ENVIRONMENT DESIGN GUIDE

STRAW BALE CONSTRUCTION

Harry Partridge

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Straw is a waste side-product in the harvesting of cereals and grains and as such is a 6-month re-usable material.
- Straw, pressed together into bales, forms a thick wall with an R-rating of over 10.
- Earth renders may be used to coat the straw and to virtually eliminate embodied energy of walls.
- Straw bale construction is easily learnt and suitable for amateurs to undertake. As such, wall costs may be considerably reduced.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Straw can improve captured solar gain by limiting heat loss through the walls.
- Straw bale construction requires footing designs to be in accordance with usual domestic construction.
- Straw walls must be protected from weather by large eaves.
- Straw construction is unsuitable for tropical climates.

Cutting EDGe Strategies

- Due to its high insulation properties a straw bale building acts like an 'esky' keeping internal temperatures constant.
- Using thicker wall renders will also increase the thermal-sink properties of the walls.

Synergies and References

- Swentzell Steen, A, Steen, B, Bainbridge, D & Eisenberg, D, 1994, *The Straw Bale House,* Chelsea Green Publishing Company, Vermont.
- King, B, 1996, *Buildings of Earth & Straw,* Ecological Design Press, California.
- www.strawhomes.ca
- www.yourhome.gov.au
- www.ecobuildnetwork.org
- http://strawbale.archinet.com.au

STRAW BALE CONSTRUCTION

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Straw bale construction has achieved considerable publicity since the 1996 EDG Note, and straw is no longer regarded as such a 'left-field' material within the conservative building industry. There have been very considerable advances in the understanding and use of straw. In this update note, its development is discussed and some current good building practices are described and illustrated.

1.0 INTRODUCTION

Many more techniques are being used in straw bale building than in building with other materials. This is because, firstly, modern-day straw bale building is very new, dating only from the late 1980s, although there are several buildings in Nebraska dating back to the early 1900s and before. Secondly, the people attracted to its use tend to be alternative, adventurous and inventive. Thirdly, there is not yet a definitive text or code that brings this proliferation of ideas and endeavours to a commonality.

It is certainly recognised now that using straw is environmentally beneficial: it is renewable on an annual basis (there are no old-growth fields of straw); it is mainly a waste product; it has superb insulation and acoustic properties; it locks up CO_2; and its embodied energy is very low (mainly transportation to site).

2.0 A LITTLE HISTORY

Before building materials become codified, and before they become used by a relatively large group of tradespeople, they evolve through a series of innovations, failures and improvements until they achieve something of a balance of functionality, cost and practicality.

The oldest building material still in use today is the brick. While its size has not changed for thousands of years (it fits the human hand perfectly), its composition has improved, and is now an extrusion of puddled clay, forced toothpaste-like, through holey metal dyes.

Steel has evolved from the carbon-rich bulky cast irons of the 1800s to the high-strength specialist recipes and shapes that now so efficiently frame our skyscrapers.

Reinforced concrete, the new material of the 20th Century, inspired a burst of architectural creativity. Pier Luigi Nervi's Exhibition Building, Turin, used ferro-cement to arch prodigious spans with a fineness and elegance not seen before. As more mundane but essential characteristics of the intimate combination of steel and concrete became more apparent, that is, as concrete cancer, shrinkage and creep effects became more apparent, Nervi's approach was seen as too radical, and concrete sections have become thicker and heavier.

And now, straw, used from the dawn of time for boat and hut construction has evolved by way of farmers' straw balers into suitable-size building block.

Murray Hollis, contracted by the CSIRO, is currently collecting Australian data on bale construction to produce a more 'definitive' text than that obtained in the plethora of web sites and in the more anecdotal DIY Earth magazines. Although one objective of this text will be to point the way to greater standardisation, Murray expects that the evolutionary course will have more time to run.

To help today's architect to design in straw bale there are a number of practical rules and engineered design advice that will assist. These are contained in Section 6.0.

3.0 TEST RESULTS

There are now many institutions around the world that have carried out tests on straw bale construction. The type, size and procedures adopted for these tests are nearly as varied and diverse as the straw bale building techniques that they attempt to emulate.

The best of these tests and the pulling together of much of the other test material, has been carried out by Bruce King, a California engineer and Director of the Ecological Building Network (EBNet), who is publishing EBNet's test results for downloading at http://www.ecobuildnetwork.org.

The tests reveal much detail about the characteristics of straw bale and generally show what the impoverished Nebraskan farmers of the early 1900s inherently felt: straw wall construction is extraordinarily strong at carrying vertical load; it is resilient, robust and hardy.

It is now felt that provided its use is well-detailed and well-protected, straw will be long-lasting, with little maintenance required.

4.0 TYPES OF CONSTRUCTION

Generally there are two different types of construction typically used with straw bale construction: load bearing and post and beam.

a) In **load bearing construction** the walls are built first, then the roof is built directly off the walls, which take its weight. This is most efficient in material usage and the quickest form of construction (Laboratory tests indicate that straw walls are sufficiently strong to accept loading from a first floor but for various reasons this has not been tried much in Australia as yet). The main disadvantage is the length of time that the walls are exposed to the weather while awaiting the roof to be erected and the possibility of their becoming wet.

b) In **post and beam construction** the roof is built first off an independent structure of posts and beams (usually of timber). The straw bale walls are then in-filled, all work being carried out under cover of the roof. This more conservative and less risky approach is most commonly used in Australia and North America at present.

5.0 WALL STRENGTH AND STABILITY

Two types of forces must be resisted by straw bale walls: vertical forces consisting of self-weight of the wall and roof (if load-bearing construction) and also wind uplift and horizontal forces consisting of both pressure and suction wind loads (and also earthquake in some locations).

Straw walls coated both sides by render become composite sandwich panels with a soft interior and rigid external skin. These two very different materials enter into a symbiotic relationship, supporting each other and sharing the loads in a complex manner.

Vertically the load is mainly carried by the thin rigid skins that are prevented from buckling by their intimate bonding with the straw bulk.

Horizontally the wall is in bending and can develop tension in either skin. This must be resisted by vertical tension members within the render; usually by fencing wire, packaging strap or chicken wire mesh. Alternatively, if the render is thick (about 50mm) the wall will be stable by its bulk alone.

6.0 GENERAL DESIGN RULES

6.1 'Give it strong boots and a good hat'

This classic aphorism contains the main advice for good bale construction; which should, at all times, be kept dry.

a) **Strong boots:** Some straw bale devotees, relishing the spirit of innovation that accompanies a material not bound with usual industry standards, look beyond bale construction to all parts of the building, including footings, where some novel ideas have been suggested and built. However, footings, our 'strong boots', should be designed in accordance with the Australian Standard AS 2870 – *Residential Slabs and Footings*. This short and straightforward standard is the result of much research into the behaviour of Australian soils, especially their shrink/swell characteristics, and unlike nearly all other standards, is not conservative. The standard prescribes footings sizes that in most (but not all) houses will prevent cracking of walls and floors. There have been many more complaints that the sizes given are not large enough than vice versa.

It is required to have each building site assessed for its soil classification. Usually this is best undertaken by a geotechnical engineer. In most cases this will only cost several hundred dollars and will tell the designer whether the soil is stable, moderately or highly reactive and thus prone to seasonal volume change (shrink/swell).

Having classified the site, one must decide what type of construction description best fits a straw bale wall. Straw is much more flexible and yielding than other building materials but the render applied to each face is a brittle skin of masonry. The size of footings chosen for a particular site classification should protect the render from cracking for the life of the building. Cracks and joints should be avoided because straw bales must be kept dry.

As it is not usual to use wall joints in a length of straw bale wall to articulate the wall and to so allow for some slight footing movement, a wall description of 'full masonry' should be chosen for the footing design to properly protect render from cracking. However if the wall lengths are less than about eight metres, a footing design for 'articulated masonry' may be adequate. Further, if earth or lime render is to be used rather than cement renders (more on this later) then a footing design for 'masonry veneer' could be adopted. This is because earth or lime renders are less rigid than cement and if they do crack are more easily repairable. Further again, if the owner of the house is prepared to accept the possibility of some ongoing crack repair maintenance (which may be as simple as to follow the 'two hours every two years' rule) then the lowest category of 'articulated masonry veneer' could be adopted. (This may, however, have complications should one sell the house to someone unprepared to accept such potential maintenance.)

Some straw bale structures have been built off timber stumps and flooring and appear to be working well, but this is outside AS2870 and could increase the possibility of future maintenance.

Next, and to comply with the requirements of another Australian Standard for termite management there should be at least 75mm of concrete footing exposed above the surrounding ground level before the wall commences. This is to allow for easy visual inspection of any termite runs. Good straw bale practice increases this freeboard to 150mm to keep the straw well away from the possibility of getting wet feet.

b) **A good hat:** This refers to rain protection, best achieved by generous eaves overhangs, which should be at least 450mm or preferably 600mm or 750mm on the weather side, for a single storey. This also means providing window sills that aggressively shed water away from the face of the wall below, and in taller walls, would strongly suggest small shed roofs and drip-edged water tables over doors and floor lines, respectively.

6.2 And a good suit – wall renders

Straw bales are rendered to protect the straw from rain, fire and vermin. Wall claddings such as corrugated iron or plywood are therefore not suitable. Driving rain will never be fully excluded, and if the wall and its internal straw do get wet it is essential that it be able to dry out. The straw may also become wet due to internal condensation usually caused by poor detailing (for example using uninsulated metal within the straw or poor steam extraction from wet areas).

The current thinking is to enable the wall to breathe by using renders, and/or surface treatments such as siloxane that will allow the passage of water vapour but not water. (Water vapour molecules are not bound together as are those of liquid water.) Thus there is a trend towards natural earth and lime renders in preference to cement render, which is more impervious, especially when mixed with waterproofing agents such as bondcrete or when sealed with paint. This may be corrected by the use of a low cement content render treated with organo-silane. (Organo-silanes are highly penetrating, long-lasting and hydrophobic but do not seal the pores of the cement). The guiding principle, as with all types of construction, is to shed water away from the building wherever possible, and then allow a means of draining and/or drying out the water that inevitably gets in anyway.

The high embodied energy of cement has caused some straw bale practitioners to avoid its use all together. Other disadvantages are its brittleness and degree of difficulty to repair.

Figure 1. External wall partially rendered to corner

If using cement render, the mix should be about 4:1 (sand: cement) for the first coat, and up to 6:1 for the second (and third) coats. Each coat is about 10-15mm thick. Chicken wire or expanded metal mesh should be use to restrict cracking and the render should always be kept damp by water spray for at least three days after application. When using chicken wire it should be pulled tight on the face receiving the render and stitched or stapled into the bale as shown in the various texts.

Renders can also be sprayed on (like swimming pool construction but using a render mix without concrete aggregate) or traditionally applied with a hod and trowel.

Lime mortars vary considerably in mix, application, strength and appearance. A typical mix would use putty lime (hydrated plasterers' lime well soaked for about a month) and sand at 5:1 (sand: lime) for the first coat, 3:1 for the second coat and 1½:1 for the final coat. Even more than cement-based renders, lime plasters are highly dependent on proper hydration (mixing and curing) for strength and durability.

Earth renders are growing in popularity for their sustainability and natural appearance values. Their mix design is even more varied than that of lime renders. They are often mixed with chopped straw or other fibrous binder and usually end up 50mm thick together with a lime-rich finishing coat.

John Glassford (see References) has carried out considerable practical research in his workshops and has developed an earth render recipe that appears to be very successful.

Neither lime nor earth renders appear to need the chicken wire reinforcing. This would also be advantageous in preventing rusting of embedded mesh in locations close to the sea.

Earth and lime renders require ongoing maintenance which is essential for the protection of the straw and building owners need to be prepared for this work. Increased roof overhangs will reduce the maintenance.

6.3 Pre-compression

The wheat bales commonly used in Australia, as many other places, have been found to settle appreciably over time when stacked in a wall.

Empirical experience backed up by tests carried out at the University of Western Sydney by John Zhang indicate that prior to the render coat being applied, walls should be pre-compressed by about 3 per cent, or 75mm for a single storey. This has been achieved in a variety of ways, the most efficient currently used is by fencing wire and tensioning grippler at approximately 450mm centres. This has the great advantage of also installing tension capacity to resist bending forces from the wind loads. If very dense (compact) bales are used, and properly stacked, the need to pre-compress the wall is diminished or even removed.

6.4 Location of wall on footing

Both skins of render should bear directly onto the footing to ensure a direct load path through the rigid render skins. This is illustrated in Figure 4.

6.5 Support at base and top of wall

To resist the horizontal forces from wind, the wall must be restrained at its base and its top. If the wall is load-bearing the top restraint is automatically provided by the roof – which must be braced for usual domestic construction to the bracing walls. The base restraint is provided by friction and also by the timber bottom rails (see Figure 4) that is becoming more commonly used.

For post and beam construction (infill walls) the base of the wall is restrained in a similar manner but the top of the wall must be securely attached to the roof or beam after the pre-compression of the straw, i.e. just prior to the render application. Note that the wall can be subject to both pressure and suction so the top fixing must cater for both.

In some old codes ('old' being only five years ago – this gives an idea of how quickly the evolution of straw construction is developing), reinforcing rods were cast into the footings and then speared down through the bale centres to pin the wall together. This is now seen to offer little advantage to the composite behaviour of the straw sandwich.

6.6 Bracing

Straw bale walls will ultimately be sufficiently tested to enable their use as a bracing element in a similar manner to that of brick walls. In the meantime, straw construction is being treated in a similar manner to studwork and thus the same cross-bracing as prescribed by AS 1684 – *The Light Timber Framing Code* is currently used. The thin steel flats are placed directly against the internal straw face and are also advantageous for pulling the walls and roof true and plumb prior to the application of render.

7.0 TYPICAL CONSTRUCTION

A sample construction detail is shown in Figure 4 that illustrates some current thinking for post and beam construction. There are many variations but this detail has already been successfully used several times.

Figure 2. The finished house and first floor addition in Killara, Sydney

Figure 3. Internal view

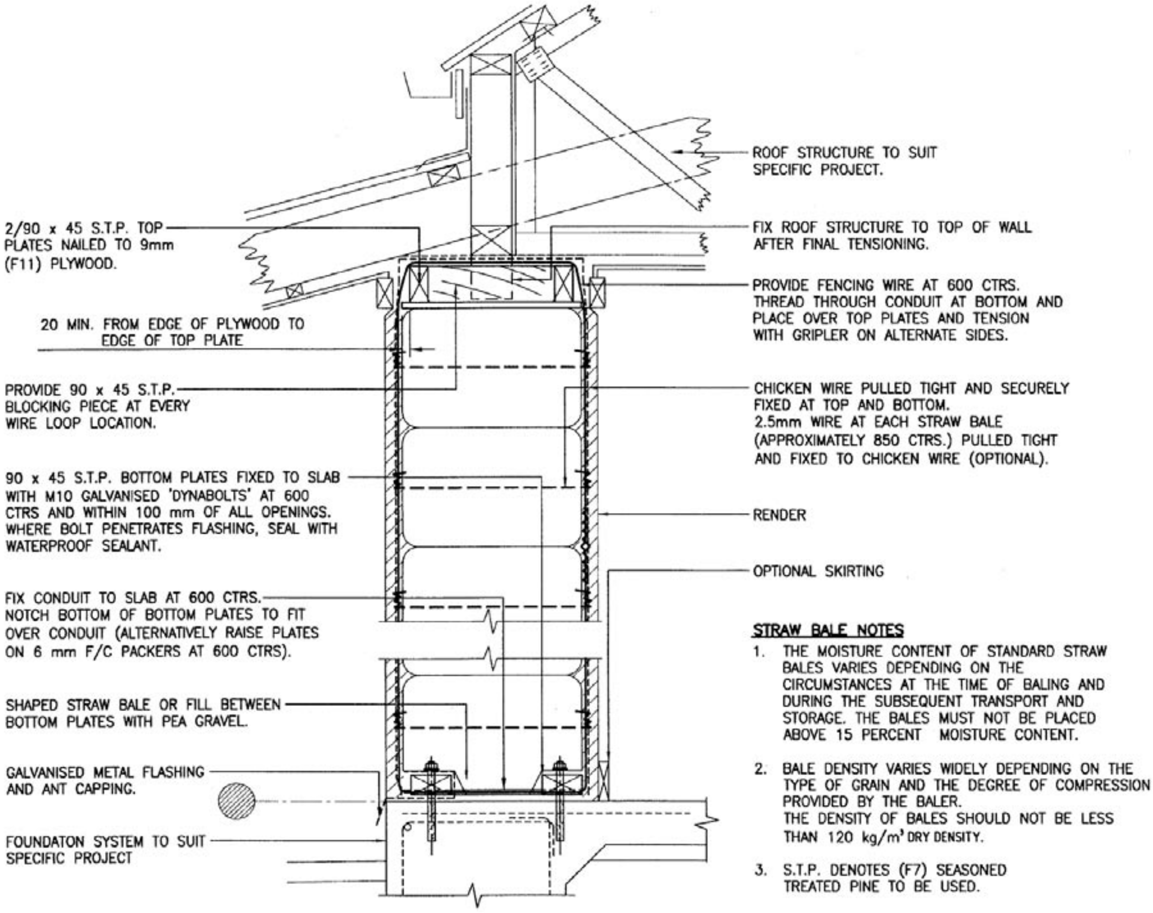

Figure 4. Post and beam construction (© 2001 Partridge Partners Ptd Ltd)

8.0 CAUTIONARY NOTES

The straw bale construction revival had its genesis in the drier states of USA, where the oldest surviving straw buildings are found. While straw bale construction is now being used throughout the world, care must be taken when planning its use in wet climates and/or where the average summer humidity is high. For example, it is probably not appropriate in tropical regions.

The current world-wide focus on issues of liability, risk and insurance could infer that obtaining appropriate construction and home-owners insurance should be an item resolved at the early planning stage rather than at early (or late) construction stage.

9.0 CONCLUSION

Straw is an active material. It inspires innovation, care for our environment, small 'a' alternate living, resource responsibility, enthusiasm, and a certain *joie-de-vivre*. In the security and warmth of a straw bale home one feels closer to nature and its seasonal throb and rhythm of life and yet comfortably insulated from its extremes.

REFERENCES AND FURTHER INFORMATION

Books

There is almost too much information available on the web and newsagents' bookshelves. Wait for *Design of Plastered Straw Bale Structure* edited by Bruce King and due early 2004 and perhaps Murray Hollis' CSIRO publication for an Australian text. In the meantime, try:

Swentzell Steen, A, Steen, B, Bainbridge, D & Eisenberg, D, 1994, *The Straw Bale House*, Chelsea Green Publishing Company, Vermont. This is regarded by many as the 'Bible' of straw construction, although the material is American and is now somewhat dated.

King, Bruce, 1996, *Buildings of Earth & Straw*, Ecological Design Press, California.

Websites

www.yourhome.gov.au
A combined Federal Government and industry funded site on all types of sustainable construction including a good summary of straw bale and some thumb nail pictures.

www.ecobuildnetwork.org
Funded partly by the Californian Department of Food and Agriculture and contains scientific and professional guidance.

www.strawhomes.ca
The journal of the straw bale movement tracks current straw bale projects, detailing and discussion subjects around the world. Quarterly issues are available in print or electronically. This is the most longstanding publication on straw bale building.

Other

Ausbale is the Straw Bale Building Association of Australia. Membership allows use of an e-discussion board and access to experienced builders, designers, new designs etc. The President is John Glassford ('The Straw Wolf') *http://strawbale.archinet.com.au*.

BIOGRAPHY

Harry Partridge BE MEngSc FIEAust MI StructE CPEng is the managing director of Partridge Partners Pty Limited, Consulting Structural Engineers, a private practice chiefly noted for designing commercial, residential and institutional projects and providing ESD project advice.

He built his own straw house in 1996 and is co-author of the BES Index, a numerical modelling tool for the ecological impact of construction. His interest lies in responsible engineering and its place in the balance between architecture, cost and the environment.