for fixing such things as shelves and kitchen cupboards simply use elements connected to the load bearing frame. With cement rendered interior skins that are a nominal minimum of 30mm thick, it is possible to hang pictures and other items off plugged holes in the thin masonry skin.

Bales are trimmed for openings and can be cut to fit structural members.

Openings

Windows, doors and other openings in straw bale walls generally have to be placed within a frame designed to withstand compression loads, unless the window or door frames are themselves strong enough to do the job. These frames are sometimes called ‘bucks’. With bucks to resist distortion, almost any kind of window or door can be set into a straw wall, ‘floating’ in the bales or tied to frames. Until the walls have undergone final compression, bucks, window and door frames must have adequate temporary cross-bracing.



Window set towards outside face of wall.

It is best to set any frames with their faces flush to the outside face of a wall to improve weather protection. This also makes a deeper ‘reveal’ to the interior, opening up possibilities for deep interior sills, window seats and angled or sculpted surrounds to the openings that can do much to improve overall daylighting qualities. [See: 6.3 Lighting]

It is very important to weather proof all window openings that are exposed to direct rainfall. This can be done using standard flashing materials and methods.

Niches can be cut into straw bale walls in almost any position or formation provided care is taken not to cut into the twine that binds the bales together.

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Finishes

There are three main kinds of render used in Australian straw bale construction: cement and sand, lime putty and sand; and earthen render (sometimes incorporating lime). Final finishes on cement renders can range from clear, acrylic based water repellents to traditional coloured lime wash. Cement renders can be finished with a lime putty render topcoat. The three layers of render should be progressively weaker to reduce the potential for cracking caused by having too brittle an external layer. Earth renders are gaining popularity as concerns about their effectiveness have been addressed. The main advantages of using earthen renders are to do with minimising environmental impact and time spent in preparation and application. Advice should be sought from experienced straw bale builders wherever possible.

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The final render finish can be applied directly to the face of a straw bale wall, particularly with earth renders. Before any render is applied the final compression of the walls must be achieved. The usual method is to fix chicken wire to the wall surfaces to be rendered by sewing lighter gauge wire (1.5mm) through the walls at approximate 450mm centres and by pinning with staples made from medium gauge wire (2mm).

Things to watch out for

It is important to keep bales dry during storage and construction and to try and eliminate vermin. It is not unusual to find mice in straw bale deliveries. Straw bales attract mice and the shorter the on-site storage period the better.

During construction, tarpaulins or plastic sheets should be kept ready for covering otherwise unprotected walls. Although it may not be ideal, if bales do get slightly wet they can often be dried out sufficiently to be usable. The moisture content must be below 15 per cent in the finished structure. Renders should be carried over any exposed straw areas to keep out water and vermin and be carried over the tops of walls so that the potential for drawing air through the wall in the event of fire (allowing it to smoulder) is minimised.

Straw bale walls are very resilient and in the event of damage they can be repaired. Wet bales can be taken out and replaced and there is at least one recorded instance in Australia of a straw bale building that suffered fire damage after construction being successfully repaired under insurance.

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ADDITIONAL READING

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