Plan Instant Shelter

Straw Log Walls for Insulation and Safety

Patti Stouter, BuildSimple.org, April 2023

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Figure 1- Straw log walls built in 2012/ 2013. Left: Banco with straw log walls in use today in Albuquerque, New Mexico. Center: Straw log dorm upper walls on earthbag base walls in northern Haiti before and after plaster. Right: Interior of straw log dormitory as currently in use shows stabilized plaster on straw walls above ledge of thicker earthbag base wall.

Abstract

Better shelters with insulation are needed for disaster and refugee response in cold weather. For short term use they should be low-cost, earthquake-resistant, recyclable and easy to disassemble. Straw-clay made from natural subsoil and agricultural waste can be utilized within strong geotextile mesh to create modest-strength 18 cm (7”) thick walls walls of R3 or higher. Located on a 38 cm (15”) high base wall of earthbag and covered with earthen and/ or lime plaster these straw log walls can support light-weight roofing. Building prototypes in the US and Haiti have survived a decade. When no longer needed, the light-weight shelter walls are more than 95% recyclable. The construction process is low-tech but relatively clean and light. Shelters can incorporate minimal amounts of wood or steel if reinforcement is needed to resist snow loads. A guide to locating structural members is based on estimates of compressive strength from laboratory testing and informal experiments.

Need for Insulated Short-Term Shelter

Disasters like earthquakes, floods, and wars can cause millions to suddenly become homeless. Housing need often exceeds extra space even after regional families have doubled in size. Camps of tents sprout up with desperate needs for sanitation, food and medical care. Refugees or internally displaced people usually stay in camps for years (Devictor, 2019). During warm seasons tents can not keep out rodents, thieves or kidnappers. In winter, they let cold air blow through.

Self-help shelter projects are often ineffective because potential supplies disappear near large camps, and camp authorities dare not allow permanent structures. Local deadwood and poles are needed for cooking and heating fuel, and costs of lumber and skilled builders rise after a large-scale disaster. For shelters to be useful, in addition to insulating and secure they must be

- low cost
- use local, recyclable materials (preferably few conventional building materials)
- structurally fool-proof (resist damage without tight quality control)
- potentially survive a decade
- easy to disassemble

Pre-fab shelters can be flimsy or difficult to deliver where needed. Some systems require expensive machinery. The best economic and social impacts result when shelter construction uses

- simple available tools
- familiar or easily learned processes
- low skill, local labor

If possible, shelters should also look safe. After Haiti’s 2010 quakes one orphanage built plywood sheds for their young children who were too afraid to relax and fall asleep in the reinforced concrete dorm that passed engineering inspections but resembled badly damaged buildings.

Background of Straw Log Construction

Fabric, Fibers and Earth as Construction Elements

Modern engineering sandwiches weak materials between layers of higher tensile strength to reduce economic and environmental costs like stress-skin SIPS panels (Maynard, 2009) or gabion footings. Geotextiles of fabric with earth or stone are spreading from site work into architecture as tube-confined cement footings (McCombe, 2019), gabion ring beams (Langenbach, 2015), drain cells (Hydrocore, 2023), or earthbag walls. Earthbag are inexpensive earthen walls built damp in fabric forms (Figure 1 center, above) interlayered with barbed wire and pierced by embedded steel (Hart, 2018). But earthbag's massive walls are too heavy to be considered temporary.

Lighter low cost structural walls can include straw-bales (Figure 2 left) with compressive ties (Elizabeth and Adams, 2005; Donovan, 2009) or bundled straw logs called StrawJet of oriented-strand cables of straw (Chino, 2009). Unfortunately these fiber-only walls use large amounts of straw, must not be wetted before roofed, and/ or use large equipment.

Natural fibers are also added for their tensile strength into earthen materials like cob and light clays. Hand made cob walls of earth and straw are labor intensive but more resilient than earthen materials without fibers (Miccolli Muller and Fontana, 2014). Thai researchers used aligned straw with liquid clay to build a round silo (Hengsadeekul and Nimityongskul, 2004). Light straw-clay (LSC) is becoming popular as an infill material. Straw dipped in liquid clay is packed randomly into temporary forms 30 cm (12”) deep (Figure 2 center). Full wall-height masses of LSC need a week per 2.5 cm (inch) of thickness to dry (Doleman, 2018). With plaster (Figure 2 right) they are code-compliant (ICC, 2018) for insulation and fire-resistance. Testing has shown high R values, modest compressive strength and high flexibility (Thornton, 2005).

Figure 2 Left: Strawbale building by Philipp on Wikimedia Commons. Center: LSC infill in stud wall. Right: Earthen plaster embedding plastic mesh over straw-clay wall.

Straw Logs for Buildings

Straw logs have similarities to StrawJet and the straw-clay silo, but are a geotextile using LSC as a wall matrix. This low-tech and low-wood alternative creates 18 cm (7”) thick walls that dry more quickly than monolithic LSC and use only 10- 15% as much straw as straw bale walls. Because the plastic mesh tubes (Figure 3 left) are stuffed with clean straw (Figure 4 left) and sewn together while dry (Figure 3 right) construction is relatively quick and does not require great strength.

Figure 3 left: Wattle mesh. Center: Plaster skin on straw logs. Right: Straw log walls with formed windows.

After later being soaked with liquid clay (Figure 4 center) and plastered the strong mesh embeds in the plaster to form a structural skin over LSC cores (Figure 3 center).

Figure 4 left: Stuffing straw logs. Center: Soaking logs with liquid clay. Right: Lime plastered straw log walls.

Straw log walls can be built with some embedded rebar (Figure 5 left) or with localized roof supports of wood or pinned rebar (Figure 5 center, right) for a hybrid structural system if needed.

Figure 5 left: Haitian dormitory impaled oversized straw logs on rebar. Center: Poles can be tied into log mesh. Right: Small straw log shelter planned for wood posts attached to earthbag support roof beams.

First developed in 2011 to win the popular vote for Jovoto's $300 house contest (Smith, 2010), several prototypes (see Appendix 2) have now weathered their first decade well. But most important, straw log walls can be temporary shelter because the light walls are easy to disassemble, leaving less than 0.2% plastic mesh by volume to discard. If the roof is removed and water-resistant plaster cracked, the straw-clay matrix decays. Lime or cement plaster coatings must be discarded, but after the straw wall core has been soaked for a while, earthen plaster crumbles and humus-rich soil can be shaken out of cut mesh tubes.

Planning Straw Log Walls

Straw log walls need a water-resistant base wall to hold them in place and a roof overhang to protect wall surfaces from rain. Finish coats of a compatible earthen plaster cover interior walls and/ or exteriors in dry climates. Lime plaster (Figure 4 right) can preserve exteriors of straw log for decades even in damp climates.

Roofing supported by straw log walls must be light-weight; not tile, reinforced concrete, or log and earth. Heavy roof materials increase danger in quakes to conventional walls and are too heavy for straw logs to support.

On long or tall straight wall sections a temporary framework is needed during the soaking process (Figure 5 right). Some shelters located in regions with a winter season will need one or more permanent roof beams supported by wood posts. Although roofing can be as simple as tarps over reed bundle supports, walls that could last a decade should be planned to be able to support wood rafters and light roofing upgrades in future.

For technical information and options for reinforcement see Appendix 4 and check online at for more complete reports on Build Simple research.

How to Build with Straw Logs

Materials Needed

Plastic mesh tube is commonly used for erosion control wattles, and named by manufacturers for the diameter of the finished log. 15- 20 cm (6- 8”) in diameter works well for straw logs[1]. A tube called only 20 cm (8”) diameter might be too large when filled, requiring more straw.

Wheat or corn straw works well. Use any fine textured dried stalks and leaves that absorb wet clay.

The small 5,67 m^2 shelter shown above (Figure 5 right) has 17,3 m^2 of wall face area on top of 5,3 m^2 of base wall and footing (to just below grade)[2]. A 1000 m (3000’) roll of wattle tube and 50 bales of straw will build about 5 of those shelters with some wood for top plates, some polypropylene cord and some clay soil. Each straw bale will fill enough tube (and make enough plaster) to create more than 1,1 m^2 (12 sf) of wall, in contrast to conventional straw bale forming less than 0,2 m^2 (2 sf) of wall surface.

1 Tube netting is sometimes defined by how wide the intact tube can be pulled when laid flat. A maximum 27- 28 cm (10.5- 11”) is recommended.

2 In standard units this small shelter is 61 sf of floor area with 186 sf of straw log wall face on top of 57 square face feet of base wall and footing.

Complete materials lists and cost estimates are included in Appendix 3 with labor estimates.

Construction Process

The straw log construction process involves several steps. Footings and base walls can be thinner than needed for conventional buildings but can hold an upper wall framework in place to make the steps of sewing and soaking logs easier. Plastering uses conventional skills although earth-compatible materials are preferable. Conventional light roofs can be attached to wood top plates.

Base Walls

The simplest base walls (Figure 6) to resist water and mechanical damage and hold the upper walls in place can be made of cohesive soil in grain bags covered by cement stucco.

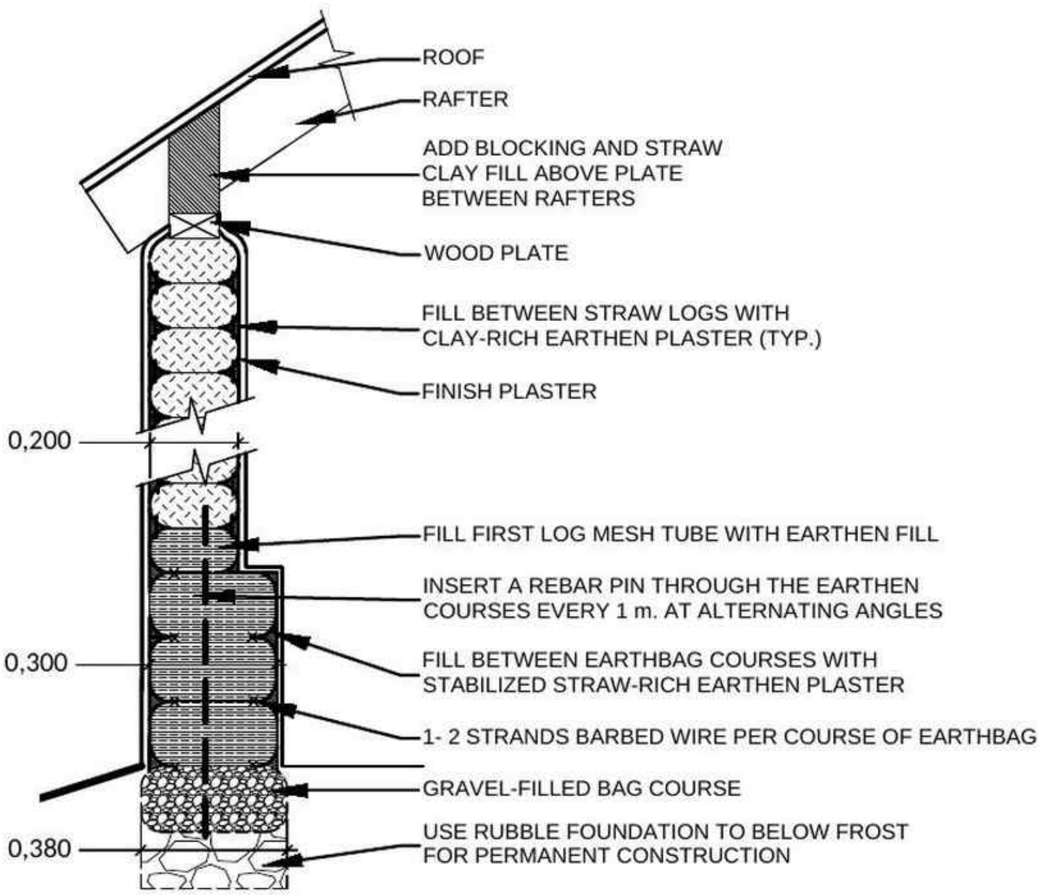

Figure 6: Section through straw log eave wall built on an earthbag base and supporting a light roof.

The conventional footing for earthbag walls, a course of gravel filled bags, effectively prevents dampness rising up through the wall from the ground (Figure 7 left). Gravel-filled bags can be double-bagged to prevent walls losing loose gravel fill if bags are damaged. Either apply stucco soon or buy UV-resistant bags (Hart, 2018). Wrap barbed wire tightly around the entire building (Figure 8 left), overlapping and binding ends with strong wire over several barb clusters.

Earthbag base walls filled with cohesive soil do not need to be double-bagged. They can be mostly recycled after use and like other geotextiles, tolerate some subsoil motion (Guyer, 2013). Because straw log walls are light-weight, base walls can consist of a few 30 cm (12”) thick courses.

Fill the first erosion control wattle tube course with cohesive subsoil as an attachment course. Tamp it to 18 cm (7”) wide (Figure 7 right).

Figure 7 left: Gravel in bags for a water-resistant footing. Center: Gravel in wattle mesh makes a narrower course but is not damaged by water or by sun. Note that gravel bag below are coated with clay for temporary protection from sun. Right: Earth in wattle mesh on earthbag courses.

Under the attachment course lay the first vertical strapping cords. These can cinch courses closer to what their final height will be if they overlap every 3- 4 courses (Figure 8 right).

Hammer rebar pins through the earthen attachment course into one or two earthbag courses below at slight angles (Figure 8 left). If rebars are desired in straw log upper courses, also hammer longer vertical bars through several earthbag base courses.

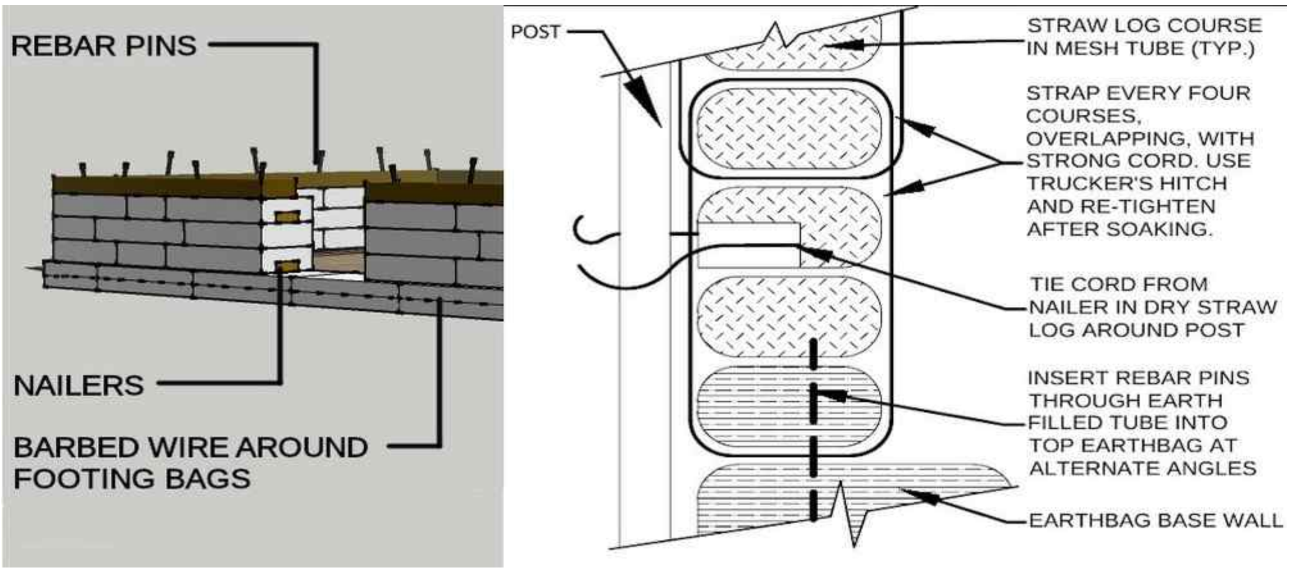

Figure 8 left: Lay nailers for posts between earthbag courses, and hammer rebar pins through the earthen wattle tube course. Right: Insert nailers into the straw logs where posts will later be attached.

Wood Framework

If wood posts are needed, attach them to the base wall by screwing or bolting to wood nailer plates embedded in the base walls (Figure 8 left). Nailers between earthbag courses have several long nails protruding upward into the course on top, and several more nails hammered at slight angles through wood into damp fill below (Hart, 2018).

Straw Logs

Straw log construction starts by filling erosion control wattle netting firmly with straw. If structural posts are used, also include nailers in some straw logs. For flat wall sections lay logs on a table and sew one side of each course before turning the mat over and sewing the other side.

Curving walls and overlapped corners sewn together stiffen vertical stacks (Figure 9 left) even before soaking with clay. Sew several strands of mesh in each stitch (Figure 9 right).

Figure 9 left: Sew all surfaces snugly at corner overlaps. Right: Partly soaked vault tubes sewn to mesh base.

If the shelter will use a tarp roof either temporarily or for long term, add attachment points on the third course from the top every 30 cm (12”). Use loops of strong wire woven through at least 5 cm (2 inches) of multiple strands of the mesh that stick out past the plaster level.

Shelter wall portions can be assembled and stored dry under cover. Never soak straw logs unless there will be 2 weeks before freezing for them to dry completely. Although electric fans can speed wall drying, prevent mold by never wrapping tarps tightly around a damp straw log structure.

Soaking the Straw

Clay slip is made from subsoil containing some clay. Sticky clay used for pottery works well or can be mixed with weaker soil. See Appendix 5 for more information about soil for slip and plaster.

Straw logs wet with liquid clay become much heavier and temporarily lose stiffness. Brace long straight walls of straw log before soaking, and/ or soak only 1 m (39”) in height at a time. Use a watering can with a spout to pour liquid clay close to the center of the straw log (Figure 3 center). To spread the liquid into the straw knead the straw with fingers for a minute, then move on. Don’t overwork the clay as it starts to harden.

Leave one course that is not soaked on top of your walls or tie cords on the top course before soaking. After fill settles 5- 8% in height more courses may be needed and are easier to add onto dry straw mesh. Top the straw log weight bearing walls with a wood plate by strapping it to the top course and stapling the mesh tube onto the edges of the plate. Then finish soaking the top course.

Plaster

After the log surfaces are firm dried to feel like leather add earthen plaster containing sticky clay and a lot of straw to fill nooks between the courses. Push it strongly into place to connect with the mesh and clay-covered straw (Figure 10 left). Leave the surface lumpy or add finger-holes. The next layer of plaster can be less sticky and applied with a trowel to level the wall (Figure 10 right).

Figure 10 left: Push the first plaster firmly into the nooks. Right: Shaping plaster will stick more easily.

Finish plaster needs fine straw, less water and some fine sand. Find a mix that does not dust off much on your fingers after it is dry (Guelberth, 2003). Walls need a consistent and entire plaster layer to resist fire and prevent insects living in cracks in the walls.

Hydraulic lime plaster survives rain on exterior walls (Figure 11 right) and adheres well in thin layers to earthen materials. It doesn't crack in the months after application over natural walls as much as cement-based stucco does. Lime plaster also allows straw-clay to dry well (ibid.).

Cement stucco has been used on earthbag and gravel bag base walls in dry climates. If lime is not availabe, use cement stucco on top of stabilized earthen plaster containing 3% of lime or cement (Figure 11 left). Cement stucco doesn't dry out well, so may shorten straw log wall life in damp climates. When it cracks it often needs mesh and a thick stucco layer to patch the crack.

The impersonal maze of identical shelters found in most displaced persons camps can be avoided by decorating with raised details of shaping plaster (Figure 11 center) with or without added color.

Figure 11 left: Stabilized earthen plaster forms a smooth Haitian dorm wall. Center: Straw-rich plaster forms raised designs on straw log walls, finished with colored lime plaster. Right: Lime plaster protects this LSC-shaped window sill from water on the straw log banco wall.

Conclusion

Rough estimates of material costs for the straw log walls of the small 2,8 x 3,5 m (9’ x 11’) shelter shown in Figure 5 right range from US$ 500- 800 including purchasing straw bales. Base walls and footing materials could be US$ 25 for bags plus US$ 30- 40 for barbed wire and rebar pins. If supplied with all materials, a pair of workers could build the base walls in a day, build the straw log walls in another day or two, and a single person could soak and plaster the walls of one shelter in 3- 4 more days. For more information on exact materials and tools needed, see Appendix 3.

Straw log shelters are the perfect self-help project to allow displaced people to improve their lot and/ or help each other without laying permanent claim to the site of their shelter. Create a small demonstration building for someone important and make it beautiful and culturally appropriate so that the new material will be perceived as good quality (Elizabeth and Adams, 2005). A community warming/ cooking shed or a more secure medical clinic could be built for a heater with seating.

The few new skills involved in straw log construction may also benefit communities by teaching transferable concepts like redundant interconnection and the use of light-weight flexible materials to better resist earthquakes.

Although the stays in displaced persons camps varies widely, more people stay for years than find better housing in less than a year. If I was one of the residents facing an average stay worldwide of five years (Devictor 2019), I would want a chance to live in a sturdy, natural walled building with thermal mass that I could personalize and make safer for my family,

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Appendix 1: Straw Log FAQ

Aren’t Mud and Straw Buildings Poor Quality Material?

In regions that have not witnessed a craftsman-quality revival of natural materials, many feel strongly that a building of earth and straw is a step backwards. To reverse prejudice, involve local leaders in choosing the shape and use, then build a high quality example first for use by someone of importance (Elizabeth and Adams, 2005) with special detailing.

If residents equate natural walls with dangerous huts that decay or were damaged by the local disaster, show how tough straw log walls are and how impervious to water the base wall is.

Are there Alternatives for Foundations and Base Walls?

The footing course can be a double row of the same wattle mesh used in straw log upper walls, filled with coarse gravel (Figure 7 center) for a thin but UV-resistant footing layer.

If gravel is not available, chemically stabilize earthbag layers to resist water by adding 3% by volume of cement or lime (Halsted, Adaska and McConnell, 2008). This CMS (chemically modified soil) fill cannot be recycled to fields, and also increases construction time because it must be measured and mixed accurately and tools cleaned frequently. Stabilized courses also harden too quickly to add rebars into more than one course at a time. Use a plastic moisture barrier below the attachment course so that stabilized courses don’t transmit rain splashback upward.

Vertical rebars can pass through courses of stabilized earthbag fill by using cut-bag technique. Anchor the rebar in the lowest CMS course as soon as it is laid and tamped. On upper layers, fill the bag or tube, cut a small slice near the rebar and slide the filled bag around the rebar. For more information on cut-bag and general earthbag techniques see the B102 Build Standard Grade Resilient CE Earthbag pdf online at BuildSimple.org’s resources page.

Base walls could also be made of gabion footings of rubble or stone in metal mesh, or conventional masonry walls. Use long strapping cords and/ or anchored pins to attach the earth-filled attachment course onto a masonry or gabion base wall.

Can Straw Logs Be Soaked Before Assembly?

Yes, but they get heavy and are too hard to sew together.

Dried blocks of the light straw-clay material have been used for wall infill to decrease drying time, but still have low strength. LSC blocks work well for furniture or interior partitions.

Why Put the Straw Clay in Mesh?

Straw log’s manufactured mesh tubing raises costs. Four main benefits that sets it apart from traditional techniques like quincha or bahareque[3] and straw bale:

3 Straw clay tucked between lathe caging, or wattle and daub applied to pole frameworks resist earthquakes better than earthen or stone and mud construction, although weak attachments leave it vulnerable (Carbajal, 2005).

- Walls can be built almost instantly
- Walls need less wood
- Mesh tubing layers unify and toughen plaster surfaces
- Rounded log courses have more surface area than LSC masses and dry more quickly

Straw log walls can be dry before adding plaster, separating the two processes to speed drying.

Can Straw Logs Use Cheaper Mesh?

Yes but don't use mesh weak enough that stuffing results in many holes. The stiff mesh reinforces the walls, but a slightly weaker mesh may be fine for small shelters.

Can Earth Plaster be Mixed More Easily?

Earth plaster is traditionally made by trampling straw into wet clay soil. If dry subsoil (with little or no gravel) is available, mix straw and very wet soil in a wheelbarrow with a hoe. After the straw is all wetted, stir in enough dry soil to thicken the mix. Or layer wet soil and straw on a tarp, have two workers fold the tarp in half and walk on top to mix the straw, then fold the other way and repeat.

Can the Courses be Tied More Quickly?

Straw log sections could be fastened in place with zip ties on one side to speed construction. Haitian builders simply impaled the straw logs on embedded vertical rebars.

Finely interconnected mesh transmits stresses throughout the walls, including across to the plaster to the other side of the panel. Wall shear strength and resistance to both thieves and rodents depend on the attachment. Sewing courses can be done by women and children and elders.

Can we Use Lime Plaster Without an Expert?

Yes. Lime plaster dries more slowly than cement stucco but the process is similar.

Just be careful mixing- pour powdered type S lime into water and stir into a thick sour cream-like putty. Keep powder and putty off bare skin and out of eyes. Have vinegar water (1:1) nearby to dab any splashes on skin. One 45 kg (90 lb) bag will fill about two 19 L (5 gallon) buckets. Store covered.

3 buckets of clean sand stirred into a bucket of lime putty make plaster. Stir in a few handfuls of 25-50 mm (1- 2") fibers like chopped straw just before use. For thin finish layers use finer fibers.

To patch existing plaster, use a milky liquid lime wash of thinned putty without sand (Guelberth, 2003). For more information about lime plaster see *pdf B50* online at: BuildSimple.org/Resources.

How Do We Attach Straw Logs to Wood?

Where a door or window interrupts an area of straw log, tie mesh first to the wood frame. After the wall is soaked and dried, screw through the frame into the log nailers, but also nail or staple both sides of the end of the mesh to the frame. For a metal door or window frame, attach a wood nailer strip or weld metal pins onto the frame sticking up.

Can Temporary Door or Window Coverings Let in Light?

Panels of several layers of clear plastic can both insulate and light the interior. Add bubble pack in between for more insulation if available.

Form a door from at least two layers of 4 or 6-mil plastic. Attach one panel to the inside of the door frame and slit it down the middle. Attach a longer panel to the outside of the door frame along the top and one side. Roll up the extra fabric at the bottom and staple it to a short pole. Pull the pole up snug against the wall to close the door. Or get a dust door used by contractors with a zipper.

Can Windows and Doors be Used?

Small window openings formed in the straw logs can be filled with glass or plastic panels. Or attach framed windows to a wood sill plate. Attach doors on the hinge side to one embedded wood post.

Attach a window frame on top of straw log and build the straw log next to the frame and above it. Leave 10% extra height on top. After the straw log has been soaked and dried, gaps will be smaller. Fill remaining gaps with loose LSC (Figure 12). If a window is wider than 60 cm (24”), extend the window buck up to the top of the straw log wall. Fill above the window similar to a transom area, either with short straw logs or use batten strips and a form for LSC while filling.

Figure 12 LSC to fill gaps- Left: Light straw-clay fills the gap under deep window framing of a thick veneer wall. Center: Leveling plaster of earth with little straw, textured to help finish plaster adhere well. Right: Finish plaster of earth smoothing edges of exposed adobe wall.

Can the Roof be Insulated?

Yes. Warm ceilings have a high temperature difference to the outside and can lose a lot of heat.

Low cost alternatives to provide some insulation value in the ceiling include grain bags filled with insulation and laid on mesh, thatch bundles, lighter straw logs with reeds or poles, and air duvet insulating blankets. In areas with diseases caused by insects in building walls, seal any loose fill or LSC with plaster.

Lay thinly filled bags of lightweight straw or rice hulls on chicken wire stapled to rafters. Lay thatch (bundles of strong straight straw or reeds) under a metal roof or tarp. Or make lightly filled straw logs the width of the rafter spacing, with a reed or small diameter pole inside. LSC can be half the weight of the dried straw log walls and use light fabric in smaller tubes. Fill, insert the stick, and when dry coat the bottom half with plaster before laying.

An air duvet is made by layering recycled fabric and plastic to hold air pockets between the layers. If sewn to match the rafter spacing, panels can be attached to the rafters. For more information, see *https://buildsimple.org/disaster-response/* or download a *how-to pdf*.

Can the Floor be Insulated?

Yes. Since people are close to the floor when sitting and sleeping, insulation really helps.

Layer sheets of cardboard on reflective emergency blankets and top them with a tarp over it all. More effective is insulation under seating/ bed areas by:

- Crocheting a plastic bag blanket and covering it with a plastic sheet
- Stuffing a pad with clean plastic trash
- Making raised platforms

Crocheted *airy blankets* will trap heat better when covered with plastic or a heavy fabric that you can not blow through. Or sew an insulating trash pad from any scrap fabric using material for fill that holds air but does not compress: clean straw, fill from life jackets, foam scraps, or plastic containers. More information online *https://buildsimple.org/disaster-response/* or a *how-to pdf*.

Make light clay into a platform. Use a frame of wood or reeds since LSC edges can chip. Use wood chips or rice hulls or sphagnum moss instead of straw, or stir plastic bag strips well to twist.

Make light clay as light as possible for best insulation (Thornton, 2005). Let a strong plaster cover weaker very light clay. Make the light clay in small blocks in a form lined with plastic. Dry until it stays together when removed and stacked for quicker drying. Use straw clay mortar between blocks. Wrap with mesh (like fine bird netting) and plaster (Nienhuys, 2011).

Appendix 2: Prototype Buildings

Mesh tubes of LSC were first explored in 2011. Prototypes were built in 2012- 2013 in three locations with dry climates and little or no snow loading on the roofs.

HCDP DORMS

To date these dormitories by Haiti Christian Development Project (Figure 13 as well as Figures 1 center and right and 5 left) are the largest structures using straw log walls. Built near Gonaives, Haiti (6,5 cm/ 2.6” annual rainfall) with upper walls of straw logs impaled over evenly spaced vertical rebar. Slightly oversized mesh tube was filled with dry corn straw and stems.

Reinforced buttresses of earthbag between straw log panels held up reinforced concrete roof beams. Finished plaster was cement-based. The buildings are in good condition and frequently used for their agricultural training programs.

Figure 13 left: Haitian dormitories combined earthbag buttresses with reinforced concrete ceiling beams. Right: Current interior of the dormitory under intense use.

STOUTER WALLED BANCO

A bench enclosure in Albuquerque, NM (23 cm/ 9” annual rainfall) was built with no vertical wood or steel in the straw log walls (Figure 14 left). Three vertical posts were anchored in the bench but not attached to the straw log wall. These 1,5 m (5’) high walls 2,4 x 3,7 m (8’ x 12’) are supported on each end by earthbag buttresses. A small roof protected the wall top (Figure 14 right) from rain.

Figure 14: Left: Straw log bench wall attached to earthbag buttresses at each end. Right: Banco with lime plaster covering earthbag, gravel bag bench and straw logs.

About 4 years after construction the small roof was removed and cement stucco added over all the lime plaster. Although a decade old without the important roof overhang, the walls are standing firm but need only a small hole patched in the finish plaster.

Build Simple SHED

Two small panels of straw log were used as infill on a galvanized metal shed project in Placitas, NM (28 cm/ 11" annual rainfall).

Existing stud framing was supported by reinforced concrete post footings. Between footings a U of metal mesh was tied into a base course of gravel fill in wattle mesh tube and stapled to a wood wall bottom plate. When filled with gravel and covered with cement stucco (Figure 15 left) the gabion base performed well to keep rodents out. A panel of straw log infill (Figure 15 center) was added above and finished with hydraulic lime over earthen plaster (Figures 15 right, 17).

Figure 15 left: Gabion-type base wall between RC footings. Center: Panel of straw logs attached to studs with lower portion plastered. Right: Earth plaster leveling layers on interior of straw log infill panel.

This author also used light straw-clay as infill in an interior stud wall (Figure 2 center) above tamped earth infill for thermal mass containing radiant heat plumbing. Straw log infill takes more time than plain straw-clay infill in forms. Only use straw log mesh on walls with little or no wood.

Roofing of Straw Logs or Other Filled Tubes

Roofs can be created out of mesh tubes with light fill but the process is not easy.

BSI STRAW LOG VAULT

A 1,5 m (5') span Nubian-style vault of straw log finished with earthen plaster was built without wood during July 2013 but disassembled after testing in November. Nubian vaults are usually built of earthen blocks without formwork (Elizabeth and Adams, 2005) by leaning beginning courses against an existing vertical wall (Figure 16 left). The straw log vault required formwork to build and to prevent collapse when soaked (Figure 16 right).

Figure 16: Left: Vault straw logs laid at slight angle against vertical wall. Right: Support for vault.

It might be possible to build segments of roof vaults in forms and pre-soak and dry them before assembling. Concerns about poor maintenance would need to be addressed, because light straw-clay filling would lose all strength and collapse if normal straw-dlay was soaked by leaks.

TRASH MESH VAULT ON BSI SHED

The shed wall in Placitas NM included an arching entry roof of plastic trash-filled wattle tube (using a lot of plastic foam) finished with cement stucco. Trash fill is not fireproof, but will not lose strength when wetted. The vault was attached to the straw log wall panel by tying. The base wall was several courses of earth-filled mesh tube base walls pinned with diagonal rebars (Figure 17 left) to resist arch forces pushing outward.

Plastic foam scrap-filled tubes alternated with tubes of other fill (Figure 17 center). Small plastic bottles were helpful between other container scraps and bags, but overlapping long foam segments was needed to stiffen the tubes. Forms were used until the arch's exterior stucco coat and interior earthen plasters had dried (Figure 17 right). Plastering the vault ceiling was difficult.

Figure 17 left: Panel of plastered straw wattle with arch form, behind thin earthbag base walls. Right: Stiff sewn tubes of wattle mesh filled with plastic trash. Right: Finished arch of trash tubes on earthen base wall.

After completion two people totaling more than 150 kg (330 lbs) sitting on the arch did not cause noticeable damage.

Appendix 3: Straw Log Wall Supplies and Costs

Whether straw log shelters are the right choice for short-term shelter depends on local climate and resources, and on labor needed and material costs. A small shelter plan online (Figure 18) gives dimensions in metric or standard units and detailing for a tiny gable-roofed shelter.

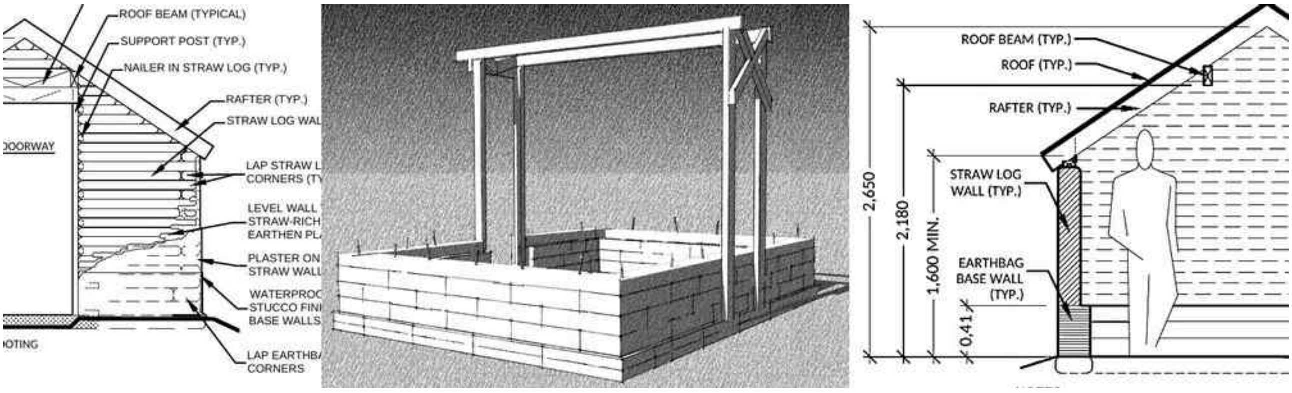

Figure 18 left: Front elevation. Center: Earthbag base walls can hold a structural post and beam frame. Right: Section through shelter showing base wall bench, eave wall and roof beams.

Tools Needed

Make a chute to fit inside expanded wattle mesh by cutting the bottom out of a small bucket or planting pot. Other tools you must have:

- Scissors or knives, crochet hooks or yarn needles, shovels, pitchforks, hoe, plaster trowels
- 5 gallon buckets
- Long spout watering can to apply the liquid clay
- Protective glasses and rubber gloves if using lime plaster

Helpful tools:

Gloves, hose, tape measures, leaf rake, tarps, level

Screw gun, stapler, drill, grinder, mallet, mortar stirrer, wheelbarrow

Chisel and hammer or wire cutters to cut barbed wire

Supplies Needed

Often if subsoil is local and labor rates are low, gravel bag walls cost one third to half as much as comparable concrete block walls (Hart, 2018).

Base walls of earthbag can be estimated by pricing 38 x 69 cm (15 x 27”) polyethylene bags sold as sandbags, used at a rate of 1 per 56 cm (22”) length of each base wall course. Gravel bag footings are best with slightly larger bags to leave a ledge for any wood framework needed. 46 x 76 cm (18 x 30”) bags doubled for gravel are used at a rate of 1 per 30 cm (12”) length of footing gravel course. Barbed wire, gravel fill, rebar pins and cement or lime plaster are also needed.

The small 5,67 m^2 (61 sf) shelter plan online at https://buildsimple.org/disaster-response/ (Figure 12) is 2,8 x 3,5 m (9’ x 11’) exterior dimensions. The inside floor area is just 2,06 x 2,76 m (6’- 9” x 9’) fitting two standard UN-issued sleeping pads with room to walk or use a heater between them. This shelter plan has 17,3 m^2 (186 sf) of wall face area built in straw log on top of 5,3 m^2 (57 sf) of base wall and footing (to just below grade). Material amounts (Table 1) are for straw log portions.

Table 1: Straw Log Supplies per Wall Area

	Unit	Cost per unit (not including shipping)	Units per m^2 face of straw log wall	Cost per m^2 face of straw log wall	Units per face sf of straw log wall	Cost per face sf of straw log wall
Mesh wattle netting	m	$0.30	11.2 m/ m^2	$3.36	3.5 lf	0.31
Straw for tubes	bale	$18	0.58	$10.45	0.054	$0.97
Straw for plasters	bale	$18	0.21	$3.87	0.02	$0.36
Subsoil for nook plaster	L	Processing time	31 L		0.10 ft^3	
Screened soil for slip and finish plaster	L	Processing time	15 L		0.05 ft^3	
(Added clay)	L	$2.10	0.42 L	($9.49)	0.015 ft^3	($0.88)
Sand	L	$0.16	27.3 L	$4.37	0.09 ft^3	$0.40
Hydraulic lime only for ext. base wall	22 kg bag	$25	0.19 bag	$4.84	0.018 bag	$0.45
Cord	m	$0.028	37 m	$1.04	11.5 lf	$0.10
Misc.	Some nails, staples, and wire…					
Estimated totals				$29- $38		$2.70- $3.53
Estimated with 15% contingency				$33.40- $43.70		$3.11- $4.05

Wattle net tube was first purchased from MasterNet Ltd of Canada as their nominal 6- 8” diameter MN3-7WA8. The tube netting should be a maximum of 27- 28 cm (10.5- 11”) wide when stretched (hard) out flat. Check for stretched dimensions with a sample before buying. Organizations able to pick up wattle netting from a warehouse or buy a pallet of a dozen rolls will keep costs lowest.

Labor for Building Straw Log Walls

Earthbags and straw log walls can be built by an individual alone, or by groups (Table 2). Workers can learn either technique quickly, but have a site supervisor with some experience. Building a trial small project may be enough for someone who has built conventional masonry before.

Table 2: Face area of wall built by one person (minimums for new workers)

	m^2 per day	Sf per day	
Build gravel bag and earthbag base wall	>1/3	>4	If trench is dug and supplies delivered to site.
Build straw log upper wall	2/3- 1,1	8- 12	If supplies are delivered to site.
Infill plaster straw log	2,2	24	If subsoil with little grit is available, includes time to trample straw into earth.
Finish earth plaster coat	2,8	30	Includes time to screen subsoil and mix in straw.
Finish lime plaster coat	9,3	100	If lime putty has been prepared ahead. Assume a worker familiar with applying cement stucco. Includes time to mix sand, putty and water with hoe.

This Small Straw Log Shelter was planned for the snow loads Turkish building code specifies for the region affected by the February 2023 earthquakes. Always check code requirements for your exact building location. Have local designers specify roof rafter and post and beam sizes. Engineering advice is recommended.

Appendix 4: Plan Safe Straw Log Shelters

Although many shelters will be roofed with tarps in the short term, plastered LSC walls look permanent. Plan so that future improvements will allow these modest shelter walls to support wood rafters, metal or asphalt shingles and the weight of someone repairing the roof.

How Much Weight Can Straw Log Walls Support?

Designers choose deflection allowable for their building. Wood joists for attics must deform 1/180 or less, to prevent damage to sheetrock ceilings and walls. Plastered walls are easier to repair than sheet-rock. Researchers testing light straw clay (LSC) chose 5% deflection as a reasonable maximum load because although straw-clay can compress, it is unlikely to crack under loading (Thornton, 2005). In a short-term shelter if an unusual snowstorm compresses the walls 5% shorter and some of the plaster cracks, it can be repaired.

Laboratory testing of 15 cm (6") cubes of LSC showed 520 kg/m^3 (32.5 pcf) density samples (similar to straw log cores at 416 kg/m^3 (26 pcf)) averaged 0,068 mPa (9.8 psi) at 5% compression. This is equivalent to 8,58 kN/m (588 plf).[4] Larger sample experiments did not reach 5% compression. To estimate pressures causing different amounts of strain in full-size straw log walls, the stress strain curves of the small samples are used to make rough estimates of possible bearing strengths of unreinforced, rebar pinned and embedded rebar reinforced straw log (Table 3).

Table 3: Estimated Straw Log Compressive Bearing Strength with 480 kg/m^3 (30 pcf) fill[5]

	Light Straw Clay small sample results	Unreinf	Pinned rebar on 1,2 m (48") centers	Embedded rebar on 30 cm (12") centers
Yield		1, 17 kN/m (80 plf)	1,20 kN/m (82 plf)	1,59 kN/m (109 plf)
0.4% def		unknown	unknown	2,77 kN/m (190 plf)
2.4% def	1.35 x yield	unknown	2,38 kN/m (163 plf)	unknown
5% def	1.62- 1.83 x yield	unknown	unknown	unknown
Force causing 5% deformation estimated as 1.6 x yield		*Estimated: >1,87 kN/m (>128 plf)*	*Estimated: >1,91 kN/m (>131 plf)*	*Estimated:1 >2,54 kN/m (>174 plf)*
Assumed bearing strength		*1,82 kN/m (125 plf)*	*2,33 kN/m (160 plf)*	*2,77 kN/m (190 plf)*

4 Assuming a 5" wide straw-clay core in each straw log course in contact with the course beneath, although the continuous mesh-embedded plaster also contributes to compressive strength.

5 Detailed test information is included in Straw Log Structural Testing online at BuildSimple.org/Resources.

The pinned and embedded rebar experiments performed better than estimates extrapolated from the LSC performance, so their assumed strengths are conservative, using their highest recorded stress levels well below 5% compression or ultimate strength. The bearing strength assumed for unreinforced straw log walls is well below observed strength of other lightly pole-reinforced walls.

Compressive strengths of straw-clay are influenced by its density and of earthen plaster by its subsoil cohesive strength. This author's tests used strong adobe building soil which tests at 2,06 mPa (300 psi) for unconfined compressive strength of dried blocks.

Builders concerned about seismic risk or bearing strength should use strongly cohesive subsoil and test that samples are reaching similar 480 kg/m^3 (30 pcf) densities or higher (see Appendix 5).

How Much Weight do Straw Log Walls Need to Support?

Light roofs are estimated at 0,48 kN/m^2 (10 psf) for roof rafters and metal or shingle roofing (plus the weight of a person on top for repairs). Builders should plan to also support the estimated maximum local snow load. For the recently quake-affected area in Turkey, snow load is calculated at 0,75 kN/m^2 (Dlubal Software, 2023). With the 0,48 kN/m^2 for the roof itself, the roof load could be 1,23 kN/m^2 on a bad day (21 psf snow, 10 psf roof, 26 psf total weight).

Which walls support roof weights? A simple shed roof with one slope (Figure 19 left) places half of the roof weight on each side of the building, on the walls that support the rafters.

A roof with a peak in the middle sloping in two directions is called a gable roof. Half of the roof weight rests on whatever supports the highest part, one ridge beam or two roof support beams (Figure 19 right). The lower eave walls that support rafters each carry one quarter of the roof weight.

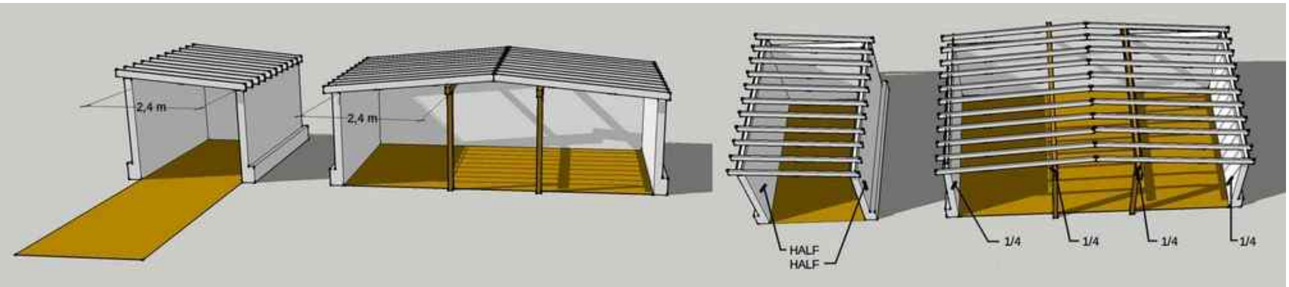

Figure 19 left: Shed roof. Next: Gable roof with similar span to support posts. Right: Each shed side wall supports half of the roof weight. The gable shelter eave walls and roof beams each support a quarter of the roof weight.

Turkish building code maps detail two different levels of snow load near the 2023 quake-affected region of Turkey (Dlubal Software, 2023). Always check local building codes and/ or ask an engineer for advice to be sure to make the safest plans. With heavier roof loads, shed walls need to be closer together, and gable walls may need to have posts and beams closer (Table 4).

Table 4: Estimated Maximum Span to Beam for Roofing Supported on Straw Log Walls[6]

Snow conditions	Roof must support (snow load plus structure)	Assumed compressive strength of straw log bearing wall	Distance from eave wall to nearest beam or support wall	
			metric	standard
No snow	0,48 kN/m^2 (10 psf)	1,17 kN/ m (80 plf)[7]	4,88 m**	16'- 0"**
0,48 kN/m^2 (10 psf)	0,96 kN/m^2 (20 psf)	1,17 (80)	2,44 m	8'- 0"
Turkish level III	1,23 kN/m^2 (25.6 sf)	1,17(80)	1,93 m	6'- 4"
Turkish level II	1,64 kN/m^2 (34.2 psf)	1,17(80)	1,42 m	4'- 8"
No snow	0,48 kN/m^2 (10 psf)	1,82 kN/m (125 plf)[8]	7,62 m**	25'- 0"**
0,48 kN/m^2 (10 psf)	0,96 kN/m^2 (20 psf)	1,82 (125)	3,81 m**	12'- 6"**
Turkish level III	1,23 kN/m^2 (25.6 sf)	1,82 (125)	3,00 m	9'-10"
Turkish level II	1,64 kN/m^2 (34.2 psf)	1,82 (125)	2,23 m	7'- 4"
No snow	0,48 kN/m^2 (10 psf)	2,33 kN/m (160 plf)[9]	9,75 m**	32'- 0"**
0,48 kN/m^2 (10 psf)	0,96 kN/m^2 (20 psf)	2,33 (160)	4,88 m**	16'- 0"**
Turkish level III	1,23 kN/m^2 (25.6 sf)	2,33 (160)	3,81 m**	12'- 6"**
Turkish level II	1,64 kN/m^2 (34.2 psf)	2,33 (160)	2,88 m	9'- 5"

** Straw log walls >3 m (9'- 10") need external or embedded reinforcement to stiffen against buckling.

The highly conservative use of actual straw log strength before damage works well in areas without snow. Each linear meter or foot of eaves wall can support a light roof if another eaves wall or a roof beam supported by wood is located 4,88 m (16') distant or less (Table 4). If snow is likely, only small buildings can use these same bearing strengths. In an area with 0,48 kN/m^2 (10 psf) snow loads a long narrow shed roofed structure could be built if the walls bearing rafters were only 2,44 m apart (8'). For Turkish level III snow shed roofing would be impractical but a gable roofed shelter could be about 7 m (23') long if posts supported two roof beams located 1,9 m (6'-4") from each eave wall.

6 Assumed bearing strengths of straw log walls from Table 3 with minimal roof overhangs of 10 cm (4").
7 1,17 kN/m (80 plf) has been proven before yield in a straw log experimental wall.
8 1,82 kN/m (125 plf) is estimated for moderate compression of unreinforced wall.
9 2,33 kN/m (160 plf) is estimated for moderate compression of wall with pinned external rebars on 1,2 m (4') centers .

Straw log walls need an overhang to help earthen wall material survive repeated wetting by drying completely between soakings (Standards New Zealand, 1998). In humid climates provide larger overhangs over mostly shaded walls. But the larger the roof, the more weight it can be subjected to if it receives snow. Sketch your building cross-section and add up the actual weight that will bear on the walls including snow on all the overhangs.

Building Layouts for Small Shelters

For a very small shelter, the door must be centered (to fit a bed on both sides). Small shelters can have the base wall ledge on the inside to provide a storage shelf or support seating. Any wood posts need to rest on the foundation. Wood posts located on the other side of the wall from the ledge are easier to attach to both the base wall and straw log walls because the surfaces are flush. Posts can be embedded into earthen base walls, but construction will be slower. In damp and/ or heavy termite infestation areas locate posts inside the building to stay dry and visible.

Because straw-clay walls aren't very stiff, eave walls with shorter heights work well without wood. A pair of wood posts near the gable (roof peak) can stiffen a taller wall area under the roof ridge, carry some of the roof weight and also be the door frame (Figure 5, right and Figure 20, left).

Shed roof buildings do not need roof support beams (Figure 20 center), but a few rafters can be attached to the top plates and posts to help stiffen the walls while soaking. A larger shed roofed building may need diagonal bracing to hold posts vertical and stiffen long walls (Figure 20 right).

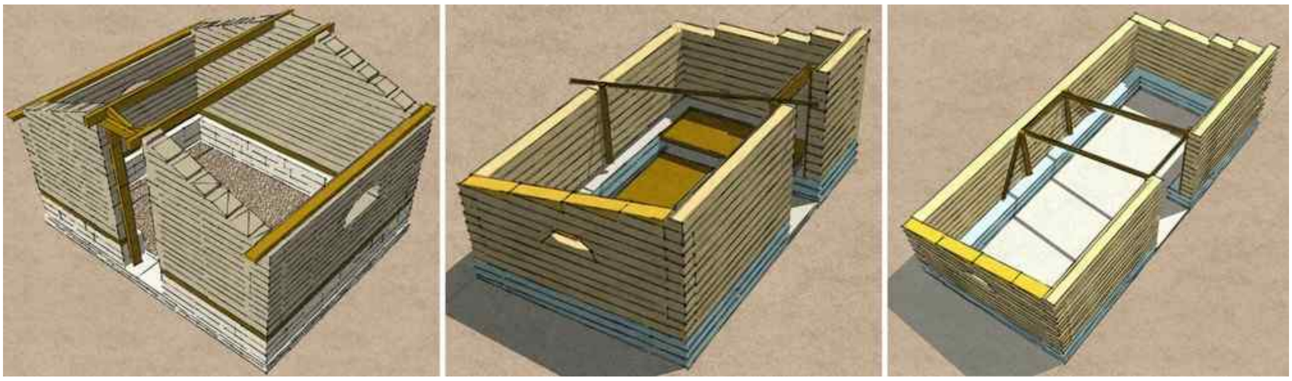

Figure 20 Shelters incorporating support posts- Left: Gable roof with two pairs of external posts and two roof beams. Center: Shed roof on shelter with offset door and one pair of interior posts attached to a rafter as bracing. Right: Longer shed roof shelter using two pairs of interior posts with diagonal bracing.

Reinforcing Straw Log Panels

Embedded or pinned rebars in straw log walls will stiffen walls against racking and/or buckling. Straw-clay will survive earthquakes more easily than heavier earthen walls. But for higher seismic risk and bigger shelters, reinforcement may be needed. Use strong soils for clay slip and for base courses (see Appendix 5). Carefully make connections, tie courses together and soak straw well.

Check the hazard that GEM estimates (Pagani, 2018), using their online *interactive map resource*. If your site is in a yellow-orange or orange area (risk >0.35g), then special care will result in greater safety.

Appendix 5: Soil for Straw-Clay

Use subsoil. If debris floats on water when you stir some soil in, you have topsoil. Dig deeper. Build with soil below the first layer, that doesn't contain humus or organic material.

Most types of earthen construction work best with soils that feel gritty. Base walls of earthbag can be built with any soil that holds together when damp, but it is easiest with gritty soils.

Straw log works really well with pottery-type clay, the smooth sticky clay that doesn't have much sand and that no one wants under roads or near basements.

Check Available Soil

All soil is a mix of different proportions of 3 kinds of particles: ultrafine clay, silt and coarse sand.

Dampen a little soil so it forms a ball. Pinch it between your fingers. If it sticks to the underside of a finger, it contains some clay (Figure 21 right). Good! You can use it to build earthbag or to make slip, the liquid clay that soaks straw log walls. You can use a very sticky clay in the base wall earthbags but it will stick to shovels when filling bags. It will be easier to use in earthbags if you can add some sand or gravel or even silt to it.

Wet it a little more- and feel it between your fingers. If it feels like flour it probably has a lot of silt. When it dries does it brush it off and leave your hand clean? If it didn't stick well to the upper finger (Figure 21 left) it has more silt than clay and is low strength. When damp soil can be squeezed into a ball but slumps flat when you shake it, the soil is mostly silt (Figure 21 center). This won't make good plaster or walls.

Figure 21 Soil texture- Left: silty soil doesn't stick much to the upper finger. Center: Ball of silt shaken will slump flat. Right: Soil with a good amount of clay will stick to the upper finger.

If soil feels a little gritty like salt, it contains sand. A ball that forms when squeezed but falls apart when moved has too much sand for earthbag base walls or for straw clay. A lot of sand is good for the finish layer of earth plaster, and works ok for all the other plaster layers.

If soil feels smooth and is very sticky, it has a lot of clay. If you can squeeze out a 2- 3 mm (1/8”) thick ribbon that hangs >25 mm (1”) before it breaks off, good. Dissolve this soil in water to make slip. The liquid clay should be a little thicker than milk.

Concentrate the Clay

Too much sand or silt can be removed from a weak soil by mixing water in, stirring, and letting it sit for 15 minutes. The liquid clay will still be dissolved in the top layers of water, and sand with some silt will be settled to the bottom. All silt won’t settle until 6- 8 hours. Pour off the liquid upper half of the bucket into a clay collection bucket. Stop pouring when the liquid starts to look sludgy or grainy. Cover the clay buckets if it rains so the clay doesn’t become too diluted.

Keep your clay wet since it takes time to rehydrate and is dangerous to inhale if powdery.

Subsoil for plaster should be about a third to half sand. If it is hard to buy sand, save any sand you remove from your clay soil. Sand settles in the first half minute to minute after you stop stirring. So give the remaining bucket another stir, wait a half minute, and then pour the muddy top layer offand save the sand that is left in a bin or on a tarp. It’s ok if it dries or gets rained on more.

For Earthquake Risk Areas

Check your seismic hazard. If your location is shown as <0.35 g on the GEMS Openquake hazard map (Pagani, 2018) viewer online (in yellow, green, blue or white), the soil strength used for clay slip and earthbag base walls may not be too critical. If the seismic hazard is >0.35 (orange-yellow, orange or red) use extra care when building.

The base of walls only receive a small part of the forces that stress wall tops during an earthquake. Heavy walls of solid earth receive more force as the heavy walls shake back and forth. Light straw log walls are both very resilient (if the mesh is interconnected) and relatively light. But if your site has hazard listed as >0.35 g and you are using earthen base walls and any wood or metal posts attached to the straw logs and/ or vertical rebars to stiffen upper walls, use good strength earth in your base walls. A good minimum for strength is the 1,3 mPa (188 psi) standard grade as chosen by New Zealand’s earthen building standards. Aim for 1,7 mPa (250 psi) or higher if possible in higher seismic risk regions.

One indicator of a weak soil for use in earthbags is a sample that doesn’t firm up well. Make a half size sample that is 30 cm (12”) wide by at least 46 cm (18”) long. Use soil not too damp (not making water drip out through the bag fabric when you tamp it). Protect from sun and rain. After a full 24 hours, gently try to turn the bag over. It should feel solid in your hands. If the edges feel like they are crumbling or the fill cracks (cut open the bag to check this) it is a low strength soil.

3 cm Ball Crush Test

Field tests can estimate compressive strength in a day or two.

Remove gravel bigger than 4 mm (1/8”) from your soil sample. Make a dozen balls exactly 3 cm diameter (compare them to a plastic bottle cap that is the right size). Dry completely in an oven set at 93° C (200° F) overnight. The balls can be a little flat, but must be the right diameter when seen from above. Discard balls that are too big or too small.

Use a tester who is patient and just under one of the listed weights, wearing shoes with rubber soles. Add some weights in their pockets to reach the right weight for better accuracy. Have them stand on their toes, and place a ball under each foot. As they put their heels down and let go of anything else, watch if the ball crushes. They shouldn't twist their feet at all.

- If the ball crushes, have them stand evenly on two balls, one foot on each.
- If the ball does not crush, put a flat piece of metal on the ball and stand on it.

Test all the balls and write down every result for at least seven or preferably ten balls.

Soil compressive strength estimated by 3 cm diameter dry ball[10]

Tester weight	45 kg (100 lb)	59 kg (130 lb)	82 kg (180 lb)
Two balls crush under partial weight	1 mPa (150 psi)	1,8 mPa (260 psi)	2,1 mPa (300 psi)
One ball doesn't crush with full weight on it	>1,8 mPa >(260 psi)	>2,0 mPa >(290 psi)	>2,2 mPa >(320 psi)
One ball crushes under metal only when full weight is on it	2,1 mPa (300 psi)	>2,2 mPa >(320 psi)	

Find the average strength of the whole group. If one ball tested much weaker, assume it was a flawed sample and find the average of all the rest.

More information about estimating soil compressive strength is online at https://buildsimple.org/resources/ or download B30 to see pictures of the samples and testing process.

10 This table is a loose approximation. Small dry soil samples have great variation and more testing is needed. Email simple_earth@yahoo if you would like the full testing information or to ask how you can help with this research.