FOREVER HOMES
EARTH CONSTRUCTION

ENCOMPASS - AN EARTH ARCHITECTURE PROJECT
IN NEVADA COUNTY, CA

presented by
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INTRODUCTION

In 1997 a nonprofit organization in Nevada County called EnCompass (see last page) was interested in creating a conference center on 122 acres. They were looking to develop 12 overnight cabins for visitors. Each cabin would be several hundred sq. feet. A 12,000 sq. foot conference center was also designed, which included more domes, as well as rammed earth walls. The conference center has a main hall 33 feet tall by fifty feet wide. The final project was a school of 14,000 sq. feet that was a series of connected vaults that narrowed at one end to create a combined shape of the spokes of a wheel. Half of the wheel would be the vaults the other half a large amphitheater cut into the hillside. Little did I know, but this project was to stretch beyond four years and become one of the largest earth projects in the northern hemisphere in the last 1000 years (or so I am told).

The primary vehicle of construction initially introduced was Earth Bags. Earth Bags are plastic grain sac material purchased from the manufacturer in uncut lengths of 6000 ft. with tubing of various dimensions. Soil is placed inside the tubing, creating an earth sausage and then compacted flat to become a continuous brick. This process can be shaped and curved to create many forms, but I have found it most useful for domes and retaining walls. In building the straighter walled lodge and school, a standard rammed earth technique was used. This process employs construction of wood forms in which the soil is compacted in to. Preparation for the project was intense. There were several challenges facing us. The only other application of Earth Bag construction at the time that we were aware of used wheelbarrows and coffee cans to mix and pour the earth into the tube. Then the soil would be shifted from the head of the bag to the tail by a process of several people lifting the bag and walking the soil to the end like a snake swallowing a rodent. We would end up compacting over 7.5 million lbs. of soil, so we needed a better way. The initial renderings prepared by an inspiring visionary lacked small details like dimensions, details and engineering. This required that we begin to put together a plan and a team.

STARTING THE PROJECT

Planning was the most demanding aspect of this project. A staff had to be hired and trained, a network of professionals developed and the site and forms prepared.

Earth construction can be very frustrating because of the general lack of knowledge available at a local level. Finding experienced guidance took time, but was very valuable. Even hiring laborers required extensive training. Once we got good help and trained them, we went to great lengths to keep them and continue to improve staff moral and experience.

One of the best steps we made was enrolling Paul Platner to assist us by managing the project. Paul oversaw the planning and most importantly the budgeting necessary to keep the project rolling and the owners informed. He greased the wheels of progress and allowed me to keep my energy focused on the technical aspects of running the project and keeping production on schedule.

At the same time we enrolled David Wright, a local architect with an excellent reputation for special projects. He began work on details and finish drafting for the three projects. David is a fun person to work with and had his hands full producing the complicated drawings that were our roadmap on site.

Bruce King was hired as our primary engineer. Bruce was critical for a professional relationship with the local building department. Bruce's experience with rammed earth was blessed and he was easy to work with when changes had to be made in the field.

Soil from the site was extracted for testing. The soil had to be free of organic material. We performed an initial site test by a liquid separation test. Place soil in a jar half filled with water. Shake vigorously and note the separation of fines, medium and heavy aggregates. Then soil samples were compacted and
tested at our local engineering lab, using various combinations of cement and additives. Tests proved very favorable and we needed only three sacks of cement per yard to obtain our ideal mix.

We began in earnest creating the landings and building sites for the cabin projects. An elaborate infrastructure plan was created placing all utilities underground. Painstaking effort occurred establishing these building sites with focus on solar, wind, working around existing trees and features and overall relationship to the rest of the facility. The cabins were located on a steep slope and meandering retaining walls were created that wove around trees and reflected the outlines of the circular foundations of the domes. The cabins were grouped in threes called clusters.

This is where Earth bag construction was great. We were able to shape these retaining walls with ease and speed. On an average we bagged 30,000+-lbs. of soil a day. We would stack 5 courses of sac material then backfill. The wall was sloped back 15deg. You can only stack 5 courses before they want to tip. Each retaining wall was built on a 30" wide footing 8" deep. 20p galvanized nails were placed into the concrete sharp end up for binding the first course of bag to the concrete footing. Weep drains were installed and deadmen mats tied the wall farther into the compacted backfill. Backfilling had to be compacted to 98% and we had this tested every two feet.

Forms for the cabins were started the winter before. Circular stem wall forms for the foundation, forms for the doorways, windows and skylights had to be constructed. Special rebar hoops had to be bent, vent pipes cut and materials ordered and scheduled to be delivered to the job site.

A large excavation at the school site provided plenty of soil for the rest of the projects. Several weeks of sifting rocks out of the dirt and transportation to the mixing site. We poured a mixing slab 30 x 40 ft. with a short 8'x 4' push wall in the middle of one end of the slab. This allowed us to have two mixes going at a time.

**THE CABIN PROJECT  EARTH BAG**

The cabins were started with the foundation. The footing was dug with a small mini excavator that was great at excavating circles. We had a plywood laminate inner stemwall form that screwed together and was braced with a number of radiating spokes that met at a center hub. We built heavier duty forms because we planned on using them 12 times. The stemwall was 16" tall which was the height of the spring line of the wall. This avoided the need for extensive buttressing. The cage work was complex. Prebent hoops every 16 inches enclosed 8 #4 rebar sticks that circled the cage. Everything was tied and braced off the center form for stability and
accuracy and then the outer form was installed. We poked out bar to tie in the vaulted doorways and apses. 1200' of rebar per dome. We trained one person to head this crew and he would stay ahead of the concrete and bagging crews.

We used our own mixer for about half of the foundations till we got smart. Four yards would do a foundation and two for the slab. After the stemwall was poured we would excavate the interior down to make room for insulation and gravel for the radiant floor slab. The top of the stem wall would be porcupined with 20galv. nails that would bind the first course of bag to the wall. This was a hazard and we would typically run a first course of bag the next day regardless where we were to cover the pungie infested wall. Forms are set next. Doors would get two plywood panels with 2x4 framing stood and braced on each side to bag to. This helped make the bagging go faster. After a few courses we would set the window box forms in preassembled (designed to dismantle for removal) and brace off.

Soil was mixed at our staging area located in the parking lot 300yds away. This was not ideal because of the distance to the site. A medium sized tractor with a loader and rototiller would blend the soil and cement together before adding just the right amount of water. The water quantity was a common point of correction with new tractor operators. It is critical that the mix be timed from the point of adding water. Don't add water till you are ready to mix. There is enough moisture in dry soil to start the cement cooking. The mix only has a 90 min. life. Don't push this limit. There is nothing more frustrating than tearing down a dome because one layer is bad. Then a full sized tractor would carry a large yard of stabilized soil to the site and empty it into a 4x8 plywood bin with short sides attached. The soil was shoveled out of the bin into buckets and the buckets then passed to the funneler. The funnel was one of our greatest solutions. We were able to put 80 ft. of bag tubing onto the funnel at a time and the soil would dump through the funnel and into the tube to resemble a fat sausage. The technique required a good funnel operator who could control the size of the tube by the angle of the funnel and the placement of the bag as soil was dispensed.

We had several funnel operators that could trade off and several funnels so that there was always a funnel ready when the bag ran out. I found it critical to tape finger ends to protect cuticles from the harsh bag texture.

Next the tamper would set the bag. Initially we used a compass. An adjustable rod hinged from radius that is checked for proper length then used to role the bag in or out to set the proper curve of the wall. The tamper then jumps up on the wall and using a hand tamper (8x8) compacts the soil in the bag till you
can hear a faint ring in the soil/tamper contact. This job is best done by someone macho who gets into tough hard work. We found the pneumatic pogo stick tampers with a 6” modified head works the best. This exchange of muscle for machine cuts time by 300% at least. After tamping each section a length 1x4 is held up next to each course and a line is transcribed onto the storyboard. This is done every 3-4 feet to find the high and low points in the wall. Then a marking pen is used to place plus or minus on the bag for the proceeding courses to indicate fat or thin bags. The final team player is the wirehead. He/She would place two strands of FOUR prong barbed wire onto the bag. Whenever this wire would reach a window or opening in the wall a #4 8” piece of rebar would be pinned vertical into the bag leaving 2 inches or so sticking out. The wire would wrap around the pin and exit the structure with a 6 inch loop before coming back around the pin and lapping 24” back over the bag run. This hoop would later provide a mechanical bond for window eyebrow features that would be cobbled into place.

On later projects when several domes of the same size were needed to be built, a thin plywood shell would be constructed reflecting the dimensions of the interior surface. We used light KD hemp fir with ¼” plywood. This was done in sections that were numbered so it could be easily disassembled and removed through the doorway. This also would provide a surface to secure forms to, poor bond beams onto(skylights) and brace against when working high up. By eliminating the compass and storyboard we made bagging and plastering much faster. The three domes built at the conference center took 1.5 days to bag vs. the 7 days on the cabin project.

To access the dome's exterior we would install 2 inch PVC tubing every four feet vertically and around every 6 feet around. Into these holes we would place 5 foot lengths of 2x2 square steel tubing and place scaffold planks on top of these. Where scaffold planks overlapped, we would screw them together to avoid one being kicked off. It is important to have several layers of bag stacked on top of the scaffold tubes before installing scaffolding. Quick and easy scaffolding is important.

Each of the main cabins had a five foot skylight and each of the sleeping niches or apses had a 24” skylight. A larger form was made that was bagged against. After bagging, the larger form was removed and a smaller one installed. A cob bond beam would be poured between the bags and the inner form. Cobbed concrete is made rich with cement and stiff with minimal water. Around a 5-6 bag mix. We made all skylight bondbeams and vaulted passage ceilings out of cobbed cement.

We installed 6” vent tubing near the top of the dome to provide convection venting. A simple louvered cap works to shut this during winter. Attention should be made to make sure that this vent tube slants
out and down to avoid water dripping in.

There are two ways that doors and windows can be prepared for and installed. The first we used was a less expensive flanged vinyl window that needed to be installed onto a pressure treated frame. This was further complicated by the fact that the windows had a eyebrow at the top. A template was made and these frames were premade with a thin plywood panel temporally installed to help hold exact shape and square. The window forms had to be made larger to accommodate plaster and setback for window clearance. The second way is to get flangeless windows that are designed to be installed into a cement square opening. Plastering that exact opening is a pain so we used the flanged technique with great success.

After the rough bag work was complete, we would attach a form on the outside of the window forms to apply the rounded eyebrow detail. The cobbing would stack in around the vertical row of barbed wire hoops. We purchased rubber chamfer strips to round out the cob eyebrows to make plastering easier. We would also cob the top of the vaulted doorways. This was accomplished by setting a half round barrel form on top of the doorway vertical panels. Expanded metal lath was placed on top and rebar run in a one foot grid and attached to rebar pins driven into the last several courses.

This concludes the rough out stage of the Earth bag construction. The next stage is the finish. This is where it gets fun. We have been told that it is not necessary to remove the bag stock from the earth bags. If you do leave the bag stock I recommend that it is not left exposed to the sun for any prolonged time because sunlight deteriorates it. It is very thin and a quick wave of a torch wand and it disappears. We believe removing the bag provides the best bond. It also gives you a good opportunity to check work for bad sections.

We tried gunite and hated it. Gunite is a dry cement and sand mix that is blown out of a hose at high speed with moisture added at the nozzle. Shotcrete is concrete(cement, sand, and aggregate, wet) pumped through a hose and high volume of air added at the nozzle. Shotcrete is the way to go. Shotcrete is wet mixed concrete pumped through a hose with high volume of air added at the end. We hand plastered several of our first domes. This took 4-5 days to apply a scratch coat by hand, just on the interior. This was done later in the year during the winter when access to the domes was limited. When we found out about the shotcrete we were very interested. My plaster arm had grown several inches in diameter. We were able to shotcrete five domes in one day. This process is best done by professionals. Shotcrete is very powerful high volume application process that can injure or break windows in a heartbeat. The concrete pump is piston driven and pumps in surges. Add 240cfs of air at the end and you have a ballistic weapon. We broke an installed and plastered in window and several shop lights with the 3/8
aggregate that goes flying about. Expect around 20% waste when planning for cleanup labor and materials. It is a good idea to have an useful place to use the slag. We used a long handled shaped pool trowel to cut away excess shotcrete. Windows are best left off till after shotcreting for light and ventilation. It takes 6 good people to manage the nozzle and do the cleanup and trowel work. The brown and finish work was done with a small plaster gun from pump-all. It is a rotorstator pump that with some experimenting did a great job. Plastering is something great to pass off onto an experienced contractor. Many things to go very wrong. For exterior waterproofing we used several products. We experimented with a product called Zypex. Court is still out on this. In theory it is supposed to grow crystals to fill cracks that may appear. The best success we have had occurred with a polymer additive called anti-hydro. This is mixed with the brown coat. We also used a color coat called super blockaid, supposed to be waterproof. Still not sure how great this works, looks good and have not had any major failures yet. This is one area that not too many people could help us with. Plasterers who do typically vertical flat work scratched their heads till it bled. All product industry types grinned and said "sure".

The floors were finished with radiant tubing for heat. Exterior slabs and lots of footing and surface drains have kept these domes dry so far. Hope this gives you some great ideas for Earth Bags.

**CONFERENCE CENTER**

**Rammed Earth**

The conference center was to be located on top of a knoll. The knoll was filled with trees and peppered with pretty liken covered granite rocks. The trees were to be worked around and the bench was to be lowered to achieve a common floor height for the whole site. Within hours of the first heavy equipment shattering the silence of the woods, a call for dynamite was issued. There were big rocks down there. Soon the foundation contractor was busy hanging forms and pipes, conduits and radiant tubing was everywhere. Meanwhile, just down the slope a large stock pile was being created for the rammed earth walls.

Stacks of special HDO plywood with a large price tag showed up and we began to generate the forms for the main hall. The main hall is 50+feet across and over 33 feet tall. There are 12 fourteen foot wide walls 18 feet tall. Each wall has a 10 foot wide vaulted door in it. We decided to create the form in the shape of a "T". Each wall section would be joined at the narrowest section at the top of the door. This required that we build a form that disassembled into a front, back and two candycane shaped side pieces. For timing and cure time we decided to make two. The forms were huge. Over four thousand pounds each. They had to be reassembled then craned up and lowered onto a 17' tall I beam. The space at the interior of the base of the form was very small. With the 8 sticks of #5 vertical
rebar, 2-6 sticks of conduit and the I beam, there was not much space to stand and operate a tamper. We finally found the right guy, John Richards. He had come on the project to hold our hand as a technical advisor and showed no fear as he descended down the ladder into darkness. The ladder was removed and the only part of John that could be seen was the top of his straw hat he wore. We would mercilessly dump soil on top of him till he was able to climb out on the soil that he tamps.

The A form, as we called it was used on every other column. The B form was identical except for the fact that it is used to join two A columns together. In this manor we leapfrogged our ramming around the conference center taking a week to complete each T form ram. Bond Beams 12” thick were poured at the top of each form and colored to accent the natural color of the decomposed granite that we used on the wall itself.

We compacted an earth cube for each wall we did. The cubes would then be cored and the cores would be broken in sets of four. One set was broken at 7 days, 14 days and 28 days. This was charted and tracked for the duration of the project. Some of the cores tested weak initially but rose and surpassed the 1000psi failure mark. The moisture level was important and mixes that sat for prolonged time or were mixed too dry were the primary cause of low test levels. Most of the tests broke at the 28 day mark were around 3000psi.

There were 6 other rammed earth walls in the conference center. They were straight walls with arched eyebrow windows. Our timing improved on the forming to eight days turn around from set to strip. The walls were long (45’) but only 8 feet tall. A small triple stage forklift made getting the soil to the top of the wall a snap. Soil would be transferred from the mixing area in the loader to the bin on the forklift. The fork would then deposit the bin on the four foot wide platform that ran the length of the one side of the wall. We had four bins so there could be a couple bins of soil on each wall and spares waiting. Up to four tampers hurried this process along avoiding cold joints and work lights from long days.

THE SCHOOL Rammed Earth

The school also is built with long straight walls. The slab was smooth and flat with rebar sticking up at 24” centers along the length of the wall location. An advanced crew set plate ahead of the forming team. By some miracle, not one radiant tube was hit while setting the plate. The school as fourteen walls that are arranged in a semi circle. The narrow end of the rooms have a T form that is not a 90deg. Angle. This was a complex wall to set up with the doors niches and windows but they were all almost the same. Repetition is bliss.

We started on our first wall at the end of October. The weather was closing in and project
deadlines prevented me from taking any extended ski time off. Two large 60’ x 30’ tents 25 foot tall were purchased to pacify worries of doom from winter storms. The plan was to crane the tents, leap frogging them from wall to wall as we worked our way west around the school. We would have 5 days to complete each wall, but only if the process started on Monday. Monday we would strip and seal forms. Tuesday we began to set walls. Wednesday we finished setting walls. Thursday we would ram. Friday we would install the cagework for the bondbeam and pour the bondbeam. This allowed the wall to cure for 3 days before being stripped. What this meant is that we would have to set a 55’ wall in two days that normally took us five. It also meant that if we missed one day we got a week off. The school began with good weather. The second wall hurt us bad. Thursday night at 8pm found the crew ragged and exhausted. Floodlights illuminating torn tyveck suits. Rain pouring off the tent sides onto empty pizza boxes. After that we got into the challenge of the thing and didn’t have another harsh day till the ramming of the fireplace this year.

**AMPHITHEATER EARTH BAG**

The amphitheater was a project that had excited me from the beginning. I drafted the plans and submitted the budget for funding 6 months prior to start. The amphitheater was the hollow mirror of the school. It is hinged on a common center point but is built into the hillside. Its base swings halfway around a 18” tall x 30’ diameter stage. Seats, 18” tall x 32” deep step back and up from the stage. A 20’ tall pole was erected at the hinge point where the stage would go. This we pivoted off of to set our bag radius for the seating. The sides of the seating area wing back 50’ and then swing back into the hillside on the radius. The hillside itself is sloped 2 to 1 and every 8 feet steps back 5 feet. By calculating the existing slope I was able to minimize excavation into the super hard decomposed (but really solid) granite. The problem was staging the soil. The stabilized soil was mixed adjacent to the stage and tractored to two different spots where it was shoveled into 5 gallon buckets for human transport to the funnel. Once the 5 bag courses were stacked and compacted we would begin the backfill. The back fill had to be compacted in 6 inch lifts. It took around a hundred yards of soil per step. As the seats extended up the hill the climb for the tractor became too much for the larger loader. One wrong move and the tractor would slide sideways off one of the narrow dirt ramps that temporarily ascended the theater. The smaller tractor seemed to handle this and did the 280 loads a day up and down without complaint. Each one of the 5 courses per seat took two and a half yards of stabilized soil. We would start at 5am be done with the earth bags at 10 and finish the backfill by 3pm. We installed weep drains as a precaution to hydrostatic pressure and tapped hand rail post holes for the outer edge. The seats will be scratch coated with shotcrete and finished with a smooth stucco coat.
**FIREPLACE RAMMED EARTH**

The fireplace is designed to go into one of the door openings for the main hall of the Conference Center. Its mantle is poured around a river rock façade that boarders the opening to the hearth. The body of the fireplace is 11 feet wide, 7 feet deep and 12 feet tall. It is set onto a massive footing that is dug down to the bedrock. The ram was our largest. 44 yards in a single day. The soil is layered. Each face of the fireplace was stripped the next morning and chiseled to the shape of a round belly.

**STAFF**

The last thing I want to comment on is the human resource. This element requires much more care and attention than one would think. Our primary ramming crew was made up of 10 -14 people. This is besides all of the normal subcontractors on the site as well. On many days there were 30 - 40 people to oversee, a small village. Earth work requires a lot of human touch. Different than most trades this is a lot of unskilled labor as well as skilled. Finding good people, and then keeping them during a hot construction market was challenging. Delegating responsibilities helped each person develop a sense of contribution and responsibility other than just being a flesh tool. Off site activities, like intense whitewater trips, helped create a sense of teamwork that carried onto the job site and eased tensions during tough work days. Frequent reviews featuring positive reinforcement and lots of encouragement also made a big difference. An inspired crew that had a sense of pride made all the difference in the world. This is one area I highly recommend planning on placing a lot of energy. The ramming is not ordinarily fun. If you want people back, serve lunch, take photos and dish out praise.

**CONCLUSION**

Working with earth is a rewarding experience. Not just because of the unusual nature of the projects, but the caliber of people available to work with. Each project holds its own challenges that are cradled in a careful network of inspiring people all focused on the same goal. There is an intent not present on most jobs of masterfully creating a finish product that is a experiential showpiece. I look forward to future projects and the opportunity to continue this fascinating and challenging work.
ABOUT THE AUTHOR

Zachi Anderson lives in Nevada County. He has been a builder for almost 20 years and specializes in unique project management. He is a passionate recreationalist enjoying many outdoor cycling and water sports. He currently works with Paul Platner at Forever Homes. Please contact Zachi or Paul with inquiries or questions at;

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ABOUT ENCOMPASS

EnCompass, located in the Sierra Nevada foothills, offers a wide variety of workshops, programs and services for the whole family. EnCompass’ mission is to support the well-being and wholeness of children and families through an array of integrated holistic programs and facilities, and to engage in the development of Holistic Education in theory and practice.

EnCompass holds the simple contention that humans are born with inner capacities for well-being. By nurturing their inherent wholeness, individuals and families have the opportunity to actualize this well-being across the diversity of age, ethnicity, class and culture. From parenting workshops and family programs, to wilderness adventures and our many Holistic Education initiatives, EnCompass strives to bring a holistic perspective and rigorous inquiry into a broad spectrum of learning opportunities.

EnCompass is in the process of building permanent facilities for its programs and services. Using a revolutionary method of super-adobe, as well as rammed earth technology, EnCompass hopes to create and model a caring relationship to the environment and it’s resources.

For more information or to schedule a site visit, please use the contact information below.

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