Building an earthbag dome

BY ROB WAINWRIGHT

Earthbag building, also known as superadobe or flexible form rammed earth building, is a newcomer to the sustainable building scene in Australia. The technique has been developed by several architects and builders around the world; well known amongst these is Nader Khalili of Cal-Earth (California Institute of Earth Art and Architecture). Although many load bearing straight walled structures have been successfully built with earthbags, it is in the curved form of domes and vaults that the technique really excels. The beauty of these shapes, combined with the low embodied energy of this building method and its excellent thermal performance, led us to choose earthbag as an appropriate human scale way to build.

Unlike conventional rammed earth construction, earthbag building is well suited to sites where an ideal soil mix isn't present, and the grunts and laughter of human labour are able to replace the roar of machinery. The basis of construction is the filling of polypropylene or hessian bags with a moist mix of soil, which is then compressed by 'tamping' with hand tools. Barbed wire is included between each row and has a dual purpose; to hold the bags in place while tamping, and to provide additional tensional strength in the wall.

The Northern Rivers of NSW is a region with a sub tropical climate, fairly consistent rainfall of 1200–1500mm per year, warm wet summers and cool dry winters. The sustainability education centre where this earthbag dome is being built experiences temperature highs of 40°C in summer, with overnight subzero temperatures in winter. The 4m diameter, 4m high structure was designed to withstand these climatic factors whilst providing a functional outdoor entertainment area and store room. It also provided us with some much-needed practice with local conditions and materials, before tackling a larger project.

My wife Stephanie and I have both had former lives in the healthcare industry; Stephanie as a naturopath and myself as a pharmacist. Unhappy with the lack of importance placed on the natural and social patterns by the economically powered mainstream culture in which we were immersed, we moved to the foothills of the Border Ranges National Park. Here we've spent the past two years studying permaculture, the last six months of which has involved the building of the dome for our major project. Stephanie studied superadobe construction with Nader Khalili at Cal-Earth in May last year, while I completed an intensive workshop in Belize, Central America earlier this year with Kaki Hunter and Donald Kiffmeyer, authors of 'Earthbag Building – The Tools, Tricks and Techniques' (see Bookshop pg 71). This book became our bible, helping us to plan and implement our design and we recommend this highly practical book for anyone looking at building in earthbag.

Trench excavation was done with a backhoe.

Some of the unique features integrated into the design of the dome include: a rubble trench footing containing a French drain, appropriate passive solar design, rammed earth flooring and a living roof.

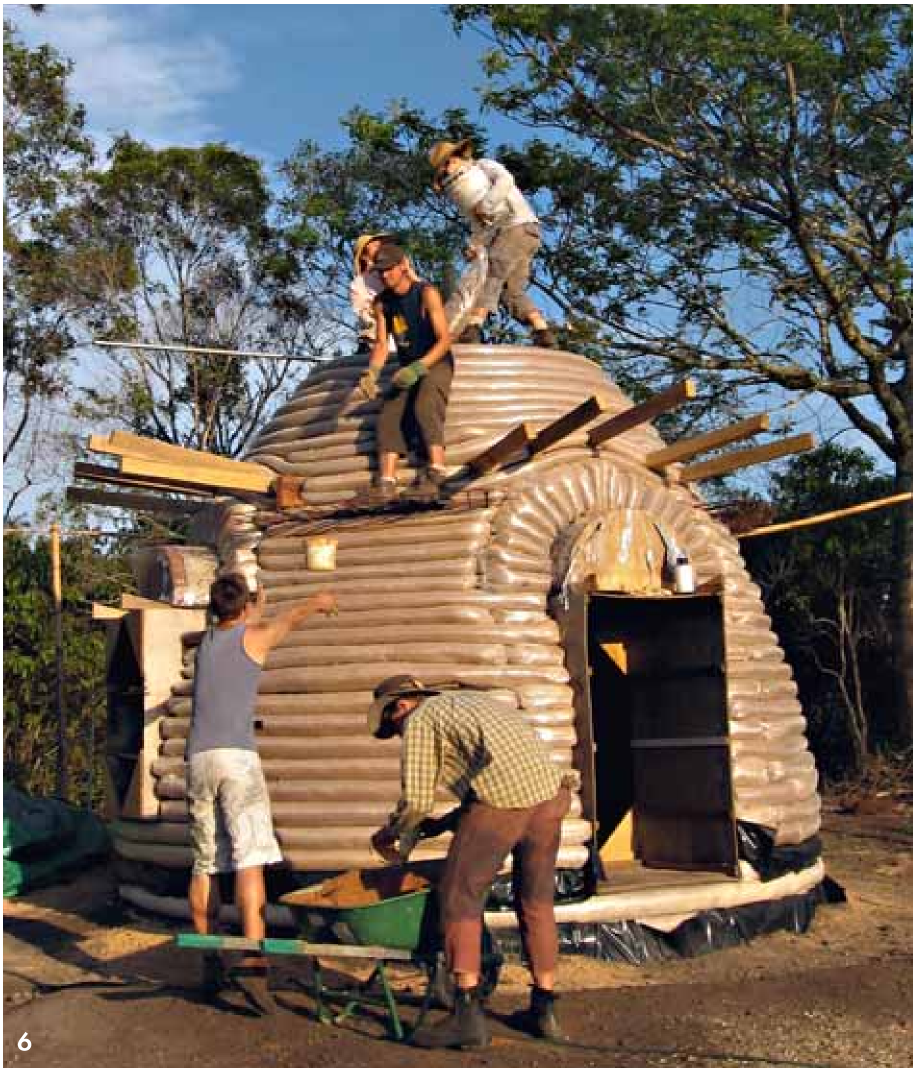
Site preparation

Rubble trench and French drain

A rubble trench was chosen for its proven track history, low embodied energy and tick of approval from famous architect Frank Lloyd Wright. Using 20mm aggregate, this style of footing, unlike conventional concrete, is resistant to the movement of water by capillary action due to sufficient air spaces between the gravel.

Initial site levelling and excavation of the trench was achieved in a few hours with the help of a backhoe and one very skilled operator. The trench was dug 700mm deep by 1000mm wide, and a thin layer of road base was placed and tamped at the bottom to create a consistent fall for drainage. Two lengths of polypipe were drilled at regular intervals, wrapped in silt stop plastic, and run the circumference of the trench, exiting to daylight on the downhill side of the site. It was important to pay attention to the fact that the holes in the pipe were pointing somewhere between horizontal and upwards to ensure the drain would function properly. The trench was then backfilled with more gravel, and compressed in 200mm lifts with a mechanical tamper.

The combination of a rubble trench and French drain is an effective way to remove any excess water that happens



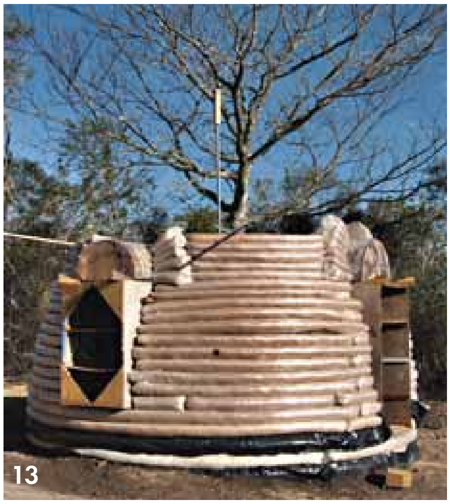
1–2. Footings consist of a combination of rubble trench and French drain.

3. A stabilised earth mix was used in the first four rows, topped with a vapour barrier.

4–5. The 'compass' is effectively two steel poles attached together with brackets, used as an adjustable guide for bag placement.

6&8. Formwork for door and window openings, and supports for awnings over these.

7. Two strands of barbed wire were placed on each row to hold the bags in place while tamping and to provide additional tensional strength in the walls.



9–10. Short, pre-cut bags were filled to a depth of 300mm, laid down and tamped into a wedge shape from each side, resulting in strong and accurate arch construction.

11–13. Formwork was used to create openings, while supports for the loft and stairs were inserted directly into the wall between rows.

14. Cantilevered into the walls, the stair treads are stable but will need some outer support.

15–16. Supports for awnings and mesh framework for guttering were also incorporated directly into the walls between rows.

17. Hand tamping whilst balanced on the previous row and two strands of barbed wire proved to be quite challenging!

18. Nearing completion, the upright catenary form becomes obvious. This shape is stronger than a true hemisphere.

to infiltrate the soil around a building. Water will move into the base of the trench after draining through the aggregate. Once it reaches a depth equal to the height of the holes in the drain, water moves into the pipe and runs downhill to an exit point away from the site. There have been some major rainfall events since the drain went in and it has proven to work well.

The compass

To produce the most stable structure, the dome isn't actually a hemispherical igloo-like shape, but a more upright catenary form. This ensures the majority of the gravitational forces acting on the walls are directed downwards rather than sideways. In order to maintain an accurate form whilst building we relied heavily on two things. Firstly, an accurate scale drawing of the dome shape, and secondly our much loved 'compass.' The 'compass' is effectively two steel poles attached together with brackets. The first – the vertical stand – is buried around a metre in the ground in the centre of the dome and set for plumb. The second – the horizontal arm – can rotate around the stand, be shifted and articulated up and down. Attached to the arm was a small shelving bracket that we adjusted inwards at each row. When the arm rotated, the bracket marked the distance the bags were to be stepped in. At completion of the building stage, the compass was dug out of the ground and set aside.

Building the dome

The main players

The soil: After conducting trials with the heavy clay subsoil from the site, it was decided to import the material from a local sand and gravel yard. Several phone conversations, and soil tests, revealed that the stuff I was looking for is referred to as 'fill sand,' and is basically a clay rich sand mix. The dome was built with two truckloads of sand, or just over 20 cubic metres.

The bags: We used polypropylene woven bags, manufactured by Bundaberg Bag Company, for this structure. Although they can easily be found as individual feed bags from any rural buyers store, or sourced cheaply as misprints from the manufacturer, we opted for a UV stabilised 1000 metre roll of 410mm wide circular woven tube. Individual bags were used around windows and doors, so we had

Above: Cantilevered stair treads were inserted between rows to a depth of 300mm. Right: Forms were built using scrap wood.

200 cut at 700mm length from this roll for a nominal fee. Working with a tube rather than individual bags allows quicker progress, neater work, and less joins to plaster into later on.

The barbed wire: As was mentioned previously, two strands of four-point barbed wire were run between each row to hold the structure in tension. High tensile barbed wire is less expensive, and easier to use than its heavier gauge cousin.

Building the stem wall

The first four rows of bags were filled with a stabilised earth mixture, consisting of 10% cement turned into our building mix. Stabilising the soil is a two edged sword; it creates a rock hard bag whose integrity won't be affected by water, but will actually tend to wick moisture more readily than the soil alone. As a result, a vapour proof membrane was essential on top of the stem wall. Builder's plastic was run over the last row of cement-stabilised bags and into the inside of the dome.

Going up

From this point on, progress occurred more rapidly. Soil was shifted between pile and wall by wheelbarrow, and then from wheelbarrow to bag by small buckets, each able to hold about two litres of soil. The damp mix was placed directly into the bags without cement, and in a good day we were able to add 3–4 rows onto the wall with a team of three people. Teams of three are particularly effective, as one person can collect the soil and pass it up to the second who is able to transfer it into the tube, which is being held by the third. Things start to get really interesting a couple of metres up, where work starts to look more like a circus act than a building site, with buckets flying up and down the wall between the 'tossers' on the ground (no insult intended) and the team balancing on a 35cm wide wall with two runs of barbed wire under their feet!

Ed's note: Please be aware of OH&S issues on site. Fall prevention is required for anyone working at a height of 2m or more. AS/NZS 1576 and AS/NZS 4576.

Adding bits and pieces

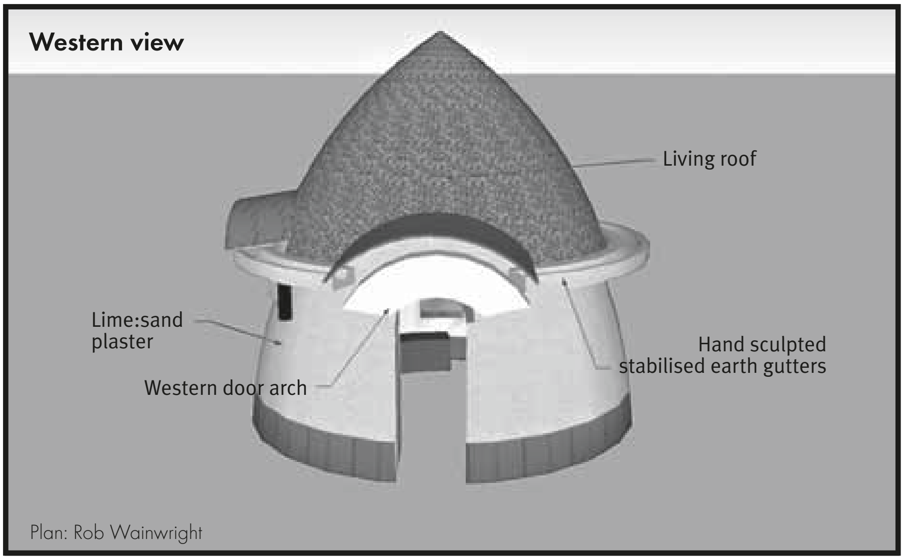
As the dome increased in height, several additions were made along the way for functional and aesthetic reasons. Formwork was built after locating the windows at local building recyclers. Scrap wood, and some purchased ply, allowed cheap construction of the box and arch forms that would eventually create the openings in the dome. These were built up to a metre in depth to account for the increasing curve of the structure as it gets higher.

Above the level of the windows, the supports for a small loft were inserted directly into the wall to make use of the vertical space at the top of the dome. To provide access to the upper level, a suspended stepladder was made by building the steps directly into the wall. The stairs were cantilevered to a depth of 700mm into the dome, with around 300mm being held in the wall. The resulting stairs were stable, but tended to flex a little when weight was placed on the edge furthest from the wall. As this could cause problems with plaster stability, it was decided to add further support to the stairs to stabilise them.

Supports for awnings over windows and door were also placed in the wall, extending out of the dome. At this point rebar lengths were placed between rows, with reo mesh tied on to provide a base for later completion of ferroconcrete gutters.

Building the arches

Arch work is a beautiful and functional way to span window and door spaces. The dome contains two arches, which were built over forms



Plan: Rob Wainwright

with the short, pre-cut bags. The bags were filled on flat ground to a standard depth of 300mm, with the top of the bag containing more soil than the bottom. When laid down and tamped, this creates a wedge shaped 'fan bag' that conforms well to the shape of the arch. In between the bags, barbed wire 'halos' were placed to further hold the arch together. Once in place on the form, further tamping was done to achieve the precise angle needed. A bag was added on each side of the arch to create symmetry until a space of around 200–250mm was left at the top. The final space was filled with the 'keystone bags;' three bags placed in at one time and filled simultaneously, tamping with a stick or the handle of a tamper until they were full, the gap was closed and felt solid.

A lot of time was spent to ensure the accuracy and structural integrity of the arches. Moisture content of the soil should be consistent, and the material in these bags tamped extremely well.

Steph and I, typically assisted by one of the permaculture students studying at the centre, did the majority of the building work. Total man hours spent on project planning, shopping and material collection, tool and form construction, foundation and dome construction came out to around 700. As a large amount of time was spent retraining new students, I think that with a consistent team of 3–4 people, construction could happen in about two thirds of this time.

These figures don't take into account the finishing work in plastering, building the living roof, windows, doors and earth floor, but these will be covered in a future article – 'Finishing off an earthbag dome.' ■

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- **www.calearth.org**
Dedicated to research and education of the public in environmentally oriented arts and architecture.
- **www.okokok.org**
Website of Kaki Hunter and Doni Kiffmeyer, authors of 'Earthbag Building' – see Bookshop pg 71.
- **Permaforest Trust**
The Permaforest Trust is a not-for-profit education centre and demonstration farm created to promote sustainability. Barker's Vale, NSW.
02 6689 7579, *www.permaforesttrust.org.au*

A note on maths and curves

After working with a dome structure for a while we became really proficient at thinking in 'round'about ways. Any material that seemed to naturally want to conform to a curve was immediately placed on the list of possible suspects for inclusion somewhere in the design. As a result, things like irrigation polypipe and old garage doors became our best friend during the building and finishing process. There were a few handy formulas, dredged out from the murky memories of high school maths, which we referred to many times over.

Circumference of a circle
$C = \pi d$ $\pi = 3.14$ and d is the diameter of the circle

Area of a circle
$A = \pi r^2$ r = radius of the circle

- **Bundaberg Bag Company**
07 4152 4988, *www.bundybag.com*
- **www.earthbagbuilding.com**
Sharing information and promoting earthbag building.
- **Build a small earthbag dome**
www.greenhomebuilding.com/riceland.htm
- **www.youtube.com**
An amazing array of videos about natural building. Just type in your requirement e.g. superadobe, earthen plastering, mud brick, cob building

Costs and labour

A budget of $2500 was allocated for the project. The major costs involved included:

• 30 cubic metres of building/plastering mix	$750 incl. delivery
• 10 tonnes of 20mm aggregate	$250 incl. delivery
• 1000m of woven polypropylene tubing *This is actually enough for nearly two domes of this size*	$600 (44¢/m plus delivery)
• Earthworks	$300
• 2 rolls 400m high tensile barbed wire	$130
• Recycled windows	$85 for 2 louvred and 1 'hopper' style window
• Materials for compass and tamper construction	$100