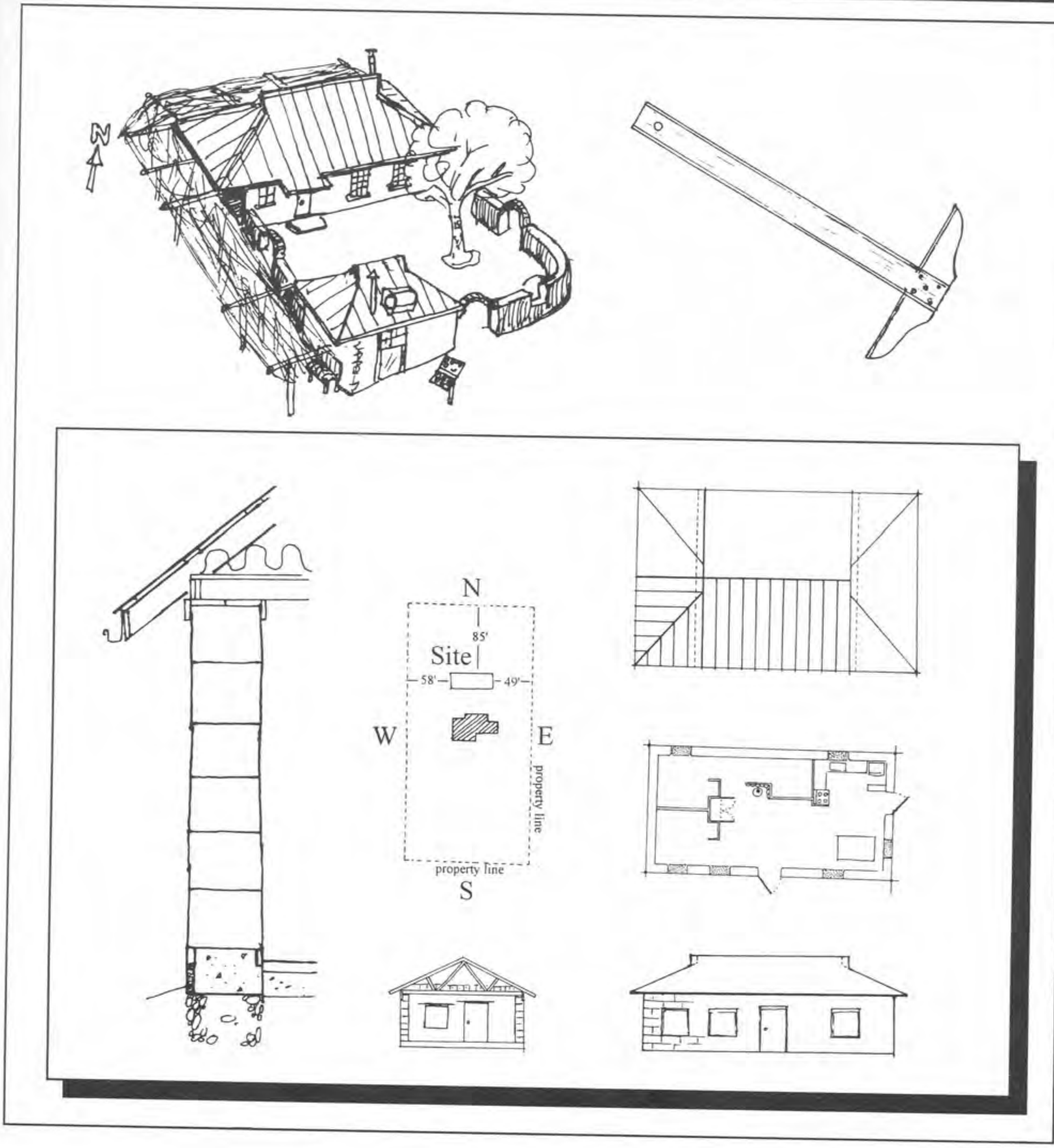
Part
One
Before You Build



Starting with Bales

Hay versus Straw

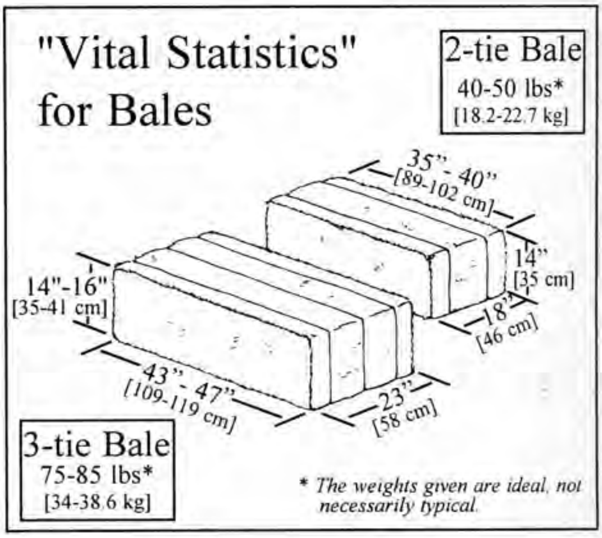
The term "hay" is used to describe the material which results from cutting certain plants while still green and allowing them to partially dry before removing them from the field. Stored in stacks or bales until needed, this nutritive product is fed to animals.

Contrast this with "straw", the dry, dead stems of plants, generally cereal grains, that is sometimes removed from the field after the seed heads have been harvested. The majority of this low-value, nutrition-poor by-product is burned or tilled into the soil—only a small percentage of that which is available is baled. Although baled meadow hay has been used by both historic and a few modern builders, straw is the preferred (and generally cheaper) material.

Bale Options

Bales come in a variety of sizes and shapes, but those most commonly used for building are the small rectangular bales. These come with either two or three ties, and the ties may be wire, polypropylene twine or natural fiber twine. Consult the diagram (next column) for "vital statistics". Although two-tie bales are virtually always 14 inches [35.6 cm] high, three-tie bales come either 14, 15, or 16 inches [35.6, 38.1, 40.6 cm] high. Don't assume, because the 16 inch [40.6 cm] height is the most common, that your bales will necessarily come with this dimension.

Builders have generally favored polypropylene twine as a tying material because it cannot rust, but wire runs a close second. Natural fiber twine is considered a final resort due to its low tensile strength and susceptibility to rot. Builders have commonly used either two- or three-tie bales in non-loadbearing designs, and have used them laid both "flat" and "on edge". For designs with loadbearing bale walls, most builders try to use the more-compact, wider, three-tie bales laid "flat", rather than the narrower, two-tie bales. Successful examples do exist, however, of structures with loadbearing, two-tie bales laid "flat", and loadbearing, three-string bales laid "on edge".



The Ideal, Building-Grade Bale

This hypothetical **super-bale** would be:

• dry—the drier the better. At a moisture content below about 20% (calculated as a percentage of the total weight of the bale), virtually none of the species of fungal spores commonly present in straw can reproduce and cause the straw to break down.

• free from seed heads that would encourage rodents to inhabit the walls should the wall surfacing not be properly maintained.

• about twice as long as it is wide. Such bales, when laid "flat", will lay up with a true "running bond", where each vertical joint between two adjacent bales in a course will fall at the midpoint of the bales above and below the joint.

• made up of stems at least 10 inches [25 cm] long and which are still tubular. When a flake about 3 inches [7.6 cm] wide is separated from such a bale, it will maintain its rectangular shape when lifted and moved. **Avoid bales consisting of short, shattered stems that won't hold together as a flake or that abrade easily at the corners.** They are messy (fire hazard!), tend to lose their outside strings, and may not have fully as much structural integrity as bales with longer stems. Also, avoid bales that have been reconstituted into smaller bales from large round or rectangular bales.

• consistent in size, shape and degree of compaction with its neighbors. Such bales will make it easier to build straight, relatively smooth-surfaced walls of uniform height. This, in turn, minimizes the amount of bale-tweaking needed to remove excessive irregularity. It also decreases the amount of plaster, if this is being used, that will be needed to achieve the desired amount of wall smoothness.

• sufficiently compact for its intended use. This proves to be easier to suggest than to provide standards for. Until some inexpensive, easy-to-construct, standard device has been adopted to physically measure the degree of compaction of baled plant stems, we're stuck with using density (loosely defined as weight per unit volume) as an easily calculated substitute for degree of compaction.

In non-loadbearing designs, the degree of compaction is much less critical, since the bales are braced against forces perpendicular to the wall surfaces by the roof-bearing framework. The code for the State of New Mexico for non-loadbearing construction requires only that the bales can be picked up by one string without deforming.

If the bale walls will be carrying the roof load, the degree of compression will affect the stiffness of the pinned walls and their resistance to wind and seismic loads. It will also influence the total amount of wall compaction resulting from a given load, per square foot, on the top of the wall and the time required for it to be completed.

This is all good to know, but still leaves us needing a way to easily determine the average "calculated density" (CD) of our bales to see if it exceeds some accepted, minimum value. The standard procedure has been to weigh a given bale and to then estimate, using a measuring tape and several small pieces of plywood, the dimensions of an "envelope rectangle" that would snugly enclose that bale. Each dimension in inches and eighths (e.g., 46-3/8"), needs then to be converted to inches and decimal inches. To do this, divide the numerator of the fractional inches by the denominator (e.g., 3 divided by 8 equals 0.375") and add this to the whole inches (e.g., 46.375"). Now multiply the converted length, width and height and divide the result by 1728 (the number of cubic inches in a cubic foot). Divide this result into the weight of the bale (in pounds) to obtain the CD in pounds per cubic foot. [Metric CD in kilograms per cubic meter = weight of bale in kg / length in m X width in m X height in m.]

The accuracy of this result depends, unfortunately, on the assumption that the bale is bone dry. The presence of moisture (i.e., liquid water) in the bale will give a falsely high result.

Moisture content is normally expressed as a percentage of the total weight of the "damp" bale, and is calculated by dividing the weight of free water in a bale by the total weight of the bale, including water, then multiplying that by 100. Thus, a 90 pound bale in which 18 pounds was due to water would have a moisture content of 20% (18 divided by 90, times 100). Conversely, if you know that this 90 pound bale has a moisture content of 20%, you know that 18 pounds of the total weight is water. The dry weight of the bale is thus 72 pounds. This is the weight you would use to determine the CD.

But how can you determine the moisture content of the bales? Most moisture meters, using a probe stuck into the bale, cannot read accurately below about 13%. However, this is well below the generally accepted upper limit for safe use in building (i.e., 20%) . If the meter indicates a maximum of 13%, it is typical to assume a moisture content of 10%. In most cases this will result in a CD that is conservatively low.

Simple lab procedures performed on samples taken from bales can also determine the moisture content very accurately, but require destroying the bales and are time-consuming and expensive.

What is needed, but not yet available, is a method for determining the degree of compaction that is independent of the moisture content and that can be performed quickly, on the building site, with an inexpensive device. Send us your ideas!

Ordering Building-Grade Bales

To custom order bales that will meet a reasonable standard for density, we must first set this standard and then translate it into simple instructions for the operator. Testing has demonstrated (see Eisenberg et al. 1993) that walls built with bales having a calculated density (CD), based on dry weight, of at least 7.0 pounds per cubic foot [112.25 kg per cubic meter], can safely carry a load of at least 360 pounds per square foot [1759 kg per square meter] without showing unacceptable compression or deformation. Using this value of 7.0, we can now determine for a given bale size, what its minimum weight should be for use in a loadbearing wall carrying no more than this 360 pounds per square foot load. We need only multiply 7.0 by the volume in cubic feet of the bale size that we want operator to produce for us (those fortunate souls using the metric system would simply multiply 112.25 by the volume of the bale in cubic meters). For example, if we ask for custom, two-tie bales that are 14" by 18" by 36", we would specify that they weigh at least 37 pounds. We get this by multiplying 14 by 18 by 36 to get the bale volume in cubic inches, dividing this by 1728 to convert to cubic feet, and then multiplying this volume by 7.0. The operator can now adjust the baler to produce bales with an average length of 36" and a weight of not less than 37 pounds.

Sources of Bales

In areas where cereal grains (e.g., wheat, oats, barley, rye, rice) or grass seeds are produced, it is often possible to buy bales cheaply in the fields or from stacks located beside the fields, but you will have to transport them. Farmers will sometimes load and deliver, but transportation is generally provided by independent truckers.

The cost per bale, bought retail in small quantities at a "feed store", is often significantly higher than the price that can be negotiated, through the feed store or the producer, for a larger quantity. Other potential sources of information on bale suppliers include state agricultural agencies, county agricultural agents, race tracks, zoos, and the summer "resource" issues of *The Last Straw*.

Flammability and Fire Retardants

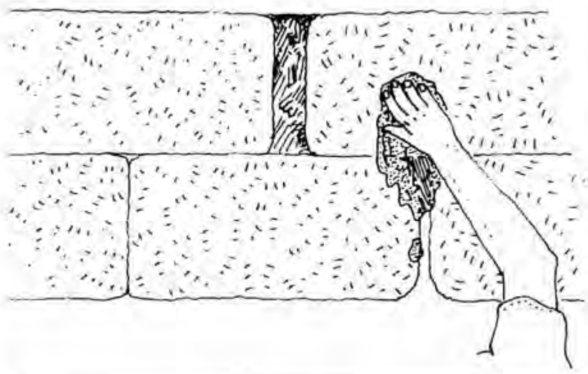
Testing by a certified laboratory (see SBCA 1994) has clearly established that a straw-bale wall, while protected by plaster, is at least as fire resistant as a wood frame wall similarly protected. **Exposed straw**, however, like wood and other cellulosic materials, **will support combustion under certain circumstances**.

The time period between getting the walls up and getting them surfaced constitutes a significant window of vulnerability. This needs to be taken seriously, as several unfortunate straw-bale builders have learned the hard way, by losing their buildings to fire during the construction process (e.g., *The Last Straw*, Issue 13, page 34 and Issue 16, page 16).

The greatest potential for fire lies not in the bales, but in **loose straw** that is allowed to accumulate on the site, particularly during the wall-raising. Under windy conditions, flames will spread rapidly through a layer of dry, loose straw. Fortunately, this danger can be easily eliminated by repeatedly raking or sweeping up the loose straw, stuffing it into plastic garbage bags and storing it at a safe distance from the building. This is an important job that even very small people can help with.

The surface of a compact bale will not normally support combustion once the "fuzz" has burned off. The least flammable, exposed-bale wall will therefore be the one with the most dense, least "fuzzy" bales. Even then, two other danger spots exist where "flakes" have been used to fill gaps between bales and where loose straw has been stuffed into the openings left where bales butt up against each other. Capping the loose straw at these locations with a mixture of straw and mud ("cob") will eliminate the danger they present.

Filling the Gaps with Cob



One additional danger relates to string-tied bales stacked on edge. Flames moving up the wall can easily destroy the strings, releasing loose straw to further fuel the fire.

Another obvious way to reduce the risk of fire is to keep the work site free from all possible sources of ignition. **Activities to be avoided/prevented** would include:

- **smoking**;
- **welding** of any kind;

• **any grinding or cutting** that will produce sparks (i.e., tiny fragments of red-hot metal);

• and, **arson**.

Although there have been only a few fires for which arson has been the likely cause, it is clear that exposed straw-bale walls conjure up the possibility of fire in a way that an exposed, dimension-lumber frame does not. In situations where the risk of arson is greatest (e.g., certain inner-city neighborhoods), the builder might want to:

• put a fence around the site;

• maintain a continuous presence (human or guard dog);

• shorten the period during which the bale walls are left unsurfaced, by pre-stressing the walls (see page 73) or by using a non-loadbearing design (see page 21);

• and/or treat the bales, or bale walls, with a fire retardant chemical (see next paragraph).

Commercially available retardants like Nochar's "Fire Preventer" (call 317-573-4860) or Northeast Fireshield's "Inspecta-Shield" (call 516-563-0960) are effective but relatively expensive. For a less expensive alternative, some builders have used a saturated solution of borax and boric acid (both in granular form) dissolved in hot water. Heating the water enables more of the borax to be dissolved, and the boric acid counteracts the caustic, corrosive nature of the borax. For maximum strength, keep the water hot during both the mixing and the application. Typical mixes have involved 1 part by volume boric acid to 2 parts borax, both of which are readily available at chemical supply houses (e.g., Hills Brothers, a national chain). An additional side benefit of the borax is that it is an effective fungicide.

Aluminum sulfate (commonly called alum) has also shown promise as a simple, home-brewed fire retardant, although we could find no specific recipe to provide. If you try it and like it, send us some specifics for version three.

Fire retardant solutions have usually been applied to the bale walls with spraying equipment. The options for do-it-yourselfers include paint sprayers or power weed sprayers that are available at equipment rental centers or a hand-pressurized, backpack sprayer. Using a plasterer's "hopper gun" would allow a little clay to be added to the borax/boric acid solution. The clay, besides bonding the chemicals to the straw, has a fire retardant effect of its own. An alternative to spraying is dipping one or more surfaces of the bales into a fire retardant solution. This will provide greater penetration than spraying.

With proper precautions, such as those outlined above, you should never have to fight a fire on your building site, **but be ready to fight the fire that somehow gets started anyway**. An adequate water supply, delivered with good pressure, provides the best defense. The hoses should be long enough to reach all the way around your building, to the side furthest from the water source, without having to be run closer than about twenty feet to any wall.

Bale Composition

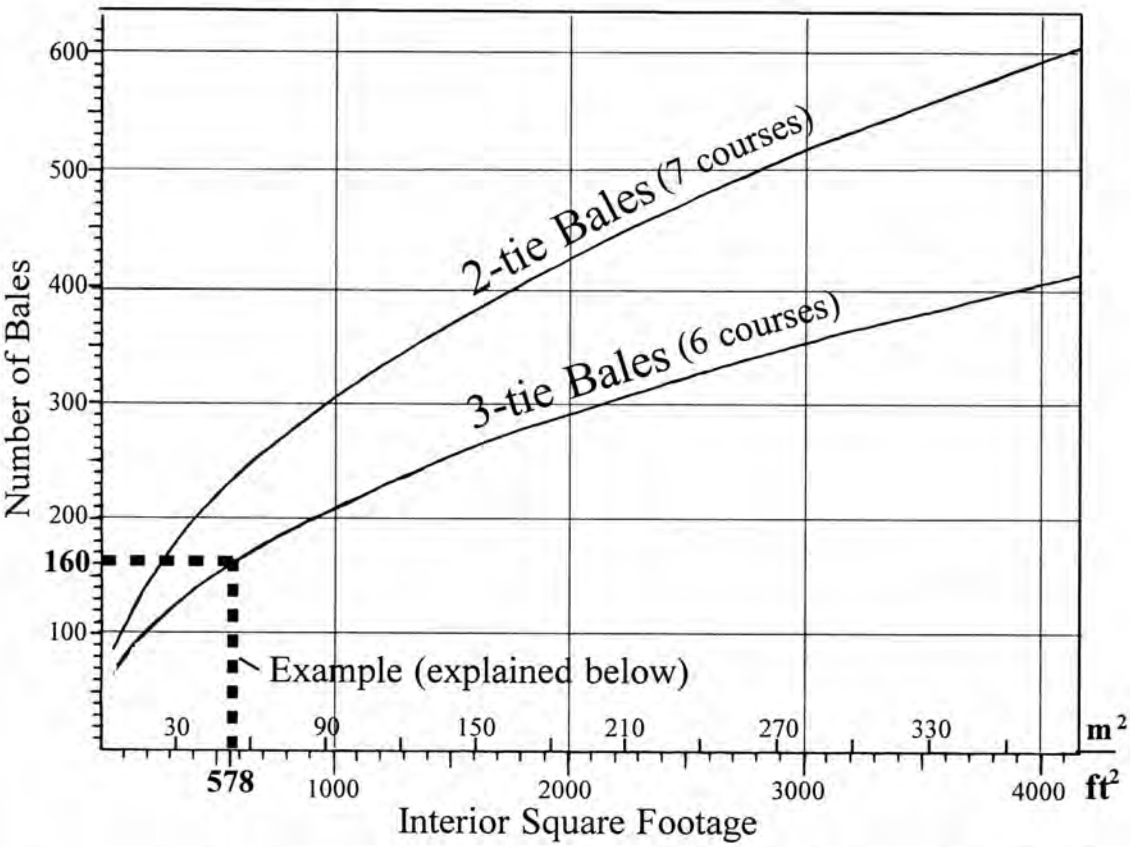
The straws of the common cereal grains are very similar in chemical composition to each other and to the common soft woods. They all consist mainly of cellulose, hemi-cellulose and lignin. It is far more important that the bales be dry and compact than that they be wheat rather than oats. Even Sudan grass, grass straw, bean stalks, and the stems of milo (a type of sorghum) have been baled and used successfully for building.

How Many Bales?

If you have completed your plans, including detailed wall "elevations" (i.e., vertical wall maps), you can determine very exactly how many bales you will need. The determination is often done as if there are no doors and windows, to insure that there will be some extra bales for temporary seating and for building ramps or to support scaffolding.

Even then, you may want to purposely order more than your plans suggest. You'll be far better off having too many, rather than too few. Use the extras to build benches, dog houses, accent walls, or to mulch the garden.

Meanwhile, for an **initial estimate**, use the graph below.



Using this graph, it is easy to **estimate the number of bales** (2-tie or 3-tie; see figure on page 15 for bale dimensions) needed to build your home. The horizontal axis is the square footage of interior space; the vertical axis the number of bales needed. We assume no openings in the walls. In the **example** shown, the interior square footage of our planned building is 578 square feet and we are using 3-tie bales. Coming straight up from 578 on the horizontal axis until we intersect with the 3-tie curve, we can then move horizontally to the left until we intersect the vertical axis at 160, the approximate number of bales needed.

Three Basic Approaches

Loadbearing

In nearly all cases, the roof weight of the historic Nebraska structures was carried entirely by the bale walls. Many of these buildings were square or modestly rectangular, with lightly-framed, true hip roofs that distributed the weight evenly, or nearly so, onto all four walls.

• Some **advantages** of the loadbearing approach include:

—greater ease of design and construction;

—possible savings of time, money, labor and materials, since no roof-bearing framework is needed;

—and, distribution of the roof and wall weight evenly along the foundation that supports the loadbearing walls.

• Some **disadvantages** include:

—certain design constraints, including the need to avoid very heavy roof systems (details, on page 31);

—the need for dense, uniform bales, laid "flat"; (This density criteria, combined with their smaller width, usually precludes the use of two-tie bales in loadbearing designs.)

—the need to wait an indeterminate period of time (generally, 3 to 10 weeks) for the bales to compress in response to the weight of the roof/insulation/ceiling system, unless your tie-down system can pull the RBA down mechanically (see page 73 for one option);

—and, the possibility that very heavy live loads (wet snow, herds of elephants, etc.) could cause the wall-surfacing materials to buckle outward. To our knowledge, however, this has never happened.

Non-Loadbearing

Many of the modern bale-walled structures have been built using an arrangement of vertical elements (generically called posts) and horizontal elements (beams) to carry the entire weight of the roof/insulation/ceiling system. The bottom bales carry only the weight of the bales above them. The bale walls provide insulation and the matrix onto which surfacing materials (e.g., plaster, siding) are attached. Typical frameworks have consisted of various combinations of 2"x4" [5X10 cm] and other dimension lumber, glue-lam beams, rough cut timber posts and beams, peeled logs, metal elements, and concrete columns and bond beams.

• Some **advantages** of the non-loadbearing approach include:

—greater familiarity, and therefore acceptability, to building officials, lenders and insurers;

—provision, by the roofed framework, of a dry shaded place for storing materials, including bales; (This enables flexible scheduling and working even when it's raining, or the sun is intense.)

—the possibility, since the framework is non-compressive, of surfacing the walls as soon as they are up;

—the possibility of using the typically less-dense, two-tie bales or less-dense-than-normal three-tie bales, and of laying the bales "on edge";

—a reduction in constraints on the size, number and placement of openings;

—and, freedom from certain other design constraints (e.g., length of unbuttressed walls, roof weight).

- Some **disadvantages** include:

—the expenditure of extra time, money, labor and materials to create the framework; (For an owner-builder, this means a more complex design challenge and the need for skills they may not have.)

—and, the need to create a more complex foundation system that can carry both the bale walls and the concentrated loads transferred to it by the vertical "posts".

Hybrid

The distinction between the first two general approaches we have described is specifically "structural". The *Hybrid Approach*, as we define it, does include buildings that are "structural" hybrids, but we will also include here a variety of building types that are both significantly straw-bale, and are "combinations" (i.e., hybrids), in other ways. By its nature, a hybrid structure often requires extra thought during the design process. Draw it, model it, get a "second opinion", and still expect to have to think on your feet once you get started.

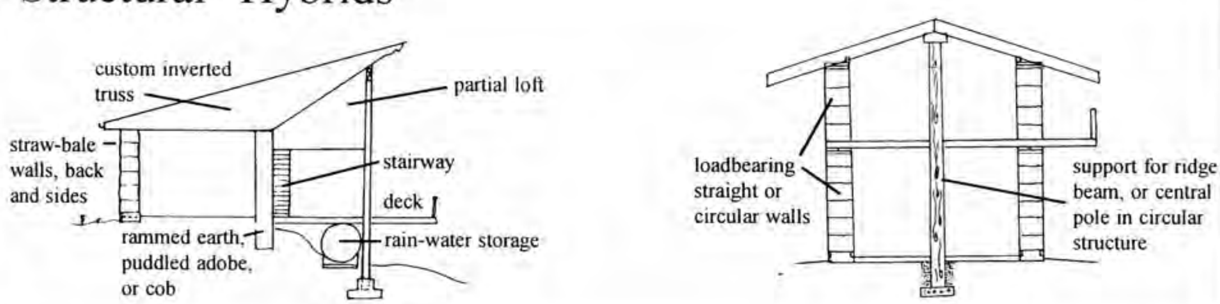
For descriptive purposes we can separate hybrids into three, somewhat overlapping, categories: "structural", "compositional", and "temporal".

- **"Structural" hybrids** are those in which <u>both</u> compressive straw-bale walls and non-compressive walls/frameworks, made with other materials, carry roof weight. Combining both of these wall types in a design can release you from some of the constraints, or disadvantages, of each. In a single story building this could mean, for example, a central adobe wall carrying half of the roof load, with the other half shared by two exterior loadbearing straw-bale walls. Or it could mean a shed-roofed building with lots of windows in a "post-and-beam" framework on the south side, and a loadbearing bale wall on the north side.

Designs of this type must take into consideration the fact that the bale walls will compress, lowering the RBA and changing the pitch of the roof. In a building involving a heavy roof system, long rafter spans and spongy bales, the problem could be significant.

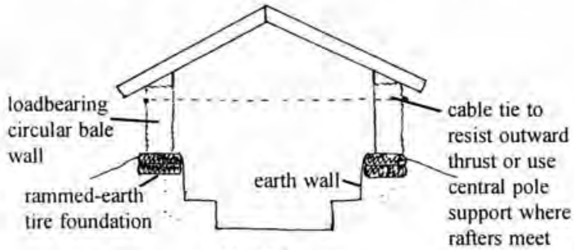
In a full, two-story structure, this could mean, for the first story, an engineered, "post-and-beam" framework (wrapped or infilled with bales) topped with a deck. Upon this deck, for a second story, could sit full-height, loadbearing straw-bale walls capped with a roof. Or, it could mean a full, designed-to be-lived-in basement, with a loadbearing bale building on top of it.

"Structural" Hybrids

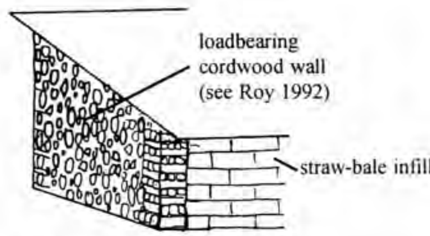


• **"Compositional" hybrids** are those in which the "combination" is primarily that of different materials. This could mean, for example, a building with a gable roof carried by two straw-bale walls, where the end walls are an infill of cordwood and colored bottles.

"Compositional" Hybrids



Pit House

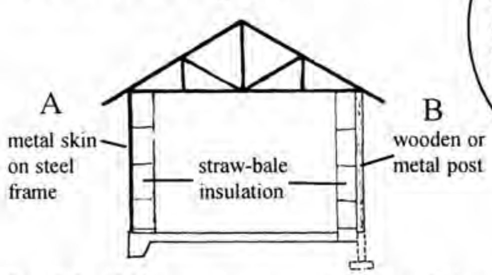


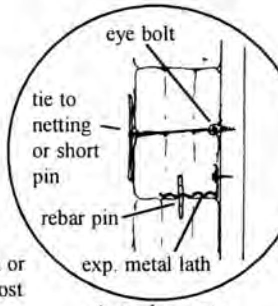
Cordwood/Straw Bale

• **"Temporal" hybrids** are those in which the old and the new are combined. One example would be a **retrofit**. You could upgrade an **old**, uninsulated masonry house, that's been sitting in some urban neighborhood wasting megawatts of energy, by installing **new windows and doors**, by adding enough **new ceiling insulation** to reach the regional standard for super-insulation, and by installing **new "outsulation"**, in the form of a bale wrap of the exterior walls. Here's the ideal combination of **great insulation on the outside** and **thermal mass on the inside**! For tips on energy-efficient renovation, see Marshall and Ague (1981) or Harland (1994). If you plan to replace old systems, appliances, or components (e.g., windows) with more energy-efficient ones, consult Wilson and Morrill (1996).

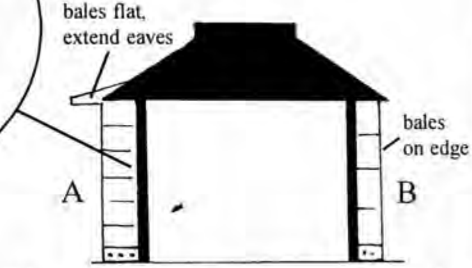
This category would also include a straw-bale **addition**; that is, a **new** straw-bale segment added to an **"old"** structure built with some other material. The Department of Housing and Urban Development (a.k.a. HUD) has a special, 203K loan program for "renovations" that has accepted straw-bale construction for additions.

"Temporal" Hybrids— Retrofit Type





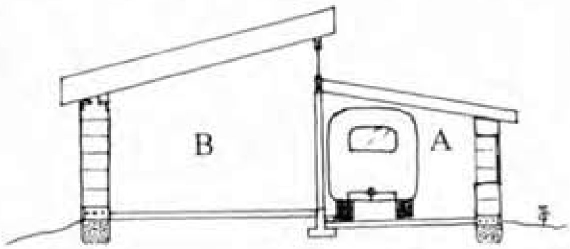
Attachments



Metal building or Pole-building Kit

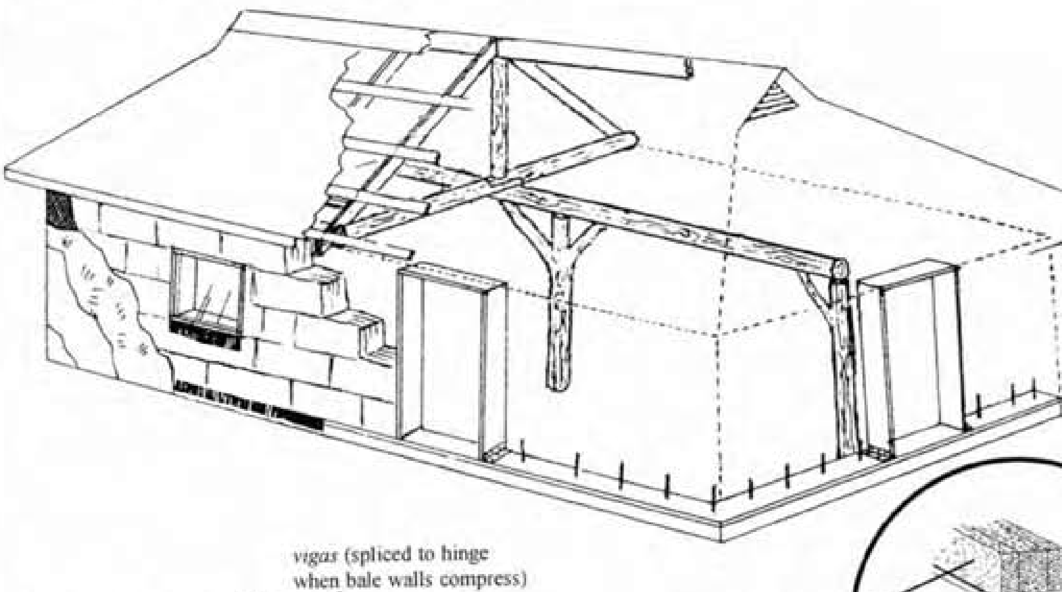
Wrap Existing Structure With Bales

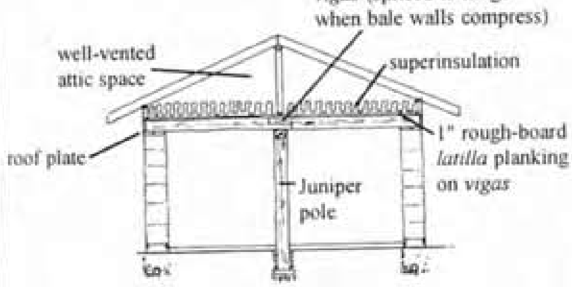
Pay-As-You-Go "Structural" Hybrid

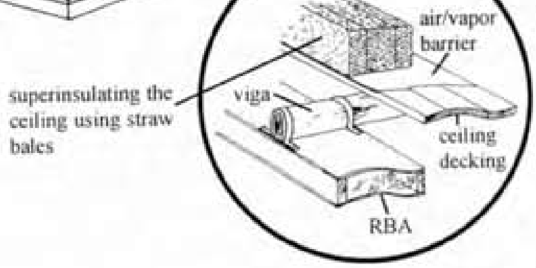


Phase 0 - Live in trailer, saving money to build a hybrid straw-bale home.
Phase 1 - Build space A to shade trailer, leaving one end temporarily plugged with bales.
Phase 2 - Save more money.
Phase 3 - Build Space B.
Phase 4. Unstack temporary end wall, remove trailer, replace end wall and finish.
Phase 5. Sell the trailer to someone who wants to do what you just finished doing.

Our Model as a "Structural" Hybrid







***Viga* Span Chart** *(from McHenry 1985)*:

Diam.	Max. Span
6" [15.2 cm]	10' [3.1 m]
8" [20.3 cm]	16' [4.9 m]
10" [25.4 cm]	20' [6.1 m]

The hybrid option, illustrated here, has a pole framework running down the middle of the building. This approach reduces the load per linear foot on the tops of the two long walls and, therefore, reduces the amount of compression (a plus, if you have less-than-ideal 2-tie bales). The sunken vertical logs provides additional resistance to lateral (i.e., horizontal) forces on the building from winds or earthquakes.

Developing a Plan

The Superinsulation Strategy

We could have accurately subtitled this book "the novice builder's guide to creating affordable, **superinsulated house-walls**, and a bit more". Although such walls are a necessary element in a superinsulated house, they do not, by themselves, give you one.

For those of you planning to build where long periods of very cold or hot weather are the norm, a **superinsulated house** will provide significant energy savings. For in-depth coverage of the superinsulation strategy, consult Nisson and Dutt (1985).

Four important components of such a house are:

• a carefully defined "thermal envelope" that separates the "climate-controlled" spaces from the "uncontrollable" outside;

• sufficient insulation, carefully installed (typically R-30 to R-40 [RSI 5.3 to 7.0] for walls; R-35 to R-65 [RSI 6.2 to 11.4] for ceilings; whole-window U-values of 0.37 or lower [U metric values of 2.1 or lower]);

• air tightness, with controlled ventilation that often includes an air-to-air exchanger;

• and, a modest amount of south-facing glazing to provide solar gain to replace the small amount of heat lost through the thermal envelope.

A Different Way Of Building

Straw-bale construction encourages us to explore a different philosophy of building, one which includes imperatives like those listed below:

• Use passive heating and cooling systems to the extent possible (EPA 1992, Givoni 1994, Anderson 1996).

• Design to enhance eventual expansion, but build now only what is enough for now.

• Build accretionally, with final inspections as each major stage is completed. For example, complete the basic core, with kitchen, bathroom and a multipurpose living space. Move legally into this and then add a bedroom. Future additions might be a master bedroom and bath or an office space. See the drawing of the "model" structure on page 42 regarding window frames that convert easily into door frames to provide access to additions.

• Make a <u>gradual</u> transition from a small, actually mobile, trailer, to a finished straw-bale home. (See the drawing on page 24.)

• Design your spaces to be wheelchair accessible. Sooner or later, someone will thank you for this foresight. For guidance in this area, see Wylde et al. (1993).

• Keep the design simple, the size small (keep asking yourself if you've drawn more than enough), and the storage inventive (utilizing otherwise dead spaces). For suggestions, consult Metz (1991), Brown (1993), Smith (1995), and Dickinson (1996). Make the spaces multi-functional, and the partitions easily movable. In temperate climates, consider a fully-climatized core, with zones around it that become increasingly less enclosed as you move outward.

• Use scrounged/recycled "green" and materials where possible (see Harris [ongoing], Stulz and Mukerji 1993, Pearson

1989 and 1996, Good Wood Alliance 1996, Mumma 1997).

• Choose materials with the lowest potential toxicity (Bower 1993, Marinelli and Bierman-Lytle 1995, Venolia 1995, Steen and Steen 1997c). If the structure will house someone who is environmentally hypersensitive, see CMHC (1995).

• Do all or part of the building yourself (or as a family effort).

• Pay for the building as you go, as you can. Imagine no mortgage payments and, particularly, no interest payments. That would be another galaxy, and a kinder, gentler one at that.

You will find additional philosophical underpinnings for these imperatives in Alexander (1979), Kern (1975), and in Henry David Thoreau's classic, *Walden*.

Site Selection Considerations

The term "site selection" seems to automatically conjure up the idea of locating and buying a piece of land out in the middle of some beautiful chunk of uninhabited country and building a new house on it. We would ask you to instead consider **staying put**, "outsulating" your existing home with bales, and/or adding onto it with bales, or razing it and replacing it with a straw-bale house, or building on a vacant lot within an existing community (see Sanders 1993).

Consider helping to make an urban neighborhood more whole, more vital and more healthy, rather than unintentionally making a rural ecosystem less so. Where you build can be as important to planetary sustainability as what you build with. As Nadav Malin (1995a), of *Environmental Building News*, sees it, "...Where we choose to build will dictate, in many cases, transportation patterns. Energy use and pollution from driving cars far outweighs the energy use in buildings, so even the most efficient building can be undermined if the occupants are set up for long commutes...Building location also affects the wildlife and habitat of its immediate surroundings. Remote, self-sufficient, off-the-grid homes are often the first intrusions into pristine wilderness areas, but they are rarely the last."

When you have finally chosen your lot or parcel, you will need to select the specific spot for your building(s). On a small lot, you may have little latitude in positioning your building. Given a larger piece of land, careful study of the whole piece will probably reveal several possible sites where the footprint of your "destruction zone" will do the least damage to the land and the other living things that will share this land with you. All construction involves destruction, but why damage a really beautiful spot, with great wildlife habitat, when you can pick an already damaged, or less healthy site, that you can restore to health after building on it? The landscaping you later do around your home can provide both energy-saving seasonal shade, and habitat for the wildlife whose land claim predates yours. Having identified a number of such potential sites, one can then try measuring each site against a list of characteristics of the "ideal" building site for the type of design you envision.

For a "floor-on-earth", single-level design, here are some possible characteristics:

• The views are attractive to you (could mean vast or restricted), and don't destroy some neighbor's views.

• Access to the site is reasonable.

• There is a reasonably flat area big

enough for the building.

• If the site has a slope, it is generally toward the south (unless solar gain is not an issue.

• The drainage pattern will not present any unplanned-for difficulties.

• The position of the site in the general landscape will ameliorate the least attractive aspects of the climate rather than accentuate them.

• Winter sun, for passive solar gain, reaches the site.

• The geology of site is such as to minimize problems and expenses related to site preparation and foundation design and construction.

Although none of your sites may exhibit all the desired features, this exercise will enable you to compare them and develop a ranking that reflects how strongly you feel about the various "ideal" characteristics. Valuable aids for this process include Lynch and Hack (1984), Mollison and Slay (1988), Walters (1991), and McHarg (1995).

Preliminary Conceptual Design

After coming up with some loose, informal, preliminary sketches, but before spending time developing detailed plans, you may want to initially consider some relevant, generic issues. You may also want to now involve an architect or designer in the process, rather than forging on alone. If so, shop around—talk to former clients, explore philosophy, find someone whose creative ego won't bury your input.

Very early in the process, check on the availability of good bales in your area. When you get information from potential sources of three-tie bales, be sure to determine what different heights they offer. Although they are most commonly sixteen inches (40.6 cm) high, you cannot safely make any assumptions. Designing for one height and having them deliver bales with another, can spoil your whole day. **Don't procrastinate!** For a loadbearing structure, there is nothing more important than acquiring the right bales. It may take months. Start shopping early!!!

If only two-tie bales are available, **seriously** consider using the non-loadbearing approach. A possible exception would be for a small building with walls no higher than about eight feet (2.44 m), if you can locate, or have made for you, bales that are sufficiently compact to carry roof load. You could even consider doing what the authors did for a project in Mongolia, i.e., using a homemade, lever-arm bale press to further compress the bales prior to retying them.

At the same time, be exploring the code situation for your state, county or municipality. Don't assume anything! Should a building code apply to the type of building you propose, at the specific location you propose to build it, you must then decide whether to do the building legally, or to "bootleg" it. Before choosing the latter, consider carefully the consequences of being discovered.

In working with your building department, it will help to provide them with information about this technique as early as possible. The *Straw Bale House* (Steen et al. 1994) has proven very helpful in convincing code enforcers that these houses are demonstrably durable, and do not endanger the health and safety of their occupants.

Other effective tools for educating your building officials are:

• the video called *Straw Bale Code*

Testing;

• Issue No. 14 of *The Last Straw*, which focuses on getting straw-bale construction into the mainstream;

• and, David Eisenberg's working paper, *Straw-Bale Construction and the Building Codes*.

These materials are available from various sources, including:

• *Black Range Films* (888-252-5652);

• *The Development Center for Appropriate Technology* (520-624-6628);

• and, *Out On Bale—By Mail* (520-624-1673).

Bend over backwards not to develop an adversarial relationship with your building officials. This doesn't mean being a wimp and letting them bluff you into thinking you can't do something that you believe is legitimate. It does mean doing your homework (get and study the appropriate zoning descriptions and code sections) and making them aware, in a non-threatening way, that you have done so. Assure them that you want to work with them to do something that is safe and legal, and provide testing data as backup. Put them in touch with building officials in jurisdictions that have already issued permits. If necessary, utilize the existing appeals process. **Good-natured, informed perseverance is a formidable tool.**

For help in working effectively with building codes and officials, see Eisenberg (1995) and Hageman (1994). Your local building department will have a copy of the code they use, for you to read on the premises.

As part of this preliminary design work, you can also begin considering possible foundation options. Relevant background information may include hydrologic data (e.g., floodplain designations), climatic data (e.g., depth to frost line), geologic data (e.g., depth to, and nature of bedrock), and soil data (e.g., permafrost conditions, slope stability, bearing capability). For some specific options to consider, see *The Loadbearing Option, Step 1* and Issue No. 16 of *The Last Straw*. Explore the possibility of having perimeter insulation, perhaps with a termite shield, as part of your foundation system.

Structural Implications of Openings in Bale Walls

When we stack and pin bale walls, we create a sort of "fabric", whose strength and stiffness is greatest when no openings are made in it. Skylights don't affect this "fabric", but doors and windows will. As general rule, it is probably not wise to have the total area of openings in any wall, unless it has a braced framework, exceed fifty percent of the total wall surface area.

Another general rule followed by most modern bale builders is to place no opening closer than one and a half bale lengths to any corner or to another opening.

Wide openings require a stronger, heavier lintel or roof-bearing assembly (RBA) to bridge the opening, or a beefier, loadbearing frame to carry the roof and/or wall weight sitting above it. For these reasons, openings are often made higher and narrower, rather than lower and wider (see *The Loadbearing Option, Step 2*, for details). If the climate dictates a large amount of south-facing glass, it may be wise to consider using frame or post-and-beam in the south wall.

Idiosyncrasies of Bales as a Construction Material

The intent of this section is to help you to start "thinking like a bale". Such thinking can generate a design process based on what these "fuzzy, squishy bricks" really are comfortable doing. A design process based on "thinking like a bale" will honor the unique qualities of bales, and result in buildings which reflect these qualities in their form and feeling.

Structural engineers involved with the revival tell us that bales are unlike any building material that they normally encounter. The basic technique resembles masonry, but masonry units (adobe blocks, fired clay bricks, concrete blocks, etc.) are brittle, non-compressive and fail catastrophically when loaded past their limit. Wood frame construction has some inherent flexibility, but is essentially non-compressive under vertical loading until failure occurs. Bale walls are flexible, compressive and relatively elastic, responding to loading by gradual deformation rather than sudden, brittle failure. For an excellent guide to structural design for straw-bale buildings, see King (1996).

The structural uniqueness of bales is only the first in a long list of unusual characteristics for you to consider as you begin the design/build process:

• In a given area, bales are usually produced during a short period and the supply for the next twelve months is fixed at this point. Everyone doing straw-bale buildings in your area will be diminishing this fixed supply, so it makes sense to buy and build soon after the new batch becomes available. An additional concern is the regional availability of compact, three-tie bales versus the typically looser, less compact, two-tie bales. Rather than have three-tie bales brought in from great distance, you may decide to have customized, denser-than-normal, two-tie bales produced locally to meet your needs.

• A load of bales, even if all have come from the same field and from the same piece of baling equipment (baler) with the same operator, may show considerable variability in dimensions (primarily length), degree of compaction and moisture content.

• Even a single bale is not the same throughout (i.e., is not homogeneous). This has to do with the way in which the stems are folded or cut inside the baler and to their orientation within the eventual bale. The cut side of a bale often has a slightly rippled appearance and exposes the cut, tubular ends of the stems. The folded edge looks "fuzzy" and tends to shed loose straw easily when rubbed. In compressional testing of two-tie bales at Washington State University, the cut edge of the bales compressed more easily than the folded edge (for more information, contact Chris Stafford at 360-379-8541). When building a loadbearing wall with these bales, you would want to have all the cut edges out, in one course, and then all the folded edges out, in the next course, and so forth.

A different kind of non-homogeneity is evident when you try to drive things like stakes, dowels, or rebar pins into the different surfaces of a bale. Assuming a bale laid flat, the ease of penetration is greatest for the sides, somewhat less for the top or bottom, and significantly less for the ends. Experiment with your batch of bales, and then size things accordingly and sharpen them as needed.

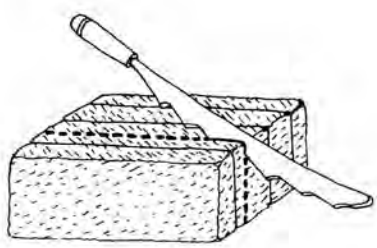
• Bales can come tied with a number of different materials, including rustable, non-galvanized wire, polypropylene twine and a variety of natural fiber twines. Our general concerns must be that the tie material be strong, resistant to rust or rot where exposed repeatedly to damp plaster, and not attractive to rodents. Even if the bales are being laid flat (so that the ties are within the wall), the ties will be exposed where bale ends form a corner and, to a lesser extent, where bales butt against a door or window frame. If wire-tied bales are being used, backup ties of galvanized wire or polypropylene twine can be added before bales are laid at such locations, or the exposed wires can be spray painted with a rust-inhibiting paint. In general, polypropylene twine is favored over regular baling wire by many builders and fiber-tied bales are avoided.

• If simplicity and speed of stacking is a major goal, the design should involve only full and half bales. This is possible only if the bales are about twice as long as they are wide and if all openings are some whole-number multiple of half of the effective bale length (see *Finalizing the Design* on page 34).

• Under normal circumstances, the only **enemies** that the bales have are the ever-present fungi. Even these are harmless if the bales remain dry, but in the presence of sufficient, liquid moisture the enzymes they produce can gradually break down the straw. **The contract that you make with your bale walls to protect them from water (i.e., liquid water), is irrevocable.** The consequences of failure to live up to the contract are considerable, especially in a loadbearing design. An unsurfaced wall, whose top is protected, can survive repeated wettings, as long as the water can quickly be removed by evaporation. That same straw, however, if kept wet for a sufficient length of time at temperatures above a certain level, will turn into a non-structural, slimy mush. Under wet, humid conditions, you may need to wrap the whole exterior with a waterproof, preferably breathable, material until you are ready to put in place the "permanent" surfacing. So, are you willing to commit the time, energy, materials, and maintenance needed to ensure that your bales are properly protected, from the time of delivery until the building they go into is ready for recycling? If not, a more water-tolerant building material may be a wiser, safer choice for you.

• To our knowledge, all successful, purely loadbearing bale-wall designs to date have been limited to a single story, and the bales have almost without exception been laid flat. However, some single-story designs have used a sheltering gable, gambrel, or hipped roof to provide additional living space. And, hybrid designs (see page 22) offer the possibility of even three livable levels (e.g., basement, first floor, and space under the roof). For designs of this type, where structural considerations loom large, you would be well-advised to have an engineer review, or even put their stamp on, your design.

• Finally, bales can be easily (1) **divided** to create custom bales of various lengths and shapes, (2) **sculpted** to create rounded corners or edges, wall niches and *bas-relief* decorative elements, and (3) **bent** for use in curved walls.



Generic Constraints for Loadbearing Design

There is agreement, among those most involved in the design of structures with loadbearing bale walls, that there are some limits regarding how far one can safely push this material. There is not agreement, however, as to exactly what those limits are. What we will do here is list a number of areas where constraints seem justified, and provide quantitative values taken from the straw-bale code presently in effect in the City of Tucson and in Pima County, both in Arizona (available from *Out On Bale—By Mail*, at 520-624-1673, or *DCAT* at 520-624-6628). This code provides a "prescriptive standard" for loadbearing straw-bale construction. Anyone within this code jurisdiction willing to build as the code "prescribes", using the techniques described (or acceptable alternatives) and staying within certain numerical limits, can get a permit without the stamp of a registered architect or engineer. Although further testing and experience may lead to changes in the prescribed techniques and to less restrictive numerical limits, the present version does provide conservative guidelines for decision-making.

A list of areas where constraints seem justified would include:

• **Maximum moisture content** at time of installation—20% of the total weight of the bale

• **Minimum calculated dry density**—7.0 pounds per cubic foot [112.25 kg per cubic meter].

• **Nominal minimum bale wall thickness**—14 inches [35.6 cm].

• **Maximum number of stories**—one.

• **Maximum wall height**— "...the bale portion shall not exceed a height-to-width ratio of 5.6 : 1 (for example, the maximum height for the bale portion of a 23 inch [58 cm] thick wall would be 10 feet - 8 inches [3.27 m]), unless...".

• **Maximum unsupported wall length** (i.e., unbraced or unbuttressed)—"The ratio of unsupported wall length to thickness, for bale walls, shall not exceed, 13:1 (for a 23 inch [58 cm] thick wall, the maximum unsupported length allowed is 25 feet [7.54 m], unless..."

• **Maximum compressive loads**—"The allowable vertical load (live and dead load) on the top of loadbearing bale walls shall not exceed 360 pounds per square foot (1759 kg per square meter) and shall act at center of the wall." This number controls how far apart the loadbearing walls can be, given a prescribed live load and a given combination of roof-bearing assembly (RBA), roof, ceiling insulation and ceiling. For a specific live load, the combination of a lightweight RBA (made possible by using loadbearing door and window frames) and a lightweight roof / ceiling system will enable the roof to span a greater distance, while still not exceeding the allowable load. For Tucson, Arizona, given the prescribed "live load" of 20 pounds per square foot [97.7 kg per square meter], and a typical wooden RBA/roof/insulation/ceiling system weighing about 15 pounds per square foot [73.3 kg per square meter], the maximum allowable span, as influenced by the roof shape, will be on the order of 25 to 30 feet [7.6 to 9.1 m].

• **Maximum area of openings**— "Openings in exterior bale walls shall not exceed 50 percent of the total wall area, based on interior dimensions, where the wall is providing resistance to lateral loads unless..." Openings do decrease a wall's resistance to lateral forces, particularly those being applied horizontally and parallel to the wall. In addition, if these openings are spanned by lintels or an RBA acting as a lintel, any compressive load will be concentrated solely on the columns of bales between the openings. •

Moisture Protection Strategies

The matter of how to protect the straw from liquid moisture that may reach it in a variety of ways should not be treated lightly. Even formulating the right questions is difficult, and the answers are very specific to the local climate and even micro-climate. In any case, it makes sense to prevent water from reaching the bottom course of bales from below, or from the exterior, and to provide a waterproof drape at window sills and at the top of all walls. A review of the "building science" literature on moisture protection reveals significant disagreement among the "experts", and not just on the picky details. Wood, which is chemically similar to straw, is also subject to water damage. This means that longtime, conventional builders in your area can provide relevant advice. The written resources range from popular magazine articles (with oversimplified, cookbook answers) to scholarly texts that will panic and confuse all but the engineers among us (and sometimes them, too). We can recommend Gibson (1994) for an overview, and Issue No. 8 of *The Last Straw* for a variety of opinions. For overall coverage of moisture in buildings, see Lstiburek and Carmody (1993). For moisture-related, cold climate strategies, see ACHP (1995) and Lstiburek (1997).

Mechanical and Electrical Systems, Et Cetera

Before starting to develop a more final floor plan, decide how you will deal with your needs for the following:

- Water (water harvesting [Pacey and Cullis 1986]? well [Burns 1997]? etc.).
- Electricity (grid? stand-alone PV? wind? water? (see Potts 1993, Strong 1994).
- Transportation (interior space for vehicles, including bicycles? 220V charging station for electric vehicle?).
- Gas or LPG (butane or propane).
- Disposal/usage of "wastewater" (composting toilets [see Jenkins 1994, Van der Ryn 1995, ARCHIBIO 1995a]? artificial wetlands [Reed et al. 1994]? gray water [Ludwig 1994]?).
- Space heating (passive/active mix? radiant floor [Luttrell 1985, Siegenthaler 1995]? wood stove? etc.).
- Daylighting (gravity operated skylight/ vent [see Reynolds 1991, page 151]? RBA that includes vertical clerestory windows [see The *Last Straw*, Issue No. 4, page 6]? commercial or homemade light tubes?).
- Cooling (venting? evaporative cooler? cooling tower?) (see Lechner 1991, Cook 1989).
- Mechanical ventilation and/or air exchanging (see Bower 1995).
- Food production (e.g., attached sunspace/ growspace [see Clegg and Watkins 1987]).

Such decisions may heavily influence certain aspects of the floor plan(s) and roof shape. A decision to rely heavily on rooftop water harvesting could, for example, lead to incorporating the storage containers into the structure as loadbearing elements and/or as thermal mass. It might also suggest including generous roof overhangs or porches to increase the harvesting surface and a simple roof design that can be easily equipped with gutters.

Developing a Building Plan

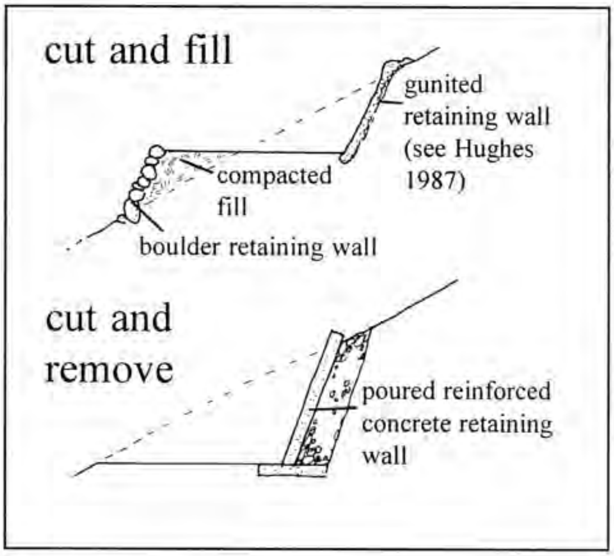
Here's where you finally get down to the nitty-gritty of developing the building plan(s). You aren't likely to forget to provide spaces for cooking, eating, excreting, bathing, sleeping, lovemaking, socializing and relaxing. However, don't forget to design in space for traffic and air flow, various kinds of storage, a home office, your mechanical systems (space and water heating and cooling/ventilation, appliances [esp. washer/dryer], etc.). As mentioned earlier, consider building additional small buildings later as needs change or letting a single structure grow over time by pre-planned additions.

Even if you eventually plan to sell your house, don't let "resale" considerations bludgeon you into creating one-plan-fits-all, generic blah. Let your instincts and creativity be reflected in a design that delights you and yours, while not making it so personal a "glove" that it cannot comfortably serve anyone but you.

Sources that we have found helpful for the design process are Alexander (1977), Taylor (1983), Cecchettini et al. (1989), Day (1990), Jackson (1990), Brown (1993), and Connell (1993).

Site Preparation

This step involves whatever modification of the site is necessary in order to be able to lay out the building you have designed and create the foundations. A time-honored resource for this step is Roskind (1983). For a flat site this may be as simple as scraping the surface to remove vegetation, loose soil and roots. If the site slopes, varying amounts of cutting and filling can be done by hand, or with machinery, to create a level pad large enough



to put the structure on.

Any fill soil must be adequately compacted as it is put in place to insure that the material will not later settle under the weight of the building (see Monahan 1986). Steep cut and fill slopes will need retention and/or stabilization (see Erickson 1989). If the bale structure is to sit on a wood deck supported by posts or piers (a common response to steeply sloped sites), one need only completely clear the area where excavation for the posts will be done.

It makes sense to try to finish the site preparation before finalizing the design, because problems encountered during the site preparation may suggest major modifications in the shape of the building or in the foundation system initially favored.

Finalizing The Design

This part of the process includes a number of important, sometimes overlapping, steps. The process is complex, nonlinear and full of tradeoffs and interrelationships. The steps we list are only arguably in chronological order. Also, for you, the list may be incomplete or contain steps that are unnecessary. Consider it a checklist that you can add to or subtract from. For a non-loadbearing design, the list would also include considerations related to the "framework".

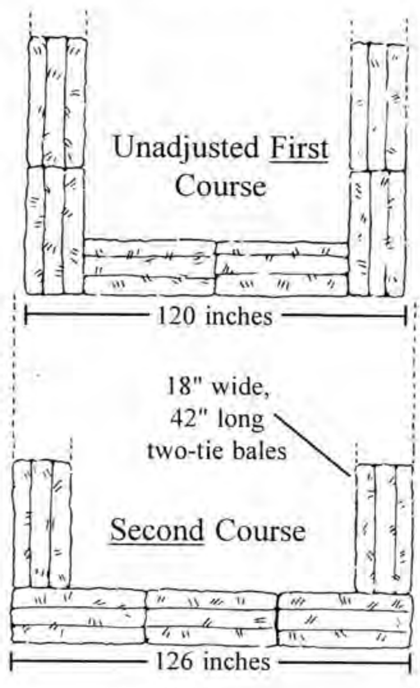
Having said all that, here they are:

• **Make a final decision on foundation and floor design.** This may include decisions about how, if at all, you will insulate under the floor (whether it is on grade or on a deck) and around the perimeter of your foundation.

• **Finalize the floor plan based on approximate bale length and a bale layout for the first and second courses.** For uncomplicated bale layouts that use only full and half bales and that give you the maximum overlap in your "running bond", you will need bales that are essentially twice as long as they are wide. This is fortunately the case with almost all three-tie bales. You will also have to base the size of all your openings on the half-bale module (i.e., a half bale wide, a full bale wide, one and a half bales wide, etc.). Any extra space left on either side of a standard door or window can be used to create angled openings, as shown in the diagram on page 56, middle right.

If the length is more than twice the width, as is common with two-tie bales, the seam between two adjacent bales in the same course will not be located over the midpoint of the bale below. This means that custom bales, that are not half bales, will be needed on either side of doors and windows. Also, with the type of layout shown top right, the length of the first course of the walls will be different from that of the second course. To avoid problems in this case, always use the longer of the two dimensions when determining the final dimensions of the foundation. You can easily increase the shorter dimension with flakes.

Determining the Final Dimensions of the Foundation



We strongly recommend that you initially model only the first course of your proposed floor plan, using "mini-bales" that are accurately scaled for at least the two horizontal dimensions. Do the layout as if there were going to be no door openings. This will enable you to quickly see which of the layout options will give you the shape you want and the amount of interior space that you need. Then, next to this layout, model the layout of the second course, and compare the length of each wall in the first course layout, with that of the same wall in the second layout. This will show you whether you have one of the potentially problematic layouts mentioned above. Dominoes work beautifully for experimenting with possible bale layouts, if your bales will be about twice as long as they are wide. Otherwise, you can cut properly scaled shapes from various materials (e.g., cardboard boxes).

Once you have made a final decision on the bale layout for your floor plan, you can work out the width and location of doors and windows. Then make a sketch of the first course layout to record these decisions.

• **Finalize the exact dimensions of the foundation**, using an assumed bale length or a measured effective bale length. If the approximate upper limit on bale length is known, for the specific bales to be used, you can finalize the foundation dimensions using the chosen bale layout and this length. For three-tie bales, a four-foot [1.22 m] module is often used. Since few bales will approach this upper length limit, occasional flakes of loose straw will have to be used to fill small gaps as the bales are laid up. This is quickly and easily done and does not significantly weaken the walls.

Another common approach, if you are lucky enough to already have your bales, is to determine the "effective bale length". This is done by arranging ten, randomly selected bales butted snugly end to end in a straight line. With short boards held vertically against the ends of the arrangement, the distance between the inside surfaces of the two boards is measured and divided by ten. The resulting number, in decimal inches or meters, is the "effective bale length". Seasoned builders often add a quarter of an inch to provide a little cushion. The halved "effective bale length" can also be used to finalize the width of openings. Bales can also be stacked in wall-high vertical columns to determine the "effective bale height". This figure is useful in finalizing door and window frame heights.

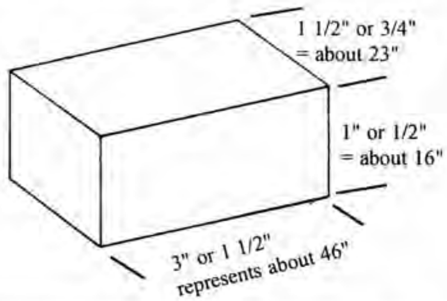
You should now prepare scaled drawings (where a certain distance as measured on the drawing equals a certain actual distance) of the bale layout for courses one and two. Except for the presence of window and doorway openings, all odd-numbered courses will be repeats of course one and all even-numbered courses will mirror course two. A scale of one-quarter inch equals one foot is commonly used in countries not using the metric system.

• **Create sketches of each wall (a.k.a. elevations)**, showing all courses and the location of each bale and all openings. You can use these drawings a little later when building your model

• **Select a roof shape.** In all probability, you will have already been comparing the various options for roof shapes (see the drawings on page 75), weighing a variety of factors related to cost, climate, esthetics, regional styles. etc. But now you've got to pick a favorite to try on your model, as you proceed to the next step.

• **Make a model**. Architects and building professionals are trained to effectively use two-dimensional drawings to represent three-dimensional buildings. For the rest of us ordinary mortals, models can reveal a world of problems and solutions. <u>Nearly</u> true-scale micro-bales can be purchased from craft supply stores. <u>Exactly</u> true-scale bales can be handmade from 1/2" [1.3 cm] or 1" [2.5 cm] expanded polystyrene insulation board (the high-density variety cuts more cleanly) or wood. These enable you to build a scale model of your building on the kitchen table and get most of the glitches out of the design before things get too real (see Feirer 1986).

To-Scale, Styrofoam or Wooden Three-tie Mini-bales for Modeling*



* *For two-tie mini-bales:* 1" or 1/2" = about 14"; 1 1/4" or 5/8" = about 18"; 2 9/16" or 1 3/16" = about 36". *For metric system users:* have the thickness of your foamboard equal the bale height.

The individual "bales" can be stacked and pinned (with glue, toothpicks or the equivalent), and the RBA and structural roof elements (e.g., rafters, trusses) can be modeled with balsa wood purchased from a store providing art or hobby modeling supplies.

A different, faster option for modeling the bale walls is to use correctly dimensioned pieces of 1" [2.5 cm] thick insulation board to represent whole walls. The seams between the bales are represented by a grid of lines drawn onto the wall panels.

Another option, for those of us who are "three-dimensionally challenged", is the "cybermodel". Software programs abound that enable you and your trusty computer to reduce your two-dimensional, architectural visions to bits of bytes, or whatever they are. The computer can then create a three-dimensional model that can be viewed on the screen of your monitor from various angles, from both within and without. One piece of software which has been successfully used for modeling straw-bale "cyberhomes" is 3-D Home Architect (manufactured by Broderbund).

• **Finalize the design of the roof/ceiling system, including the choice of RBA.** Having modeled one or more options for roof shape, and having made your final choice, you can now work out the rest of the details related to the larger roof/insulation/ceiling RBA system.

• **Finalize the elevations.** This includes finalizing the location, number and nature of doors and windows and the design of the rough frames for them. Remember the importance of the highly insulated "thermal envelope" in your superinsulation strategy. One of your structure's biggest "nosebleeds", energy-wise, will be the doors and windows. Despite extensive Research & Development, the R-value of even the most expensive doors and windows does not begin to approach that of a bale wall. Even so, it does make long-term sense to purchase units that provide double or triple the R-value of the low-cost units. For valuable counsel, consult Carmody et al. (1996). Don't be penny-wise, (energy) dollar foolish when you shop for doors and windows!

Using the model (or if you didn't build one, the scaled drawings that you made of the bale layouts for the first and second courses), you can now proceed to prepare a scaled vertical wall-map (i.e., an "elevation") of each wall, showing the placement of each bale and half bale, all frames (for doors, windows, evaporative coolers, etc.) and lintels (if any), as viewed <u>from the outside</u> (don't ever stand inside the building when using one of these maps to position a niche or opening). These maps are invaluable during the wall-raising and should be posted in front of each wall for frequent, convenient reference.

• **Create, or have someone create for you, a complete set of working drawings.** Before moving on to creating your final working drawings, review all decisions about foundation, RBA and roof design, and plumbing, mechanical, and electrical systems. This will ensure that any changes made along the way are still accommodated by the floor plan and that the choices you have made about separate things at different times have not created conflict or redundancy. Do a reality check for things that are easy to draw, but no fun to do, perhaps repeatedly.

Now prepare, or have prepared for you (by an architect or construction draftsperson), detailed, scaled working drawings. They will provide with words and lines a record of the multitude of design decisions you have made. Even years later, a good set of plans will make clear what you decided, and wanted to do, years earlier. We recommend that you have, as a minimum, the following:

- A site plan, showing how the building fits on the site, along with any easements, power sources, underground pipes, etc.
- A floor plan, showing interior partitions, window and door openings, stairways, porch extensions, etc.
- A foundation plan, showing locations of foundation bolts, rebar "imbalers", eyebolts, tubing for threading tie-down straps, etc.
- A cross-section of the foundation system, showing reinforcement bars (a.k.a. "rebar"), perimeter insulation, floor design, etc.
- A roof-framing plan.
- Cross-sections of the wall system itself, and at typical doors and windows
- "Elevations" of each wall, plus detailed sketches of each door and window frame.
- A plumbing and mechanical plan.
- An electrical plan.

These same drawings will constitute much of the package that you will have to provide if you are applying for a building permit. Consult with your local building officials regarding their specific plan requirements for a permit application. Useful resources for this process include Weidhaas (1989), Spence (1993), and Curran (1995).

Having lead you by the nose through this whole confusing, joyful, messy, challenging frustrating process, we'd like to break it to you gently that there is another way to more rapidly, and (perhaps) less expensively, end up with a set of working drawings. Unless you are firmly committed to having a custom, one-of-a-kind design, you may want to explore buying an "off the shelf" plan set. By selling the same design to several parties, the designer can sell each set at a reduced price. At least three sources now exist for this type of straw-bale house-plan sets, and more will undoubtedly appear (see Lanning 1995; or contact *Sustainable Support Systems*, [Box 318, Bisbee, AZ, 85603] for information on designs by Steve Kemble, engineer and longtime straw-bale builder; or contact the *Community Eco-Design Network* [Oak Park Neighborhood Center, 1701 Oak Park Ave., N., Minneapolis, MN, 55411] about their planbook).

With a set of working drawings and, perhaps a permit, you are now virtually ready to start building. Up to this point, we've been assuming that you are going to build this house yourself. You may be assuming that, too. Owner-building can be spiritual, joyful, educational, inspiring, economically beneficial, and more. We encourage you to seriously explore the possibility of doing it all yourself. We also encourage you to be realistic about the skills, time, energy, patience, stamina, and perseverance needed for owner building.

If you choose not to try to do it all, consider getting a builder that will let you (and friends/family) help whenever your skills and schedule permit. Or, consider being your own contractor, choosing sub-contractors to do some or all of the work. This does require time (e.g., to educate yourself; to spend the necessary time on the job site), patience (e.g., to negotiate clearly-worded, enforceable contracts), and certain other skills, but can reduce the contractor-built cost by twenty-five to thirty percent. Among the many resources for the owner-contractor are Kilpatrick (1989), Hamilton and Hamilton (1991), Whitten (1991), Shephard (1992), and Heldman (1996). In some cases, hiring a contractor to do the building may be the correct choice. Even then, seriously consider doing the wall-raising as a "community event". The loving energy of your friends and neighbors will infuse the walls, and you will truly own your home in a way that money can't buy.

Preparing a Materials List

At this point, many builders do a "takeoff". In other words, they prepare a comprehensive list of needed materials, doors and windows, hardware, fasteners, etc. (see Alfano 1985, Householder 1992). To prepare such a list, sit down with your plans and a detail-compulsive friend and start with the very first step (usually, building layout). Step through the whole project, one task at a time, and figure out everything you need to buy, borrow, rent, harvest, dig or scavenge to support each task.

Now, review your shopping list. Well in advance of when you will need them on the building site, order any materials not locally available, right off the shelf. Prepare, as necessary, to store these and other materials on site with whatever protection they require.

Safe and Sensible Bale Storage

The mere fact we give this whole section a *red flag* should tell you that this is serious business. We've never been able to understand why a person would choose to devote the considerable amount of time, energy, money, brain cells, antacids etc. that it takes to get ready to build a straw-bale house, and then not adequately protect the single, most important material they'll be using—THE BALES. And yet, time and again, people let their precious bales become, and stay, wet enough to be rendered useless or suspect.

With the intention of reinforcing your commitment to follow through on this important task, here is what we think constitutes proper storage:

• **Get the bottom course of bales up off the ground**. In many areas, slightly damaged, wooden, loading/shipping pallets are free for the taking and great for this purpose. In any case, find some way to elevate the bottom course of bales.

• **Create a stack that has a curved (a.k.a. crowned) top.** This prevents ponding and gets water off the stack quickly.

• **Protect at least the top of the stack with some sort of waterproof covering that will not be blown off.** One effective system involves first installing a piece of plastic sheeting, large enough to come down a foot or so onto the sides of the stack, where it is fastened with "Roberta Pins" (see page 92) to prevent it from shifting around. This first layer is then protected from sunlight by a canvas or woven polyester tarp, itself tied or weighted down. Silver-colored tarps that are somewhat longer-lasting (i.e., more resistant to ultraviolet light) are available from many suppliers (e.g., *Northern*, 800-535-5545).

Ideally, the edges of the tarp are somehow held slightly out from the sides of the stack, creating a drip edge. See the diagram below for one option. In extremely wet climates, especially if wind-driven rain is common, the sides of the stack may need to wrapped before the top is covered. In this case, be sure that the top edge of the side-wrapping is sufficiently overlapped, on the outside, by the upper covering. A breathable housewrap material would be ideal as a side-wrap.

Here's a final note on storage that relates not to water, but to the length of time the bales have been stored. The longer the storage, the greater the mouse population. This means visible effects of tunneling and the likelihood that they'll chew through an occasional string in the process (not so with wire-tied bales—two more reasons to minimize the time gap between the availability of the year's new batch of bales and the date of your wall-raising.

Whew!

At long last, you should be able to send out invitations for your wall-raising and to tentatively schedule the other activities in the sequence that will lead to a finished building. Veteran builders factor in Murphy's Law, delays in the arrival of materials, bad weather, that unannounced three-week visit by your in-laws, the flu, etc. For each major work effort, list out the people and equipment that you'll need, and figure out how you're going to get them. Don't schedule move-in or the housewarming party quite yet. You'll have plenty of time to do this later as light begins to appear at the end of the tunnel.

And now, into the breach we go!

The Cadillac of Stacks

Modified Version of a 60-Bale Cube of Three-Tie Bales