CHAPTER 1

The Merits of Earthbag Building

With a couple rolls of barbed wire, a bale of bags, and a shovel one can build a magnificent shelter with nothing more than the earth beneath their feet. This is the premise that inspired the imagination of international visionary architect Nader Khalili when he conceived the idea of Sandbag Architecture. In his quest to seek solutions to social dilemmas like affordable housing and environmental degradation, Nader drew on his skills as a contemporary architect while exercising the ingenuity of his native cultural heritage. Monolithic earthen architecture is common in his native home of Iran and throughout the Middle East, Africa, Asia, Europe, and the Mediterranean. Thousands of years ago, people discovered and utilized the principles of arch and dome construction. By applying this ancient structural technology, combined with a few modern day materials, Nader has cultivated a dynamic contemporary form of earthen architecture that we simply call Earthbag Building.

1.1:
Using earthbags, a whole house, from foundation to walls to the roof, can be built using one construction medium.

1.2: *Marlene Wulf's earthbag dome under construction, deep in the woods of Georgia.*

Simplicity

Earthbag Building utilizes the ancient technique of *rammed earth* in conjunction with woven bags and tubes as a *flexible form*. The basic procedure is simple. The *bags* or *tubes* are filled on the wall using a suitable pre-moistened earth laid in a mason style *running bond*. After a row has been laid, it is thoroughly compacted with hand tampers. Two strands of 4-point barbed wire are laid in between every row, which act as a "velcro mortar" cinching the bags in place. This provides exceptional tensile strength while allowing the rows to be stepped in to create *corbelled domes* and other unusual shapes (Fig. 1.1).

Walls can be linear, free form, or a perfect circle guided by the use of an architectural compass. Arched windows and doorways are built around temporary *arch forms* until the *keystone bags* are tamped in place. The finished walls then cure to durable cement-like hardness.

Simple, low cost foundations consist of a *rubble trench system,* or beginning the bag-work below ground with a *cement-stabilized* rammed earth mix for the stem walls. Many other types of foundation systems can be adapted to the climatic location and function of the structure.

Cut Barbed Wire Not Trees

We have the ability to build curvaceous, sensual architecture inspired by nature's artistic freedom while providing profound structural integrity. Earthbag construction enables the design of monolithic architecture using natural earth as the primary structural element. By monolithic architecture we mean that an entire structure can be built from foundation and walls to roof using the same materials and methods throughout. Corbelled earthbag domes foster the ultimate experience in sculptural monolithic design, simplicity, beauty, and dirt-cheap thrills. Earthbag domes designed with arch openings can eliminate 95 percent of the lumber currently used to build the average stick frame house (Fig. 1.2).

Conventional wood roof systems still eat up a lot of trees. This may make sense to those of us who dwell in forested terrain, but for many people living in arid or temperate climates, designing corbelled earthbag domes offers a unique opportunity for providing substantial shelter using the earth's most abundant natural resource, the earth itself. Why cut and haul lumber from the Northwest to suburban Southern California, Tucson, or Florida when the most abundant, versatile, energy efficient, cost effective, termite, rot and fire proof construction material is available right beneath our feet? Even alternative wall systems designed to limit their use of wood can still swallow up as much as 50 percent of that lumber in the roof alone. Earth is currently and has been the most used building material for thousands of years worldwide, and we have yet to run out.

Advantages of Earthbag Over Other Earth Building Methods

Don't get us wrong. We *love* earthen construction in all its forms. Nothing compares with the beauty of an adobe structure or the solidity of a rammed earth wall. The sheer joy of mixing and plopping cob into a sculptural masterpiece is unequalled. But for the first-and-only-time owner/builder, there are some distinct advantages to earthbag construction. Let's look at the advantages the earthbag system gives the "do-it-yourselfer" compared to these other types of earth building.

Adobe is one of the oldest known forms of earthen building. It is probably one of the best examples of the durability and longevity of earthen construction (Fig 1.3).

Adobe buildings are still in use on every continent of this planet. It is particularly evident in the arid and semi-arid areas of the world, but is also found in some of the wettest places as well. In Costa Rica, C.A., where rain falls as much as 200 inches (500 cm) per year, adobe buildings with large overhangs exist comfortably.

Adobe is made using a clay-rich mixture with enough sand within the mix to provide compressive strength and reduce cracking. The mix is liquid enough to be poured into forms where it is left briefly until firm enough to be removed from the forms to dry in the sun. The weather must be dry for a long enough time to accomplish this. The adobes also must be turned frequently to aid their drying (Fig. 1.4).


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1.4: *Cleaning adobes at Rio Abajo Adobe Yard, Belen, New Mexico.*


SOUTH WEST SOLAR ADOBE (SWSA)

1.3: *A freshly laid adobe wall near Sonoita, Arizona.*

They cannot be used for wall building until they have completely cured. While this is probably the least expensive form of earthen building, it takes much more time and effort until the adobes can be effectively used. Adobe is the choice for dirt-cheap construction. Anyone can do it and the adobes themselves don't necessarily need to be made in a form. They can be hand-patted into the desired shape and left to dry until ready to be mortared into place.

Earthbags, on the other hand, do not require as much time and attention as adobe. Since the bags act as a form, the mix is put directly into them right in place on the wall. Not as much moisture is necessary for earthbags as adobe. This is a distinct advantage where water is precious and scant. Earthbags cure in place on the wall, eliminating the down time spent waiting for the individual units to dry. Less time is spent handling the individual units, which allows more time for building. Even in the rain, work on an earthbag wall can continue without adversely affecting the outcome. Depending on the size, adobe can weigh as much as 40-50 pounds (17.8-22.2 kg) apiece. Between turning, moving, and lifting into place on the wall, each adobe is handled at least three or four times before it is ever in place.

Adobe is usually a specific ratio of clay to sand. It is often amended with straw or animal dung to provide strength, durability, decrease cracking, increase its insu-

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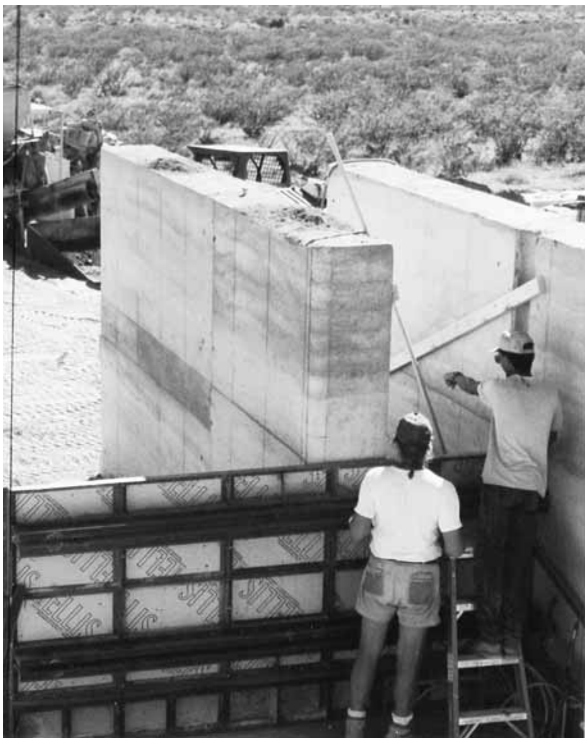
1.5: *The entire form box can be set in place using the Bobcat. Steel whalers keep forms true and plumb and resist ramming pressure.*

1.6: *Rammed earth wall after removal of forms.*



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lative value, and make it lighter. Earthbag doesn't require the specific ratios of clay to sand, and the addition of amendment materials is unnecessary as the bag itself compensates for a low quality earthen fill.

Rammed earth is another form of earth building that has been around for centuries and is used worldwide. Many kilometers of the Great Wall of China were made using rammed earth. Multi-storied office and apartment buildings in several European countries have been built using rammed earth, many of them in existence since the early 1900s. Rammed earth is currently enjoying a comeback in some of the industrialized nations such as Australia.

Rammed earth involves the construction of temporary forms that the earth is compacted into. These forms must be built strong enough to resist the pressure exerted on them from ramming (compacting) the earth into them. Traditionally, these forms are constructed of sections of lashed poles moved along the wall after it is compacted. Contemporary forms are complex and often require heavy equipment or extra labor to install, disassemble, and move (Fig. 1.5). The soil is also of a specific ratio of clay to sand with about ten percent moisture by weight added to the mix. In most modern rammed earth construction, a percentage of cement or asphalt emulsion is added to the earthen mix to help stabilize it, increase cohesion and compressive strength, and decrease the chance of erosion once the rammed earth wall is exposed.

While the optimum soil mix for both rammed earth and earthbag is similar, and both types of construction utilize compaction as the means of obtaining strength and durability, that is about where the similarity ends. Because the bags themselves act as the form for the earth, and because they stay within the walls, earthbag construction eliminates the need for heavy-duty wood and steel forms that are not very user-friendly for the one-time owner/builder. Since the forms are generally constructed of wood and steel, they tend to be rectilinear in nature, not allowing for the sweeping curves and bends that earthbag construction can readily yield, giving many more options to an earth builder (Fig. 1.6). While the soil mix for rammed earth is thought of as an optimum, earthbags permit a wider range of soil types. And just try making a dome using the rammed earth technique, something that earthbags excel at achieving.

Cob is a traditional English term for a style of earth building comprised of clay, sand, and copious amounts of long straw. Everybody loves cob.

It is particularly useful in wetter climates where the drying of adobes is difficult. England and Wales have some of the best examples of cob structures that have been in use for nearly five centuries (Fig. 1.7). Cob is also enjoying a resurgence in popularity in alternative architecture circles. Becky Bee and The Cob Cottage Company, both located in Oregon, have worked extensively with cob in the Northwestern United States. They have produced some very fine written material on the subject and offer many workshops nationwide on this type of construction. Consult the resource guide at the back of this book to find sources for more information on cob.

Simply stated, cob uses a combination of clay, sand, straw, and water to create stiff, bread loaf shaped "cobs" that are plopped in place on the wall and "knitted" into each other to create a consolidated mass. Like earthbag, cob can be formed into curvilinear shapes due to its malleability. Unlike earthbag, cob requires the use of straw, lots of straw. The straw works for cob the same way that steel reinforcing does for concrete. It gives the wall increased tensile strength, especially when the cobs are worked into one another with the use of the "cobber's thumb" or one's own hands and fingers (Fig. 1.8).

While building with earthbags can continue up the height of a wall unimpeded row after row, cob requires a certain amount of time to "set-up" before it can be continued higher. As a cob wall grows in height, the weight of the overlying cobs can begin to deform the lower courses of cob if they are still wet. The amount of cob that can be built up in one session without deforming is known as a "lift." Each lift must be allowed time to dry a little before the next lift is added to avoid this bulging deformation. The amount of time necessary is dependent on the moisture content of each lift and the prevailing weather conditions. Earthbag building doesn't require any of this extra attention due to the nature of the bags themselves. They offer tensile strength sufficient to prevent deformation even if the soil mix in the bag has greater than

C. WANEK

1.7: *Example of historic cob structure; The Trout Inn in the U.K.*

1.8: *Michelle Wiley sculpting a cob shed in her backyard in Moab, Utah.*

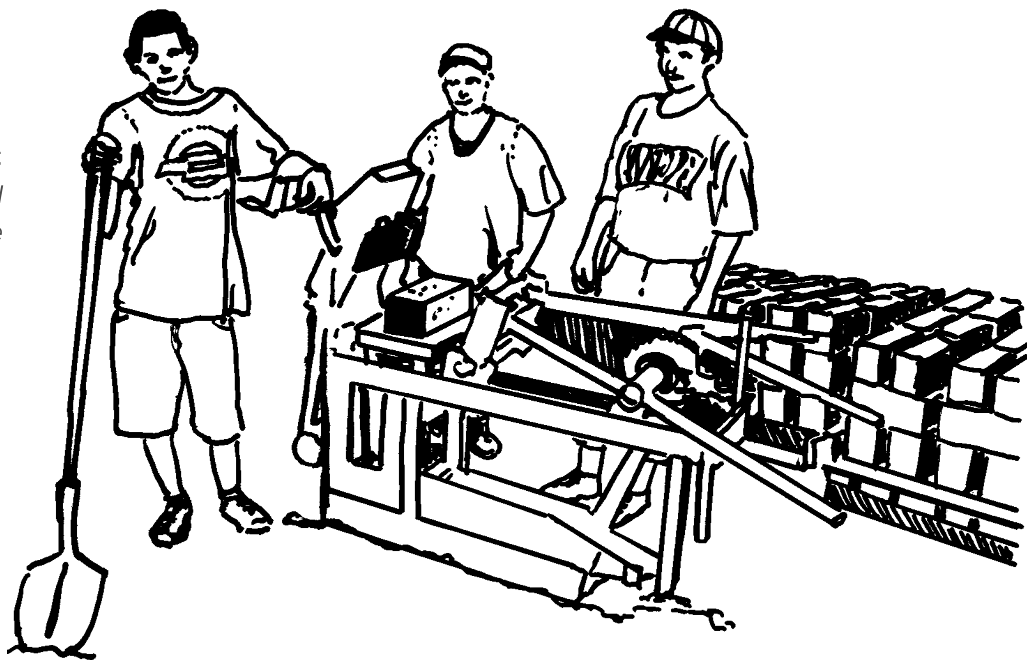
the optimum moisture content. So the main advantages of earthbag over cob are: no straw needed, no waiting for a lift to set up, wider moisture parameters, and a less specific soil mix necessary.

Pressed block is a relatively recent type of earthen construction, especially when compared to the above forms of earth building. It is essentially the marriage of adobe and rammed earth. Using an optimum rammed earth mix of clay and sand, the moistened soil is compressed into a brick shape by a machine that can be either manual or automated. A common one used in many disadvantaged locales and encouraged by Habitat for Humanity is a manual pressed-block machine. Many Third World communities have been lifted out of oppressive poverty and homelessness through the introduction of this innovative device (Fig 1.9). The main advantage of earthbag over pressed block is the same as that over all the above-mentioned earth-building forms, the fact that earthbags do not require a specific soil mixture to work properly. Adobe, rammed earth, cob, and pressed block rely on a prescribed ratio of clay and sand, or clay, sand, and straw whose availability limits their use. The earthbag system can extend earthen architecture beyond these limitations by using a wider range of soils and, when absolutely necessary, even dry sand — as could be the case for temporary disaster relief shelter.

Other Observations Concerning Earthbags

Tensile strength. Another advantage of earthbags is the tensile strength inherent in the woven poly tubing combined with the use of 4-point barbed wire. It's sort of a double-whammy of tensile vigor not evident in most other forms of earth construction. Rammed earth and even concrete need the addition of reinforcing rods to give them the strength necessary to keep from pulling apart when placed under opposing stresses. The combination of textile casing and barbed wire builds tensile strength into every row of an earthbag structure.

Flood Control. Earthbag architecture is not meant to be a substitute for other forms of earth building; it merely expands our options. One historic use of earthbags is in the control of devastating floods. Not only do sandbags hold back unruly floodwaters, they actually increase in strength after submersion in water. We had this lesson driven home to us when a flash flood raged through our hometown. Backyards became awash in silt-laden floodwater that poured unceremoniously through the door of our Honey House dome,



1.9: *A manually-operated pressed-block machine in Honduras.*

leaving about ten inches (25 cm) of water behind. By the next morning, the water had percolated through our porous, unfinished earthen floor leaving a nice layer of thick, red mud as the only evidence of its presence. Other than dissolving some of the earth plaster from the walls at floor level, no damage was done. In fact, the bags that had been submerged eventually dried harder than they had been before. And the mud left behind looked great smeared on the walls!

Built-in Stabilizer. The textile form (bag!) encases the raw earth even when fully saturated. Really, the bag can be considered a "mechanical stabilizer" rather than a chemical stabilizer. In order to stabilize the soil in some forms of earth construction, a percentage of cement, or lime, or asphalt emulsion is added that chemically alters the composition of the earth making it resistant to water absorption. Earthbags, on the other hand, can utilize raw earth for the majority of the walls, even below ground, thanks to this mechanical stabilization. This translates to a wider range of soil options that extends earth construction into non-traditional earth building regions like the Bahamas, South Pacific, and a good portion of North America. While forests are dependent on specific climatic conditions to grow trees, some form of raw earth exists almost everywhere.

The Proof is in the Pudding

Nader Khalili has demonstrated the structural integrity of his non-stabilized (natural raw earth) earthbag domes. Under static load testing conditions simulating seismic, wind, and snow loads, the tests exceeded 1991 Uniform Building Code requirements by 200 percent. These tests were done at Cal-Earth — California Insitute of Earth Art and Architecture — in Hesperia, CA., under the supervision of the ICBO (International Conference of Building Officials), monitored in conjunction with independent engineers of the Inland Engineering Corporation. No surface deflections were observed, and the simulated live load testing, done at a later date, continued beyond the agreed limits until the testing apparatus began to fail. The buildings could apparently withstand more abuse than the equipment designed to test it! The earthbag system has been proven to withstand the ravages of fire, flooding, hurricanes, termites, and two natural earthquakes measuring over six and seven on the Richter scale. The earthbag system in conjunction with the design of *monolithic shapes* is the key to its structural integrity.

Thermal Performance

Every material in a building has an insulation value that can be described as an R-value. Most builders think of R-value as a description of the ability of a structure or material to resist heat loss. This is a steady state value that doesn't change regardless of the outside temperature variations that occur naturally on a daily and annual basis. So why does an earthbag structure (or any massive earthen building for that matter) with an R-value less than 0.25 per inch (2.5 cm) feel cool in the summer and warm in the winter? Because this R-value can also be expressed as the coefficient of heat transfer, or conductivity, or U-value, which is inversely proportional, that is $U=1/R$. From this simple formula we can see that material with a high R-value will yield a low U-value. U-value (units of thermal radiation) measures a material's ability to store and transfer heat, rather than resist its loss. Earthen walls function as an absorbent mass that is able to store warmth and re-radiate it back into the living space as the mass cools. This temperature fluctuation is known as the "thermal flywheel effect."

The effect of the flywheel is a 12-hour delay in energy transfer from exterior to interior. This means that at the hottest time of the day the inside of an earthbag structure is at its coolest, while at the coolest time of the day the interior is at its warmest. Of course this thermal performance is regulated by many factors including the placement and condition of windows and doors, climatic zone, wall color, wall orientation, and particularly wall thickness. This twelve-hour delay is only possible in walls greater than 12 inches (30 cm) thick.

According to many scholars, building professionals, and environmental groups, earthen buildings

1.10: *Students working on Community Hogan on the Navajo Indian Reservation.*

currently house over one-third of the world's population, in climates as diverse as Asia, Europe, Africa, and the US with a strong resurgence in Australia. An earthen structure offers a level of comfort expressed by a long history of worldwide experience. Properly designed earthbag architecture encourages buried architecture, as it is sturdy, rot resistant, and resource convenient. Bermed and buried structures provide assisted protection from the elements. Berming this structure in a dry Arizona desert will keep it cool in the summer, while nestling it into a south-facing hillside with additional insulation will help keep it warm in a Vermont winter. The earth itself is nature's most reliable temperature regulator.

Cost Effectiveness

Materials for earthbag construction are in most cases inexpensive, abundant, and accessible. Grain bags and barbed wire are available throughout most of the world or can be imported for a fraction of the cost of cement, steel, and lumber. Dirt can be harvested on site or often hauled in for the cost of trucking. Developed countries have the advantage of mechanized gravel yards that produce vast quantities of "reject fines" from the by-product of road building materials. Gravel yards, bag manufactures, and agricultural supply co-ops become an earthbag builder's equivalent of the local hardware store. When we switched to earthen dome construction, we kissed our lumberyard bills goodbye.

Empowering Community

Earthbag construction utilizing the Flexible-Form Rammed Earth (FFRE) technique employs people instead of products (Fig. 1.10). The FFRE technique practices third world ingenuity, with an abundance of naturally occurring earth, coupled with a few high tech materials to result in a relatively low impact and

1.11: *Typical 1,000-year-old Anasazi structure, Hovenweep National Monument.*

embodied energy product. What one saves on materials supports people rather than corporations. The simplicity of the technique lends itself to owner/builder and sweat-equity housing endeavors and disaster relief efforts. Properly designed corbelled earthbag domes excel in structural resilience in the face of the most challenging of natural disasters. Does it really make sense to replace a tornado-ravaged tract house in Kansas with another tract house? An earthbag dome provides more security than most homeowner insurance policies could offer by building a house that is resistant to fire, rot, termites, earthquakes, hurricanes, and flood conditions.

Sustainability

Earthen architecture endures. That which endures sustains. Examples of early Pueblo earthen construction practices dating from 1250-1300 AD is evident throughout the Southwestern United States (Fig 1.11). The coursed adobe walls of Casa Grande in Southern Arizona, Castillo Ruins, Pot Creek Pueblo and Forked Lightning Pueblo in New Mexico, and the Nawthis site in central Utah, although eroded with centuries of neglect, still endure the ravages of time. In the rainy climate of Wales, the thick earthen cob-walled cottages protected under their thatched reed roofs boast some 300 to 500 hundred years of continual use. If we can build one ecologically friendly house in our lifetime that is habitable for 500 years, we will have contributed towards a sustainable society.