Foreword

Written by Dr. Owen Geiger

A lot of things have changed in the earthbag building movement since Kelly Hart and I started to disseminate free earthbag information on the Internet at EarthbagBuilding.com in 2007 and a few years later at NaturalBuildingBlog.com (formerly EarthbagBuildingBlog.com). Back then, there were not very many earthbag buildings or resources available. Today, there are thousands of earthbag buildings, countless online videos, as well as many websites and blogs, and numerous books.

The most prolific changes in this movement have come from abroad, in poor countries, where the need for safe, affordable housing, schools, clinics, eco toilets, and water tanks is staggeringly high. Developing countries urgently need these things. Other building materials and methods are often not affordable or practical.

Earthbag building is now very popular in Mexico, South America, Africa, Asia, and other places. Some of the most exciting development work is being done in Nepal since the 2015 earthquakes rocked that country. What caught the world's attention was the vast number (hundreds of thousands) of concrete and brick buildings that were destroyed, while all 55 earthbag buildings in Nepal that had been built before the quakes survived without major structural damage.

Earthbag building is quickly catching on in Nepal as the safest, strongest, lowest cost, most effective way of building. For instance, a 6-classroom school can be built in about two months by local villagers for the cost of a car. These buildings are so strong that you could drive a speeding vehicle into the walls, detonate grenades, or shoot them with a machine gun with only minor damage.

In my article *Low Cost Village Housing for Nepal* on our blog, I explain how the greatest need for housing in Nepal is in poor rural villages. Most of these places are in remote mountainous areas far from roads. Not only can these villagers not afford cement and steel for conventional building, it's not practical to carry these heavy materials 1–2 days over steep mountain passes. Earthbag building is an excellent choice in this situation.

The following projects illustrate the wide range of uses for earthbags, and some of the many benefits.

Since 2015 Good Earth Global (goodearthglobal.org) has built four schools, one learning center, over 20 houses, one meeting center, and four model eco toilets in Nepal and India. They have taught earthbag building techniques to almost 1,000 rural village builders, students, engineers, architects, and community leaders in Nepal and India. They won the "Best Rural Design" award at a competition organized by the Nepal Engineering Association.

This NGO, partnered with Anna University, a leading Indian technical university, co-organized an international earthbag conference in India, and supervised the construction of a model Earthbag Meeting Center on the university's Madurai campus.

Good Earth Global has designed prototype earthbag toilets that are inexpensive, ecologically sustainable, and easily built using local labor and materials. Toilets can be built by four workers in two days at $282 each for materials and labor. With sufficient support, Good Earth Global hopes to build thousands of earthbag toilets throughout India, potentially saving hundreds of lives daily.

In April 2017, Nepal's Ministry of Urban Development approved and published Good Earth Global's earthbag designs in the "Design Catalogue for Reconstruction of Earthquake Resistant Houses," giving millions of earthquake victims the opportunity to use government aid money to build safe and affordable earthbag homes. With this pioneering decision, Nepal became the first country in the world to officially endorse earthbag technology, and now emerging as a worldwide leader in sustainable building and development.

First Steps Himalaya (firststepshimalaya.org) had just completed its first earthbag building days before the magnitude 7.9 earthquake struck Nepal in 2015. Despite being in one of the worst-affected areas where almost all buildings were flattened, the earthbag teacher training center survived with just a few cracks. First Steps Himalaya then organized an Earthbag Building Summit in Kathmandu in September 2015. Since then, they have provided hands-on training on earthbag building to numerous Nepali and international organizations and individuals. The charity has completed nine earthbag classrooms and an eight-bedroom accommodation building for trainees, with many more projects planned.

Over the last nine years, Edge of Seven (edgeofseven.org) has completed four earthbag dormitory buildings for girls, and six classrooms using the method. Community leaders reported: "These were the only buildings where we truly felt safe after the earthquake."

Woven Earth (wovenearth.org) assisted non-profit Carisimo with several dozen earthbag houses in Nepal. Acting as technical advisors, in collaboration with Loving Arms Mission, Woven Earth assisted rural farmers in building 16 farm houses, some of these as training for the locals. And in collaboration with Common Action for Sustainable Development, they organized training for local workers to build one large Savings and Credit Cooperative Building for a local women's cooperative.

Woven Earth and Loving Arms Mission, with support from Kathryn Kaspar, have successfully carried out projects in which one member of each family worked on the construction of multiple houses in exchange for receiving one of the houses upon completion. Teaching the locals not only provides them with useful skills but also greatly reduces the cost of labor for the project. The local acceptance and understanding of a new building technique is also more likely because the recipients are involved in every step of the construction process.

Sacred Earth Trust (SET, sacredearth trust.org) is an NGO based in India working on sustainable development in sacred sites. SET has been building an eco training and plastic upcycling center to demonstrate low-cost effective technologies which are also earthquake resilient. To address issues regarding availability of space a "thin-wall" technique was adopted for local use to construct the office and machine rooms on site. Instead of using common 18-inch (46 cm) wide earthbags, the thin-wall method was adapted and resulted in 12-inch (30 cm) wide walls. The project demonstrated thin-wall earthbag building is practical for two-story structures on small lots in urban areas where code approval is required.

Dada Krpasundarananda (news.dadaksa.com) is a monk who has gained extensive experience with building and teaching others to build

Super Adobe domes. In Nicaragua, Mongolia, New Zealand, Ireland, Ghana, Canada, and other countries, Dada has been building/leading about one project a year on average. All the projects were domes, and generally they were for training purposes. He is seeing more interest now in alternative methods of building and more houses built, some of those as a direct result of his previous workshops.

Earthbag building is also growing in the Philippines, primarily for building hurricane resistant housing. One coastal village near Coron was devastated by Super Typhoon Yolanda in 2013, with about 90% of the houses in the village being completely destroyed. The Tamayo Foundation, a construction company in Manila, is funding 100% of a project to build a target goal of 100 earthbag houses.

Cyclone Pam hit Vanuatu as a category 5 cyclone in March 2015 and destroyed many houses and water tanks. For the first two weeks, the only clean water available in one village came from the earthbag water tanks at the earthbag Women's Center. The Tamayo Foundation has built 40 earthbag tanks since Cyclone Pam and they have started other women's groups on seven islands. These affordable (half the price of plastic water tanks) and easy-to-build water tanks could help solve the water shortage problem all across the Pacific islands and other drought-stricken parts of the world.

Project Somos Children's Village (project somos.org) created a Children's Village for Guatemalan children and mothers, with homes, staff housing, a culture dome, a preschool, and a community hall using earthbags. The Village is built to be eco-sustainable, with solar energy, rainwater capture, greywater recycling, and an organic farm.

Those at the Mlambe Project (themlambe project.org) in Malawi have been able to help hundreds of people by building schools with earthbags. This building technique addresses the "triple bottom line," because it is environmentally, economically, and socially sustainable. Malawi has a major deforestation problem that is causing serious flooding; earthbag building helps protect local forests by reducing the use of wood.

Phangan Earthworks (phanganearthworks.com) has built five earthbag structures on the tropical island of Koh Phangan, southern Thailand. The structures include two darkroom meditation domes, a large two-room toolshed, and a spacious "cave" house that artfully combines granite, wood, and earth. The earthbag walls elegantly fill gaps between large boulders that were on the property.

Chiang Dao B&B in Thailand (chiangdao-roundhouses.com) was built with bags filled with rice hulls — an abundant, low cost, local material. There are ten round buildings, mostly 5 meters across. Rice hulls are not load bearing, so the buildings are post and beam, with bamboo trellises on which the bags of rice hulls are attached. The cost to build one of these roundhouses is about $1,500, not including cost of local labor.

Japanese professor Akio Inoue has been a prolific earthbag builder and promoter, with about 30 projects, mostly earthbag domes on the campus of Tenri University in Japan; other projects are in India, Uganda, and elsewhere. Japanese architect Kikuma Watanabe has also created many earthbag projects around the world. Chinese professor Sunny Tsai and Colombian architect Jose Andres Vallejo have designed and overseen numerous other earthbag projects.

Precision Structural Engineering (structure1.com) has provided structural engineering for over 20 earthbag homes and the Seeds of Learning School in Nicaragua.

This brief list of projects shows the impact that sustained effort can have. Almost all of the projects described here were completed on small budgets, relying on the help and generosity of volunteers and donors. These projects are way more than just a tally of buildings. They address very important issues: how earthbags help reduce deforestation and flooding, provide earthquake and hurricane resistance, reduce housing costs, provide clean toilets and water tanks, and make it possible to build in remote places where it's impossible to transport other building materials.

I believe we are nearing a tipping point of significant change since the proof of concept and list of achievements is so overwhelmingly convincing that major acceptance will likely soon happen. After all, how many thousands of projects have to be built to demonstrate to the world, the media, and major NGOs that earthbag building is safe, affordable, and practical? Let's all work together to raise awareness of natural building methods such as earthbag to make a bigger impact in the world.

Chapter 1

A Brief History of Earthbag Building

Bags of sand or dirt have been used to build military bunkers or divert flood waters since at least the end of the 18th century. They are a good choice for this because they are easy to carry to where they are needed, can be quickly filled with local material, are inexpensive, and are quite effective at protecting people and property. Of course, these uses are generally only temporary. The use of sandbags (or, *earthbags,* as we refer to them here) for more permanent structures has only occurred in the last few decades.

In 1976, at the Research Laboratory for Experimental Building at Kassel Polytechnic College in Germany, Gernot Minke started experimenting with ways to make housing by stacking fabric tubes filled with loose natural materials. Pumice showed particular promise because it is both lightweight and insulating. At first, he built simple corbelled domes in an inverted catenary arch shape, using a rotating template to help place the tubes.

In 1978, Minke's team built a vertical-walled house in Guatemala using pumice-filled cotton tubes that were soaked in lime-wash as a preservative. Vertical bamboo poles were placed at intervals on both sides of the filled tubes and tied with wire between them to provide stability to the wall. The bamboo was also tied into the foundation and the top beam to create an earthquake-resistant structure.

In 1984, Iranian-born architect Nader Khalili proposed filling bags with moon dust as a way to build shelters on the moon. He refined this idea for building on Earth by placing strands of barbed wire between the courses of bags, thus unifying the shell into a more monolithic and shock-resistant structure. Khalili evolved the sandbag idea into what he called *Superadobe* by filling polypropylene bags or long tubes with moistened adobe soil that would solidify as it dried.

Khalili publicized his Superadobe concept widely and began conducting workshops and seminars on the techniques that he had developed, mainly at his California Institute of Earth Architecture. Based on exposure to these ideas, many other people started experimenting with their own building projects. Joe Kennedy, Paulina Wojciechowska, Kaki Hunter, and Doni Kiffmeyer all initially studied with Khalili, and the more general term *earthbag building* became popular.

Paulina Wojciechowska wrote the first book on the topic of earthbag building: *Building with Earth: A Guide to Flexible-Form Earthbag Construction,* published in 2001. This was followed by the publication of *Earthbag Building: The Tools, Tricks and Techniques* by Kaki Hunter and Doni Kiffmeyer in 2004. Several other excellent books have been published since then.

Akio Inoue has done extensive experimentation with earthbag dome construction, both on the campus of Tenri University where he taught in Japan and in India and Africa, where many other domes were built for assistance programs.

I first began experimenting with earthbag building in 1997, after producing a video program: *A Sampler of Alternative Homes: Approaching Sustainable Architecture.* I later documented my experience in building my own home in another program titled *Building with Bags: How We Made Our Experimental Earthbag/Papercrete Home.*

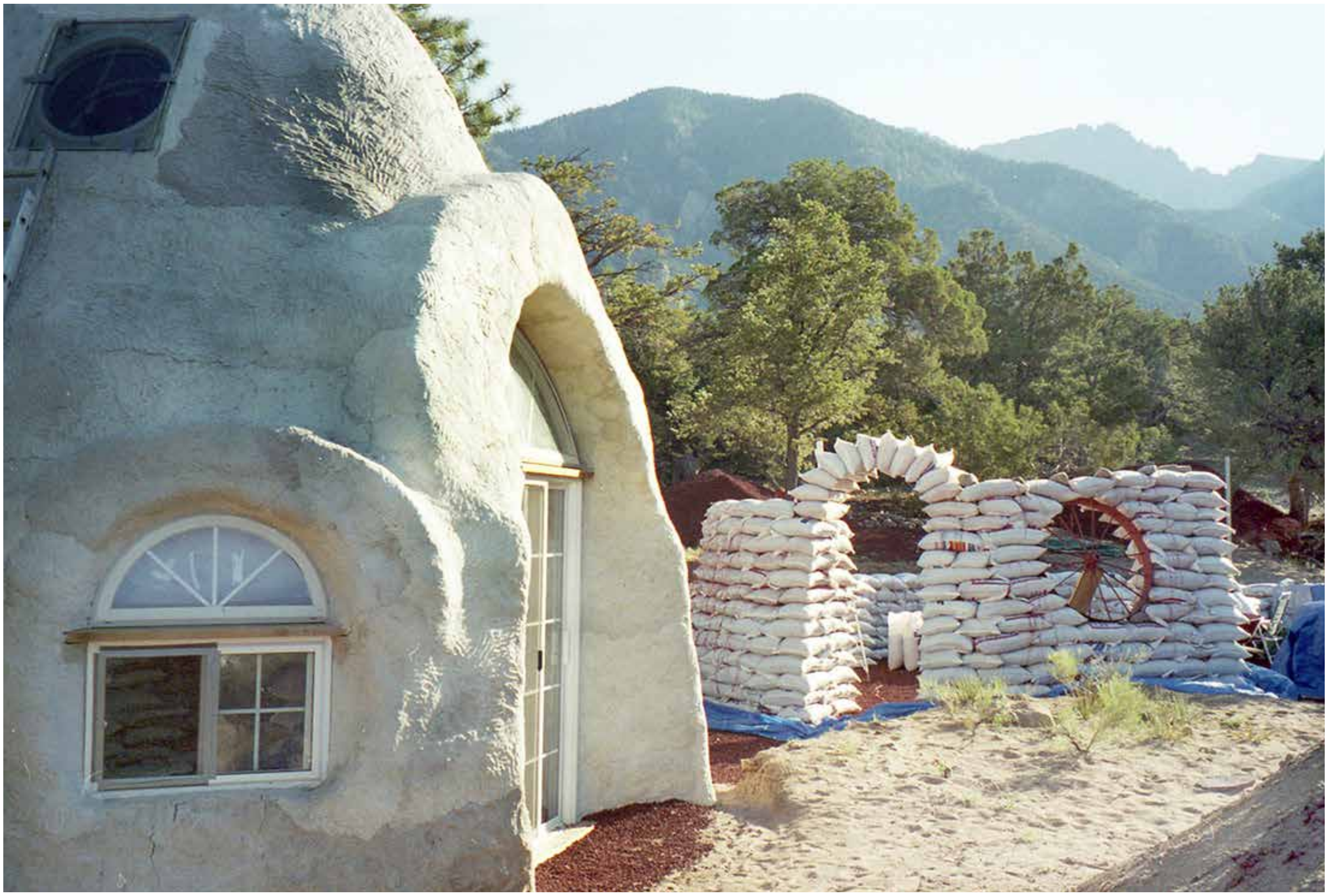

Fig. 1.1: *The author's earthbag dome home under construction in 1999.* CREDIT: KELLY HART

In 1999, Nader Khalili patented his *Superadobe* technique in the U.S. (despite the fact that patent law clearly states that such a patent cannot be obtained if the concept was publicized for over a year prior to the patent application). Khalili and his estate have rarely attempted to enforce the patent and say on their website, *"Superadobe is a patented system (U.S. patent #5,934,027) freely put at the service of humanity and the environment. Licensing is required for commercial use."*

Besides filling bags with adobe soil, many people have successfully filled bags with other materials, including crushed volcanic rock, crushed coral, non-adobe soils, gravel, and rice hulls.

Around 2009, Fernando Pacheco, a Brazilian engineer, experimented with using open mesh bags or tubing, similar to the sort of material commonly used to package bulky produce. He called his technique *Hyperadobe* and suggested that it has many advantages, such as creating a more monolithic structure and eliminating the need for barbed wire and mesh for stabilizing plaster.

Testing

In the mid-1990s, various engineering tests were performed on earthbag structures at Khalili's Institute, proving the efficacy of his techniques and enabling building department approval for some specific designs.

In 2006, at the request of Dr. Owen Geiger of the Geiger Research Institute of Sustainable Building, the Department of Civil and Mechanical Engineering of the U.S. Military Academy at West Point conducted several controlled and computer-monitored tests to determine the ability of polypropylene earthbags filled with sand, local soil, and rubble to withstand vertical loads. Their written report concluded that "overall, the earthbags show promise as a low cost building alternative. Very cheap, and easy to construct, they have proven durable under loads that will be seen in a single-story residential home. More testing should prove the reliability and usefulness of earthbags."

Even with these tests (and many others), earthbag building has yet to be incorporated into the International Residential Code (IRC). Nevertheless, hundreds of permanent and emergency earthbag dwellings have been built all around the world (and some of them are quite elegant). I wouldn't be surprised if many of these earthbag homes are still standing long after their conventional counterparts have disintegrated.

As an example of the robust permanence of earthbag building, all of the more than 55 earthbag structures that existed in Nepal prior to the devastating 2015 earthquake survived with only cosmetic damage. In some instances, whole villages were flattened with the exception of a few earthbag buildings. This has not escaped the attention of the international aid community and the Nepalese authorities; they are now recommending that communities rebuild with earthbags.

Chapter 2

Appropriate Uses for Earthbags

Earthbag construction is remarkably versatile, perhaps more than any other building technique. It can be employed both above and below ground without concern for rot or degradation. It can create thermal mass or an insulating barrier, depending on what the bags are filled with. It can be fashioned into a wide range of building shapes, from organically curvy to completely rectilinear, from domes to boxes — or combinations of any of these. It can be extremely durable, resisting fire, flood, earthquake, tornado, bullets, and time. It can also be quite economical — literally, dirt cheap. The techniques are simple to learn; for the most part, the work can be done by unskilled labor. The building shells are generally nontoxic, made of natural materials that can be returned to the earth or recycled at the end of their useful life. Often, very little wood or industrial materials are needed, so the buildings are environmentally benign. A simple rubble trench foundation may be all that is required, eliminating the need for massive concrete foundations. Besides buildings, earthbags can be used to build dams, cisterns, retaining walls, and other landscaping features. What more could you want?

Of course, all of the above considerations depend on good design and proper execution for good results. As with any building method, it is essential to be educated about proper design principles and procedures *before* embarking on any project. This book will give you not only a better understanding of the technique of building with earthbags, it will give you all the information you need to actually *do it.*

Earthbag walls are usually rather thick and heavy, which does limit some of their possible uses. For instance, they may not be the best

Fig. 2.1: *Looking straight up inside an earthbag dome shows the spiraling pattern of bags closing in to cap the dome. This was a small, mostly underground dome with earthen fill situated in the desert southwestern United States.* Credit: Kelly Hart

choice for interior walls, where space may be limited; they are not a good choice where plumbing or electrical needs to be run, or where there isn't an adequate foundation to support the weight.

In most climates around the world, it is best for the shell of a habitable building to be insulated from the extremes of ambient temperatures in order to have a comfortable and energy-efficient dwelling. Unfortunately, most soils are poor insulators, so filling earthbags with soil has limited utility. To remedy this, it is possible to either fill the bags with a more insulating material or to add a secondary insulating layer on the outside of the shell. Lightweight volcanic stone (such as *scoria* or *pumice*), perlite, vermiculite, and rice hulls are all insulating materials that can be used for fill. These materials are not available in all localities, or they might be too expensive for a given project. When investigating the possibility of building with earthbags, the availability of the most appropriate fill material needs to be a primary consideration.

While a wide range of building *shapes* are possible with earthbags, there are some design limitations. In general, vertical walls are quite stable when curved, but they usually require additional buttressing support when they are straight. Earthbags make great domes, but structures should be no larger than about 20 feet (6 meters) in diameter, and they cannot be hemispherical; catenary arches are the best dome shape to build. Domes need to be circular at the base so that all of the forces around them are equally balanced; otherwise, there is the risk of deformation and failure. Furthermore, earthbag domes are best limited to fairly arid climates, as it is difficult to assure that the final plaster will always be watertight in wetter climates. Vaults should be avoided (except for very narrow ones that are well buttressed); they are simply too unstable. Walls that have many openings for doors and windows are probably best framed with wood because there are limits to how many such openings can be placed in an earthbag wall.

Most earthbag buildings are one story high, or just tall enough to accommodate a small loft area. While it *is* possible to build multi-story earthbag buildings, they would need to be carefully engineered to assure safety. I think that a basement with two additional stories above it would be the limit for any earthbag building.

Remodeling an earthbag building can present some challenges, especially in terms of cutting through existing earthbag walls for new doors or windows. If one anticipates the need to remodel or add more space to an earthbag building, it's best to create the opening at the time of original construction and simply fill it in with temporary earthbags; when the time comes to make the changes, it is easy to just knock out the dummy bags.

Hanging heavy things on earthbag walls can present problems. It is best to anticipate the need for hanging things (like cabinets, mantels, and heavy artwork) during the construction phase — and incorporating structures that will allow attachments as the building goes up. It is possible to retrofit for hanging, but it can be awkward or inconvenient to do so.

A general problem with earthbag building is that you may have to jump through some extra hoops to obtain a building permit — if one is required. Earthbag technology is simply too new and too alternative to have generated the necessary impetus for uniform codes to have been adopted. This means that in order to be acceptable to the authorities, any given plan may need to be signed by a licensed engineer or architect who will vouch for its safety, and this can add to the time and expense of a project.

Chapter 3

Building Science Notes

The principles of building science should be applied to all parts of a building's envelope during both design and construction. Managing the flow of heat, air, and moisture through the walls is essential to creating comfortable, energy-efficient, durable, and healthy buildings. All wall systems are composed of four different control layers: thermal control, air control, vapor control, and water control.

Thermal Control: Principle

Heat always moves toward colder areas. A *thermal control layer* will slow the movement of heat, making the interior space more efficient and comfortable. There are three different ways that heat moves: *conduction, convection,* and *radiation.* An effective thermal control layer must be able to control all of these modes. Building codes and energy standards generally prescribe how effective the thermal control layer needs to be.

The usual way to express the effectiveness of a wall's thermal control layer is either through its conductivity (U-value) or its resistance (R-value), as a static-state value. But these values only give a general indication of how a wall will perform in the real world. This is because walls are not entirely uniform and variations will appear — where different materials come together, for example, or for other reasons.

Thermal Control: Application for Earthbag Building

Radiant heat can emit from any source, including the sun, heating devices, human bodies, or other bodies of warm mass. The materials struck by this radiation absorb the heat energy. With earthbag walls, it is usually the plaster that covers and protects the earthbag material that initially absorbs this radiant heat until its temperature matches that of the radiant source. Plaster is a fairly dense material and will absorb greater amounts of heat before reaching equilibrium than a more insulating material. The plaster will pass this heat on to the interior portion of the bag wall by conduction and convection. Being rather thin, the bag material will not impede the transfer of heat much, but the fill material might be either highly insulating or heavy thermal mass, which will greatly affect the performance of the wall. Insulation will resist absorbing this heat and thermal mass will absorb it.

Conductive heat energy moves by direct contact between materials. The interior and exterior plaster of an earthbag wall makes intimate contact with the thin bag material, and this heat is then conducted into the fill material. Solid earthen fill will readily conduct the heat through its entire mass—with some delay, depending on how thick the wall is. More insulating materials (perlite, rice hulls, etc.) have a greater resistance to conducting heat (and thus, higher R-values).

Convective heat exchange occurs via the movement of the air around and inside the wall. Air on either side of the wall rises as it is warmed and falls as it is cooled. These air currents make direct contact with the wall surface, imparting heat to or removing heat from the wall by conduction. The more air movement, the more heat can transfer. Within the wall itself, convective currents can occur as the plaster and the fill material heats small pockets of air, creating small convective cycles that speed up the transfer of heat. Within earthbag walls there is generally not

For a common 14-inch wall, R-values vary widely depending on fill material:

- The R-value of soil is typically somewhere between R-.25 and R-1 per inch; so a 14-inch-thick wall would be R-4 to R-14.
- Pumice and scoria (both natural, lightweight volcanic stone) have reported R-values of between R-1.5 and R-2 per inch. Thus, a 14-inch bag wall would yield between R-21 and R-28.
- Perlite is rated between R-2.5 and R-3.7 per inch, yielding a range between a whopping R-35 and R-52 for a 14-inch wall.
- Vermiculite is rated between R-2.1 and R-3.7 per inch, so a 14-inch wall would range between R-29 and R-52.
- Rice hulls have been tested at greater than R-3 per inch, so a nominal 14-inch wall would provide at least R-42.

much convective heat transfer going on because there is little air space for this, especially when the fill is thermal mass material.

Air Control (Thermal Performance): Principle

The movement of air through a wall assembly reduces the effectiveness of any insulation because heat is carried through the wall at an accelerated rate. Even at a relatively low pressure difference between inside and outside, heat flow through a wall can be nearly 25–50% higher than the R-value of the wall would be with no air movement.

Controlling the movement of air through a wall is critical to maintaining a comfortable and energy-efficient interior climate. Developing a continuous barrier to the movement of air through the shell of a building should be a primary goal during both the design and construction phases. This applies to all penetrations, including electrical outlets, pipes, and service conduits.

Air Control (Thermal Performance): Application for Earthbag Building

A typical earthbag building that has a continuous interior and exterior plaster maintains a very effective air control barrier. The flow rate of air through the bagged portion of the wall depends on the nature of the fill material, with solid earthen fill being the most resistant to the movement of air. The weakest links in an earthbag wall will occur at the seams between individual bags, especially at either end. Adequate tamping of the bags during construction will generally squeeze the bags fairly tightly together, diminishing the chance of air movement through the wall, but the plaster needs to be the primary guardian against air movement.

Air Control (Moisture Performance): Principle

Any air that does enter a wall can carry water vapor with it. Warmer air holds more vapor than cooler air; as the warmer air cools, it can deposit moisture inside the wall if it reaches its dew point. The potential for moisture retained inside an earthbag wall to cause mold, rot, or deterioration makes it even more critical to seal the wall from air intrusion.

Air Control (Moisture Performance): Application for Earthbag Building

To avoid the possibility of excess moisture condensing inside an earthbag wall, the best defense is a solid air barrier, as described above. Both the interior and the exterior plaster needs to be continuous — no gaps, cracks, or holes — as a defense against such moisture buildup.

Vapor Control: Principle

In general, the air control layer will also act as a vapor control layer since most vapor entering a wall will be carried by air. However, some moisture can still enter a wall through *diffusion.* It is possible for moisture to migrate at a molecular level through the pore spaces in a wall. This happens when there is a difference in moisture content on either side of a wall, causing vapor pressure.

To combat moisture diffusion, a *vapor barrier* or *vapor retarder* is installed in some building technologies. This generally not nearly as critical with earthbag walls because most fill materials are not adversely affected by some moisture. One exception to this is with rice hull insulation, which is best kept as dry as possible.

Different materials resist the diffusion of moisture to varying degrees. The ability of any given material to resist moisture diffusion is measured by *perms.* Vapor retarders are classified by these ratings:

Class I — 0.1 perm or less (qualifies as a vapor barrier, or is vapor impermeable)
Class II — 0.1 to 1.0 perms (vapor impermeable)
Class III — 1.0 to 10 perms (vapor semi-permeable or vapor permeable)
Class IV — 10 perms or greater (vapor permeable)

Vapor Control: Application for Earthbag Building

Because of the wide range of possible fill materials used in earthbag building, it is hard to generalize regarding proper vapor barriers. We do know that earthen materials have the capacity to absorb a great deal of moisture without ill effect; in fact, the use of natural earthen plasters, as well as solid adobe, rammed earth, or cob walls, is often touted as one of the better ways to mitigate problems associated with situations of high humidity. This is because these natural materials allow moisture to move both in *and* out of a building — allowing the building to "breathe" — in addition to their general lack of organic material that can rot or mold.

The various fill materials that act as insulation can absorb moisture to differing degrees and are potentially degraded by the retention of that moisture (also to differing degrees). In earthbag building, it is best if the earthbag wall remains vapor *permeable* — on both sides, if possible. Like straw bales, these wall systems should be kept breathable, with a rating of at least 4 perms. For earthbag buildings, this is almost always determined by the *plaster's* perm rating.

Table 3.1: Permeance of Plaster Skins

	US perms	Metric perm
Typical vapor barrier (by definition)	**<1**	**<60**
1:3 cement:sand (1.5")	1	50
5:1:15 cement:lime:sand (1.5")	4	200
1:1:6 cement:lime:sand (1.5")	7	400
1:2:9 cement:lime:sand (1.5")	9	500
1:3 lime:sand (2")	9	500
Earth plaster (2")	11	600

Water Control: Principle

Direct exposure to rain presents the greatest risk to most walls; this is best addressed at the design phase by planning for substantial roof overhangs, proper foundations, and window details that shunt water away from the wall assembly. Climatic conditions will dictate the extent of such measures, with arid climates presenting less need than humid or rainy climates; in windy climates, a design must be implemented that takes into account wind-blown moisture. The exterior plaster or cladding is generally the first guard in defense of moisture penetrating a wall.

Water Control: Application for Earthbag Building

Most earthbag buildings can be adequately protected from water intrusion by having a good

Fig. 3.1: *This small earthbag dome under construction in Mexico was plastered on the exterior with cement-based stucco that had a latex additive to make it more waterproof. In addition, it was painted with a couple of coats of water-impermeable roof paint.* Credit: Kelly Hart

plaster. This is particularly true with vertical walls that are well protected by a good roof eave.

In the case of domed earthbag structures, protection against the penetration of rain into the wall becomes much more problematic because the wall is *also* the roof, so it can be expected to receive considerable exposure to rain. One excellent way of offsetting the intrusion of moisture is to apply a plaster of *low permeability,* like stucco that has a high percentage of Portland cement or magnesium oxide cement. The surface of the plaster can also be painted with a non-permeable paint formulated for use on roofs, or it can be coated with something that is somewhat more permeable, like potassium silicate paint. Unfortunately, these measures require regular maintenance and are no guarantee that water won't somehow find its way through cracks or unseen deformations at some point during the life of the building. If this does happen, the moisture entering into the bagged portion of the wall may accumulate because the dome is no longer adequately breathable to allow the moisture to disburse. This can lead to soggy fill, mold, deterioration, or possible failure of the dome to support itself, endangering life and property. For this reason, I do not recommend that people build earthbag domes that rely on a plastered exterior in any climate other than rather arid ones.

One way to avoid the risks described above for earthbag domes in damper climates is to first of all use a solid, stabilized fill material that will not deform if for some reason it gets damp. Then, a secondary rainscreen cladding can be applied over the plastered earthbags, basically creating a separate roof structure that actively sheds the water away from the dome and leaves a space between the plaster and the rainscreen that can ventilate and provide a pathway for moisture to evaporate. Obviously, this solution would add to the expense and construction time of the project, but it makes the building more secure in wetter climates.

Earthbag walls also need to be protected from the intrusion of water wicking *up* through the foundation. This can be accomplished in a variety of ways, such as installing a rubble trench foundation with a French drain flowing to daylight to keep the foundation from accumulating water. The first course or two of earthbags can be filled with gravel that will not wick moisture further up into the wall. Another safeguard is an impermeable moisture barrier placed between the foundation and the bagged wall.