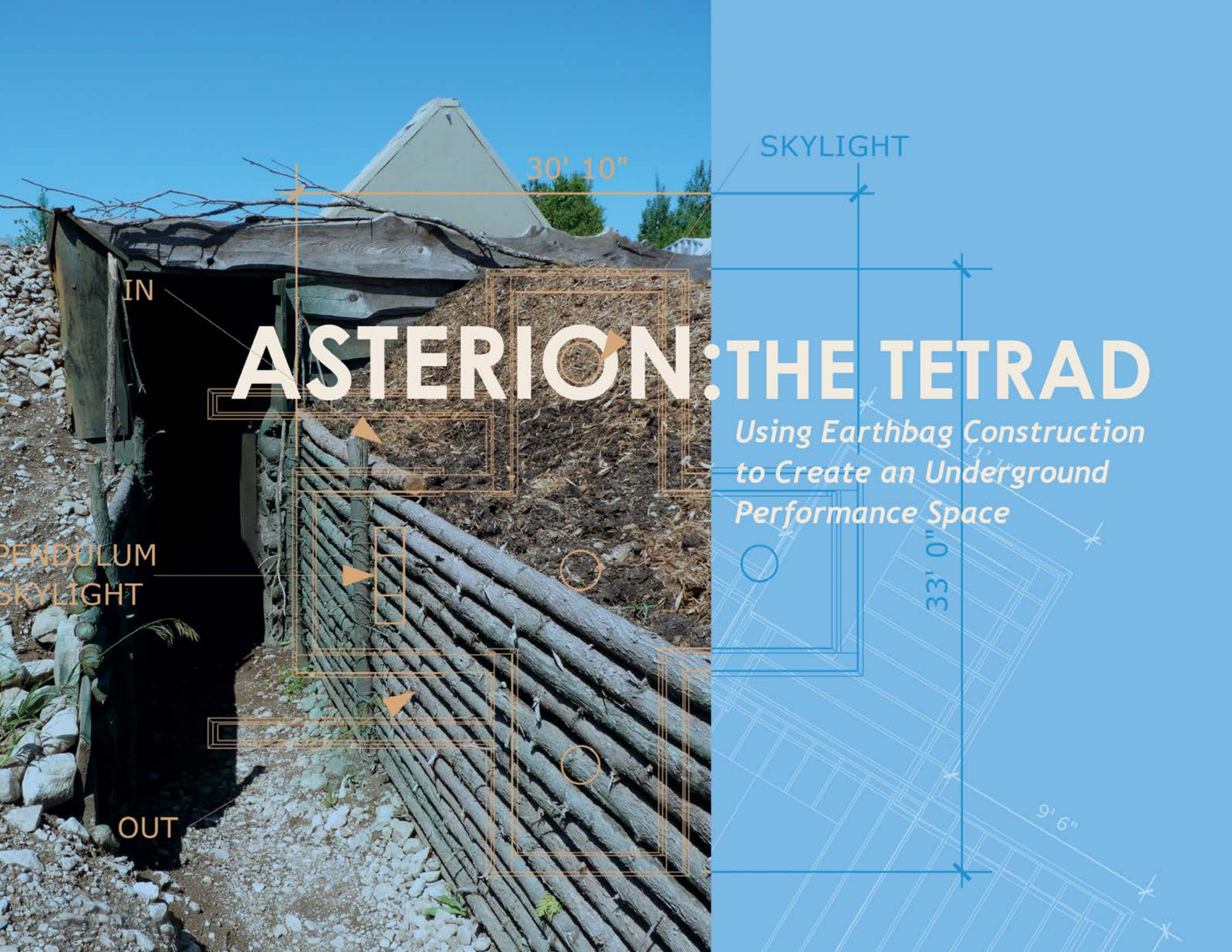
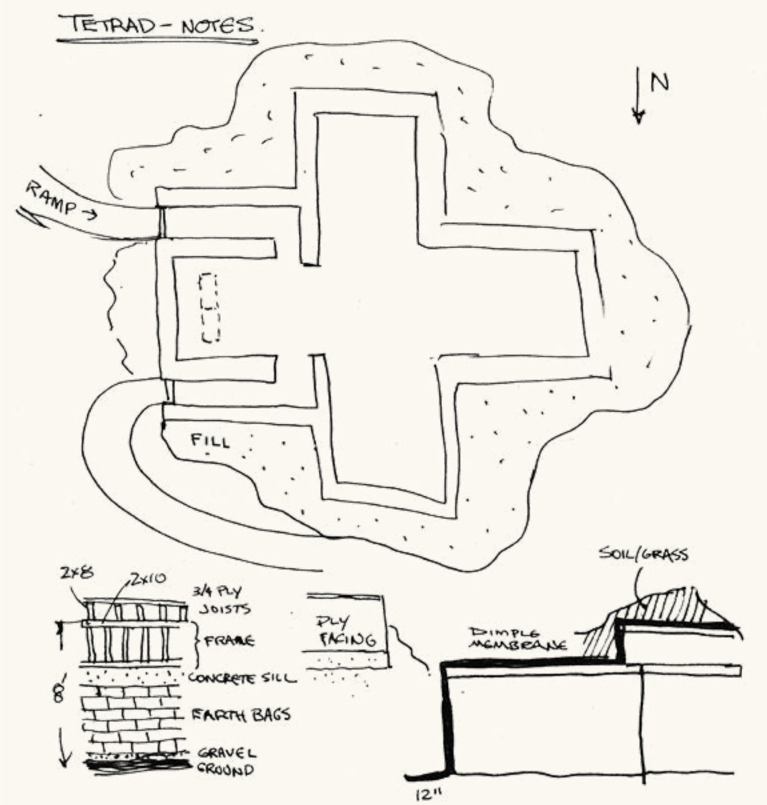
ASTERION: THE TETRAD

Using Earthbag Construction to Create an Underground Performance Space



WHAT IS EARTHBAG CONSTRUCTION?

Earthbag construction is a building technique using sturdy bags or sacks filled with earth, gravel, sand, or clay, layered in offset courses similar to bricklaying. This technique can be used to build any size or type of building, and the walls can be curved or straight. These buildings can be roofed with tensile materials such as wood or steel, or the walls can be built up into dome shapes. This method is considered a natural building technique, and developed from military bunkers and flood protection sandbags. Often, soil or gravel from the building site itself can be used to fill the bags, thus eliminating the need to bring in large quantities of heavy and expensive building materials.



Jerrard's early sketches of the Tetrad

Earthbag buildings significantly reduce or eliminate the use of wood and metal building components, making them very affordable as well as eco-friendly. They do not require highly skilled workers to complete. These structures are highly resistant to weather-, fire-, and other damage, and provide cooling or insulating properties.

OUR STORY

This build arose as part of a research project for the University of Guelph Theatre department. Prof. Jerrard Smith spent the summers from 2004 – 2013 with a crew of students, artists, and builders on a rural site near Peterborough, Ontario, Canada. There they built many types of structures, some permanent, some temporary, within which to perform theatrical works.

The project was called Asterion, and was based on the work of Canadian composer R. Murray Schafer. This is a theatrical production with a highly unusual structure, whereby a single audience member travels through a series of environments, encountering actors and installations that tell the story of the labyrinth. In order to realize this production, the Asterion crew worked with various artists to build looping and variegated passages through interior and exterior spaces. They built rooms and corridors and forest pathways, and filled these with artifacts, sounds, or living actors as the script required.

This text focuses on the Tetrad; one of the many spaces that were designed and built for Asterion. In this case, designer Angela Thomas was putting together the plans for an encounter that would take place underground. Our crew was faced with a unique challenge; the design called for a large, cross-shaped subterranean performance space, with four wings or bays. Important in our design was a 7ft.+ ceiling height; waterproof walls, as the building was below grade; a living roof; and the ability to withstand the cold Ontario winters with their heavy snowfalls, extreme temperature variations, and harsh winds.

For some of the other permanent structures on site, the team had already experimented with straw bale walls; concrete and rebar dome construction; re-purposed shipping containers; and a pre-fab Quonset hut. For this new building, they settled on the earthbag method. This is because it offered a low-tech solution, relying on person-power as opposed to complicated machinery. They were intrigued by this method because it was new to them, and would take advantage of the excavation by using the displaced earth as building blocks. The plan was also considered very cost-effective, eliminating the need for large quantities of lumber and hardware. The crew had labour available from 4 full-time and 2 part-time workers, the designer, and 2-3 volunteers at any given time, which seemed to be sufficient. The idea of incorporating the actual landscape into this structure, which would, when finished, ideally blend seamlessly with the earth, was very appealing.

*For more information on the Asterion project, visit **www.patria.org/Asterion***

*Much of the information used to plan and execute this project came from Owen Geiger's excellent material, Earthbag Building Guide (2011), and the Step-by-Step Earthbag Building video series, available at **www.earthbagbuilding.com***

A clay model of the Tetrad

IS EARTHBAG RIGHT FOR YOU?

Although earthbag construction can be an affordable and reliable way to build using sustainable materials, there are also many reasons why it's not ideal for some situations. It is a labour-intensive process with unique challenges.

As you will read further along in this manual, you'll come to understand that the digging, filling, stapling, moving, lifting, tamping and positioning of each earth bag are all physically challenging and time consuming tasks. It's important before beginning any construction to work through the steps in your head and anticipate any problems you might have along the way. The more knowledge you have before you begin, the better the outcome of the building. Take the time in preparation to draw up a thorough budget based on the size and configuration of the structure, which includes not only the materials needed, but also the time required to build it.

Other things to consider:

What purpose does this building need to serve? If it needs to be large, multi-storied, or complex, this method may not be appropriate.

Is there access to appropriate soil for filling the bags? The earth used must be sandy or gravelly soil. Soil with too much clay or moisture; or too much unprocessed organic material such as grass or plants; will be problematic.

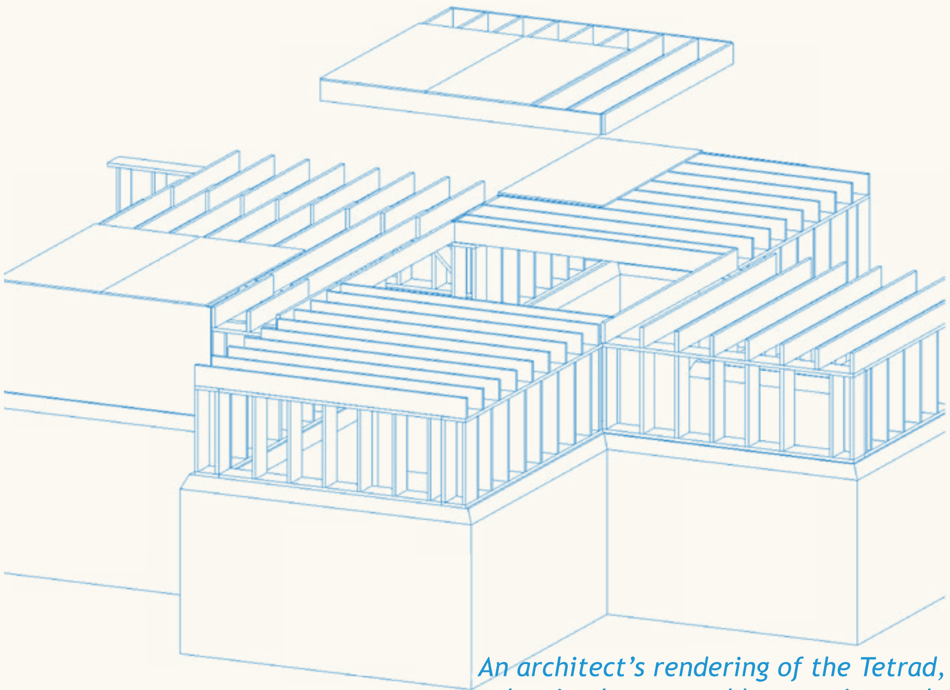
Is there a large enough team of labourers? This is a low-tech, low-cost building solution, but it does require hard physical work and will move more quickly with more person-power.

What is the time frame? Since the building blocks of the structure need to be created by the building team, on-site, this method can take longer than bringing in pre-fab materials.

What permits are needed in the area?

What kinds of weather conditions will the structure be required to withstand?

This manual will describe the construction techniques the Asterion team used to build a 500 square foot subterranean earthbag building, as well as the obstacles they faced and some of the things they learned along the way that will help anyone undertaking an earthbag build.



An architect's rendering of the Tetrad, showing lower earthbag portion and lumber-framed upper portion & roof

METHOD

Materials and Tools

-Shovels
-Rakes
-Hand tampers
-Sledgehammer
-Woven polypropylene feed bags
-Staple guns (heavy duty plier staplers)
-Plastic utility buckets
-Barbed wire
-Rebar

For the Asterion project, lumber and hardware were also required for the upper half of the walls, and the roof.

Preparing the Foundation

The Tetrad was to sit on its own in an open field. Since the building was intended to be half underground, a foundation had to be excavated. (Earthbag structures do not necessarily require a basement, so if your project is not underground you will not need to do this).

Breaking ground

A large excavator was rented, and a 30' x 30' pit was dug. The corners of the proposed building were then staked, and line levels used to make sure there wasn't a variance across the long distance. Where there was a variance, the backhoe was used to level the area. This is a time-consuming step that will pay dividends when you begin to construct the walls. Any variance in the ground level is built into the wall, and the higher you go the more drastic this discrepancy appears. Regardless of whether you are excavating a foundation, or simply building on top of the earth, it is crucial to prepare the ground by levelling it before you begin.

Having roughly levelled the floor with the backhoe, the crew then used a rented gas-powered tamper, or "jumping jack" to compact the earth throughout the whole building, paying particular attention to the areas where the bags were going to be laid. They were able to compensate for some of the grade discrepancies by adding dirt to some areas, or compacting it more in others. This ground would serve as the foundation for the entire structure so making sure that it was thoroughly compacted was of the utmost importance. If time and money allows, pouring a concrete slab as a foundation is a great solution to any leveling issues and can ensure your wall starts off on a very solid base.

Beginning The First Course

With the earth below well tamped, or a foundation poured as a footing for the earthbags, you can begin the construction of the walls. The Asterion crew used readily available feed bags from the local farm supply store. The bags were approximately 12x24" and cost less than 25 cents each. With enough notice you could possibly get all your bags more cheaply, or even for free, from a farmer in your area. It's important that all the bags are exactly the same size. The aim is to make uniform building blocks by filling each bag with earth and tamping (compressing) it into a brick shape.

When anticipating the construction, be sure to check the quality of the soil you plan to use to fill the bags. This is one of the most important parts of the process, as it will form 90% of your entire building. The soil used to fill the feed bags needs to be free of grass or other organic compounds. As the grass inside the earthbags begins to decompose, it can threaten the integrity of the structure. Ideally the soil will also be fairly free of large rocks. You want a soil that can be tamped well and can hold its shape. Any sharp or jagged rocks risk puncturing the bags when they are tamped. As well, larger rocks that make it into the bags will create an obstacle, preventing the bag from being properly tamped. The goal here is to create a malleable brick that can be put in place and then tamped into a hard brick which nests snugly between its neighbouring earthbag bricks. A rocky bag won't hold its shape and will therefore create a weak spot in your wall.

The soil the crew was working with, which had been excavated for the foundation, was heavily laden with rocks, and this presented a major obstacle. Efforts were made to sort through the dirt before pouring it into the bags. Using hand tools such as rakes and shovels they were able to separate out many of the big rocks, but it was very time consuming. Using the bucket on the excavator to slowly pour out loads of dirt caused many of the large rocks to tumble out of the pile. Most of the rocks could then be raked off, and the remaining dirt used to fill the bags. This was a great technique for removing many of the big rocks in an easy way, but it did require the use of heavy machinery.

Again, using the backhoe, large piles of dirt were distributed around the worksite. The earth is very heavy, and you want to avoid transporting it very far by hand to the bags, which are filled in place, on the wall. Conserving energy is important for the efficiency and morale of your workers. Try to fine-tune your systems throughout the building process to make each day more efficient than the last.

Since the uniformity of the bags was paramount to the building's integrity, the crew wanted to devise a system of filling the bags to an identical capacity. 40 yellow plastic 10.5L utility buckets with handles were purchased. 4 of these buckets would be used to fill each feed bag. In this way, the quantity of material going into each brick was standardized.

Plastic utility buckets help measure the fill

Labour was divided in this way: One worker would fill the yellow buckets from the dirt pile and pass or carry them to a 2-person team filling the bags, who would empty the buckets and then return them to the filler. The 2-person filling team consisted of one worker to pour, and another to funnel the dirt into the feed bag. A bucket with the bottom cut off was used as a funnel. As the bags, once filled, were quite heavy and the job was repetitive, there was concern about strain on the back and body of the person funneling the dirt. The crew fashioned a leather sling the funneler could wear around his or her neck that would relieve some of the weight on his or her back and body. The 4 buckets of dirt were poured through the funnel apparatus and into the feed bag. This would continue throughout the day with everyone taking turns on the different tasks.

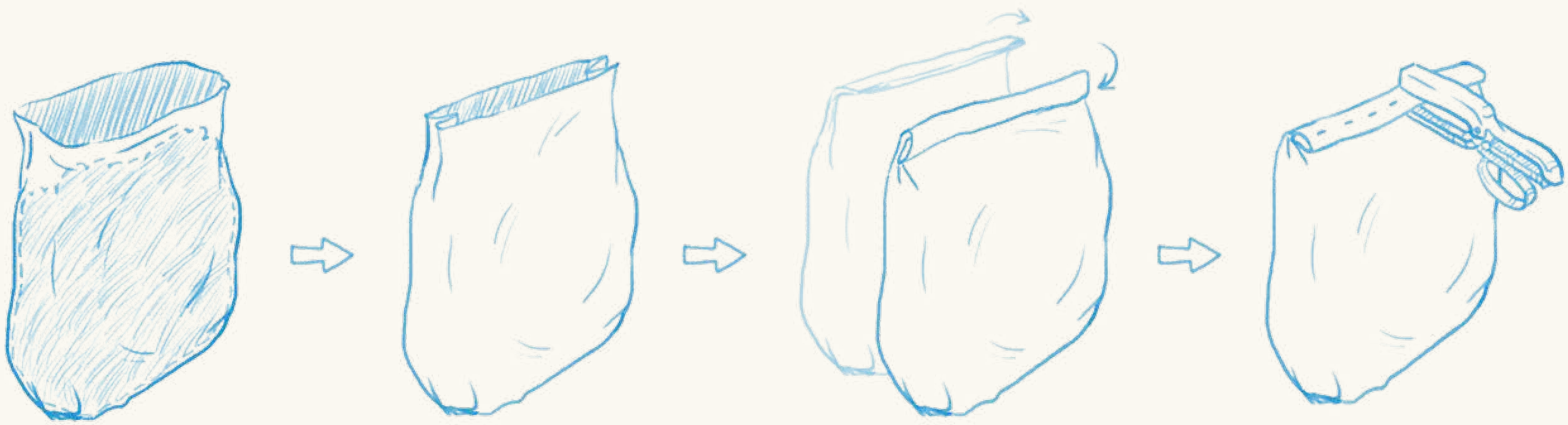
holding an empty feed bag

a bucket with the bottom removed is held inside

earth is poured through the bucket into the bag

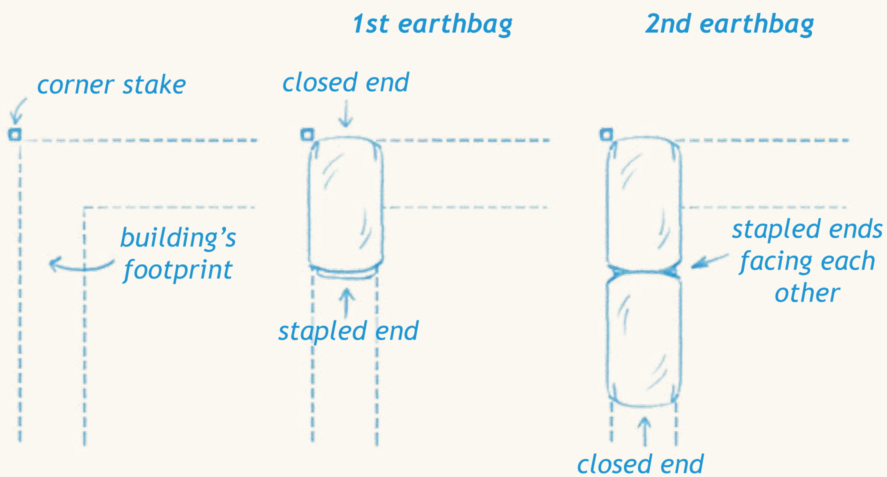
Before filling, the bottom of the feed bag was positioned exactly where it was needed on the wall. Once all 4 buckets were in the bag, the top of the bag was folded over 3-4 times creating a 2" flap that was stapled shut. The bag was then lowered squarely into position on the wall.

With the bag sitting where you want it you can then tamp it into a nice, solid rectangular shape. You want to make sure that as much of the soil as possible is compacted within the bag.



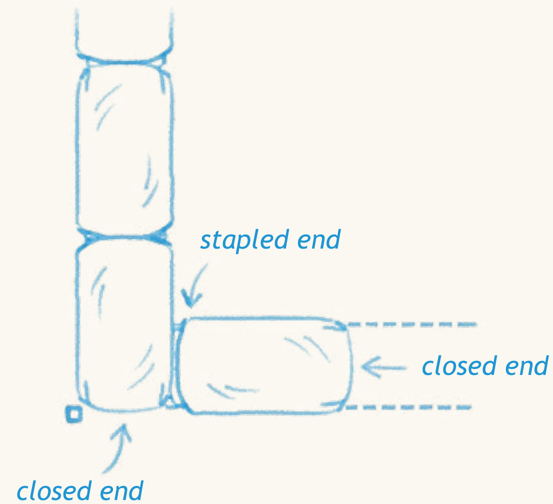
when bag the bag is full, the opening is folded twice and stapled shut

Starting at one of the corners of the building, lay the first filled earthbag, with the closed end forming the building's corner, and tamp it into a rectangular brick. Fill the next bag and butt it up against the first brick, with the stapled ends facing each other, and then tamp it in place.

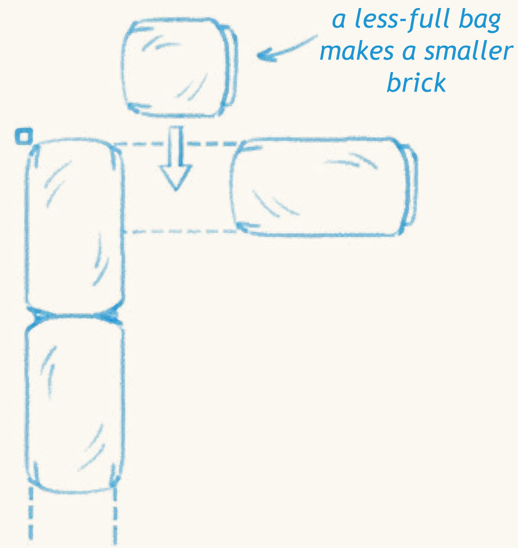


The third brick will have the stapled end butted up against the second brick's closed end and so on, up to the brick which forms the adjacent wall corner with its closed end. Turn the corner, and butt the next bag's stapled end up against the long side of the previous brick. Essentially, the point is to avoid placing any bags with the stapled opening facing outward, but rather to keep all stapled ends pressed firmly against another earthbag to ensure they stay closed. Continue this way until you've created the first course of bricks on the ground. If, when you place the last brick of your first course, joining the first brick you laid, there isn't room for a full bag, play with how much dirt you need in the last bag to make a brick that will fit the space.

turning a corner



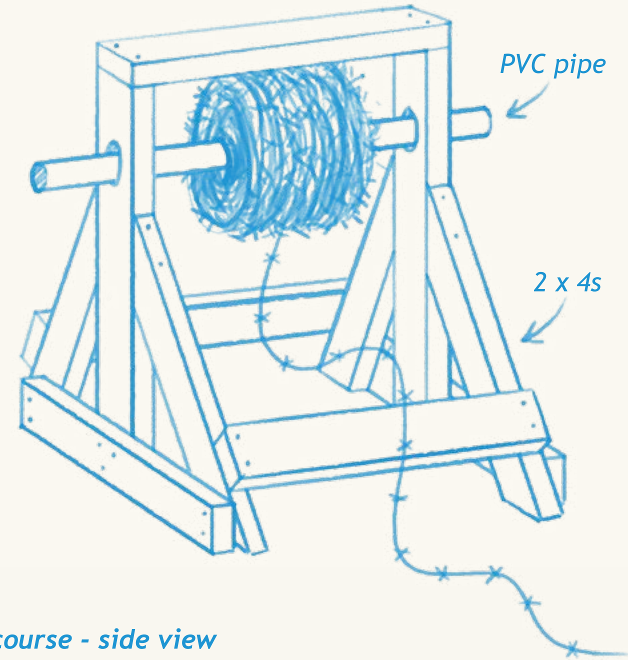
finishing the first course



The Second Course And Beyond

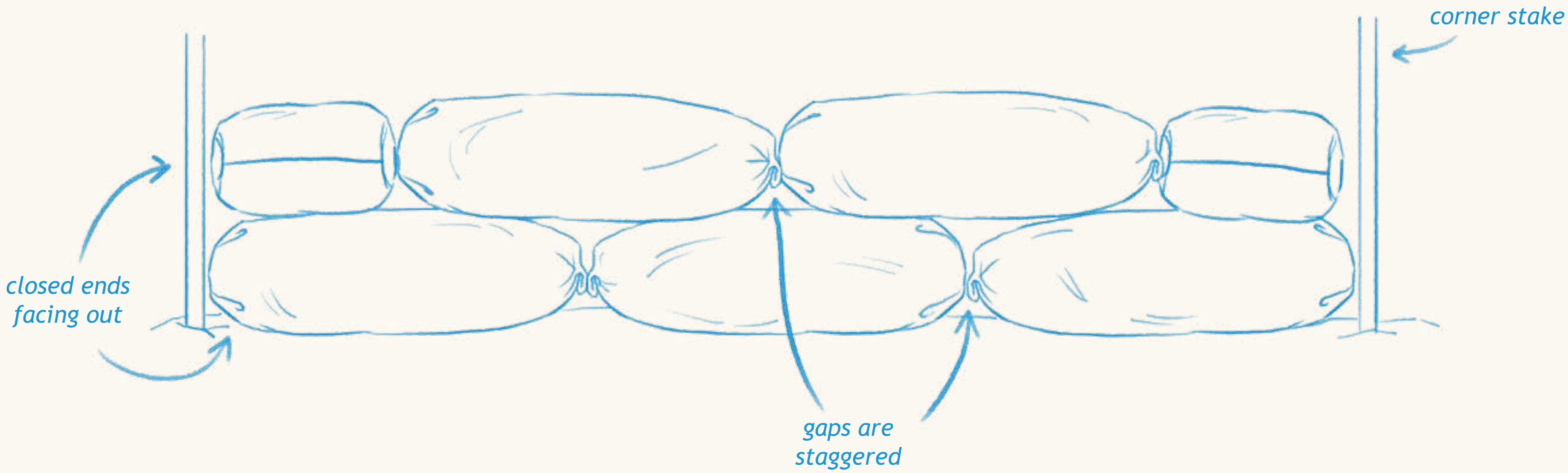
To prevent the bricks from slipping, a line of barbed wire was run between each course the whole length of the walls. The spikes on the barbed wire dug into the earthbags above and below and helped lock the bricks in place horizontally. For ease of working with the dangerous barbed wire, the crew built a wooden stand out of 2x4s to hold the spool of wire. The stand allowed the spool to spin freely so that the line could be rolled out safely and the spool moved around throughout the building. This was really helpful and worked well.

a spool for the barbed wire

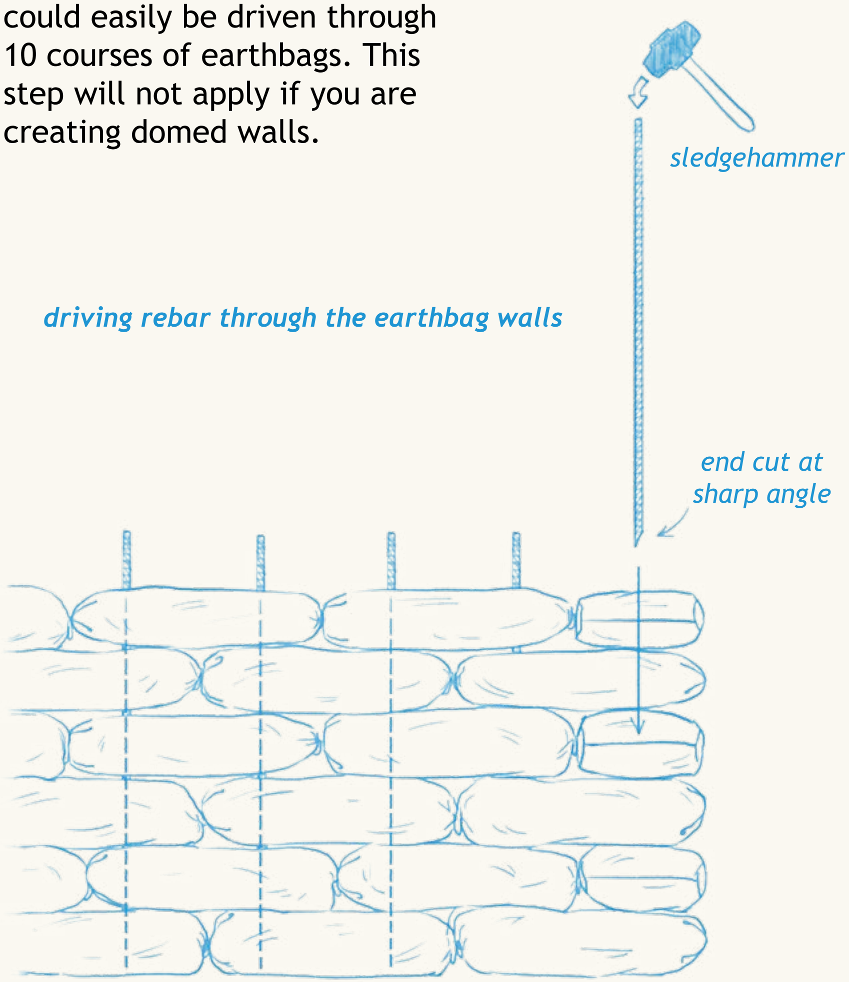


Begin the first brick of the second course at the same corner you began the first course, but progress in the opposite direction (clockwise/counterclockwise) around the building's diameter. Be sure that each brick in this course overlaps the seam between two bricks in the course below, and that the seams between bricks in this course meet above the center of a brick in the course below, so that no gap between bricks is vertically continuous. As in the first course, align the stapled end of each new bag with the closed end of the one before it, and be sure all outside-facing ends are closed.

laying the second course - side view



This process repeats for each course. Be sure to check for plumb using a level or a weighted line as you move along. You want to make sure each wall is perfectly vertical. Any slight lean as you build will continue to get worse as the wall gets higher. To help tie the structure together vertically, the Tetrad crew cut pieces of steel rebar into 4-6 ft. lengths and drove them down through the bags with a sledgehammer. The ends of the rebar were cut, using the cutting disc on a metal grinder, on an angle so that they were sharp and could easily be driven through 10 courses of earthbags. This step will not apply if you are creating domed walls.



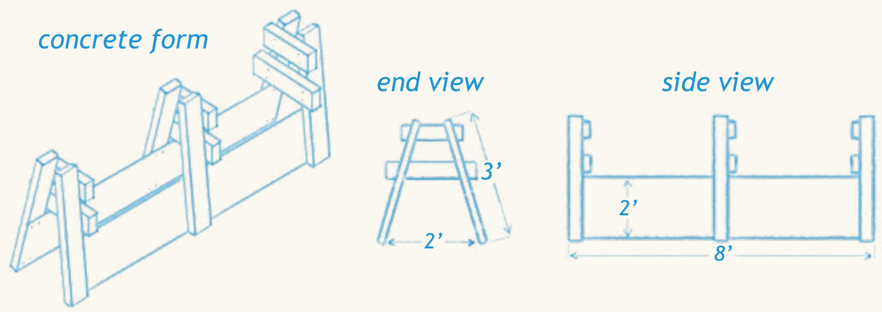
driving rebar through the earthbag walls

Completing The Walls

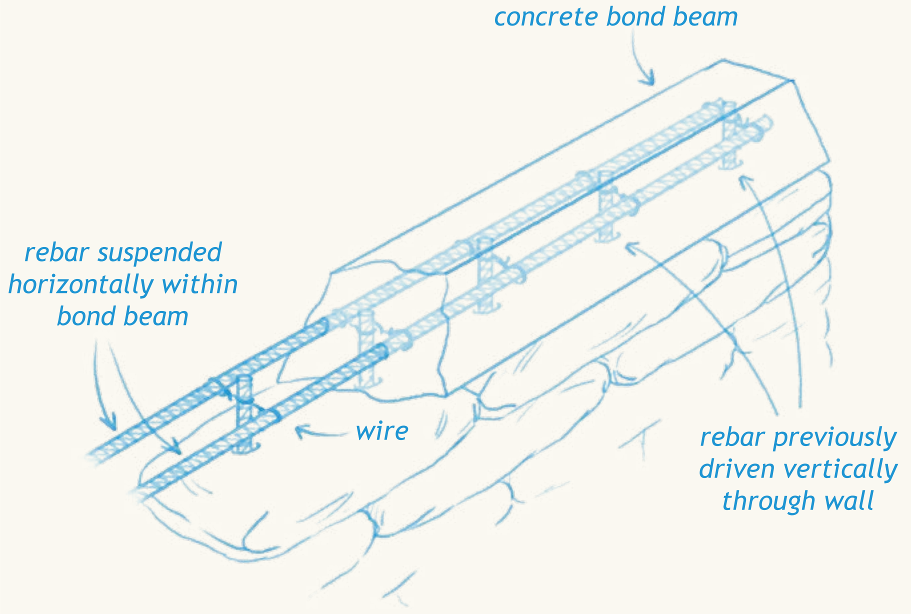
The Asterion team's original plan was to build the walls completely out of earthbags and then top the structure with a wooden roof. When the walls got up to about shoulder level with this building, which was above ground level, it was decided to switch to pressure treated (PT) lumber to expedite completion of the walls.

the contrete bond beam on top of the earthbag walls with plywood concrete forms visible in the background

In order to build a sound wooden structure on top of the earthbags, a solid, level base was needed, so a concrete bond beam was poured on top of the earthbags, over which a PT lumber 2" x 10" sill board could be laid. Several 8' concrete forms were built using plywood and 2 x 4s. These were slightly flexible so that they could fit snugly overtop of the earthbag walls. The forms were re-used for all the walls as the crew moved around the perimeter pouring the beam. Plywood forms were then custom-built for each corner. Everything was attached with screws so that it could be taken apart once the concrete had set.

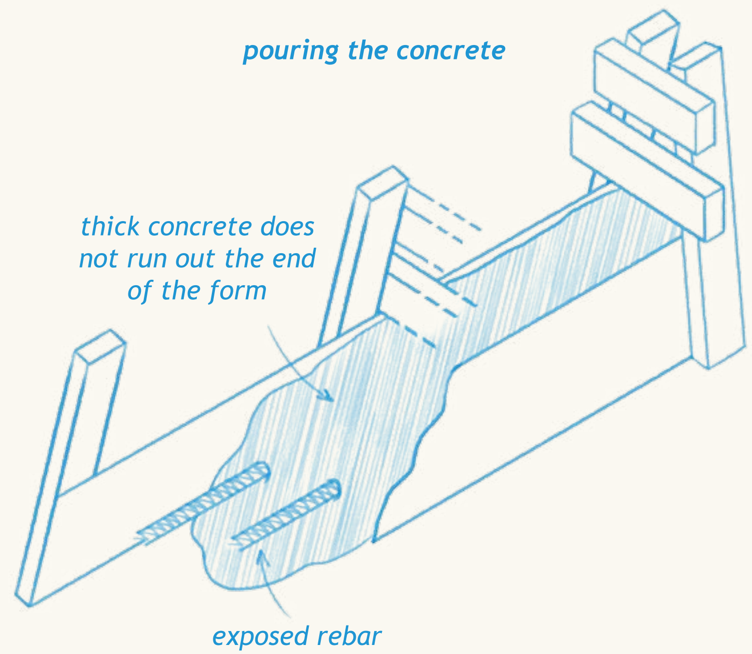


Earlier, when the rebar was driven down through the earthbag walls, about 6 inches was left exposed above the top course. This way, when the concrete was poured, the rebar was incorporated into the bond beam, increasing the rigidity of the entire building. Rebar was also run horizontally along the entire length of the walls, propped up so it would be suspended in the poured concrete of the bond beam.



Once the forms were fitted over the earthbags, all the gaps were filled. Large gaps were stuffed with pool noodles and the smaller holes filled with spray foam. When the foam had firmed up, the concrete was mixed and poured into the form.

Since the crew wouldn't be able to complete the entire poured beam in one day, they made sure not to fill the forms right to the end. By letting the pour taper off near the ends it left some of the rebar exposed. This could then be tied into with the next pour on the following day.



Large sill bolts were set into the wet concrete. These would tie into the PT sill board. Sinking the bolts to the same depth, as well as perfectly vertical, will make life easier down the road.

The bond beam partly completed, showing the embedded sill bolts

Beginning to frame up the top portion

The next day when the concrete had set the forms were unscrewed and popped off, and then positioned over the next section of wall. This procedure was repeated, adjusting the forms for fit, and building up forms for each corner, until a solid bond beam was completed around the entire perimeter.

Switching To Wood

With the concrete bond beam set and firm the team continued with construction. They decided to build the rest of the building with 2 x 10 and 2 x 8 PT lumber for strength and to withstand the Ontario weather a bit better than un-treated lumber, which would have had to be painted. The sill boards, cut to length, were placed on top of the sill bolts and with a tap of the sledge hammer the bolts were imprinted on the bottom of the wood. This marked the sill board so holes could be accurately drilled for the bolts to pass through. Once the sill was hammered down into place over the bolts, nuts were put on the bolts and wrenched down tight to keep the sill board tight against the bond beam.

With the sill board in place the framing carpentry began. Everything was overbuilt where possible, to prepare the roof for the heavy load of soil, moisture and snow which would eventually be on top of it. The walls were then sheathed with exterior plywood and painted to seal them from the weather.

Framing nearly complete


Covering the structure with plywood sheathing

Holes were drilled in each of the walls and a 2” pipe inserted for ventilation. The pipes were long enough to reach the outside air even after the structure was covered with soil. This was to help ventilate the inside of the building, and hopefully prevent moisture buildup inside.

The next step was covering the entire building, walls and roof, with Typar HouseWrap. This is a weather-resistant barrier, which allows water vapour to escape while preventing rain from getting in. The crew chose to also sheath the building with waterproof dimpled plastic membrane that allowed air to circulate between the earth covering the building and the walls. They ran the membrane over the roof and down the sides of the building to the ground and then out a few feet so that water that did run down the side of the building, once it was underground, would be routed away from the walls.

Once the structure was completely covered with the membrane it was time to carefully cover the entire structure with dirt. This was done using the backhoe, and moving around the building, so that the weight of the new dirt would be applied evenly from all sides, rather than piling a large amount onto one side at a time. The surface was finished and evened by hand with rake. The end result was a smooth dirt mound, with little evidence of the large structure below.

Finishing The Inside

The inside of the structure was to be used as a performance space. No plumbing or electrical installation was necessary, but the team did build several skylights into the roof. These were rectangular plywood shafts, built up tall enough to emerge from the earth covering the roof, and covered at the tops with Plexiglas. Inside, the rectangular openings were shuttered and rigged to a pulley system, allowing them to be opened or closed easily from within the building in order to control the lighting. The walls were parged in concrete and then painted. Designer Angela Thomas built four installations within the four bays of the building.


A view from the inside of the structure, showing the transition from earthbags to wooden framing

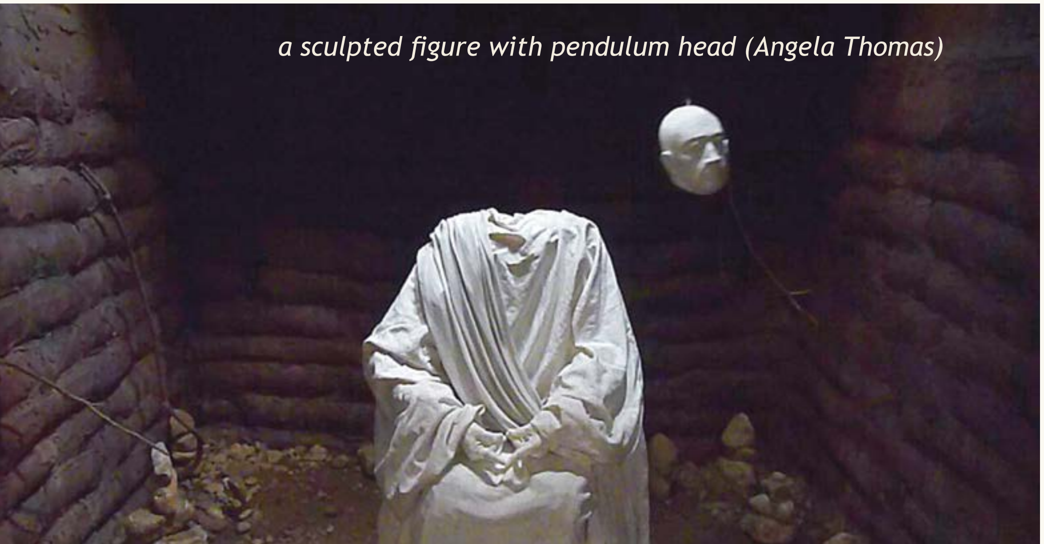

Tony Bergamin as Hermes Trismegistos


Fish sculpture (Angela Thomas)

PERFORMANCE

The Tetrad was used during the Asterion presentation in August 2013 for a series of short performances. As the solitary spectator entered the underground structure, he or she was met in the central space of the Tetrad by a robed performer. This character animated each of the four adjacent rooms with a story/song based on the sculptural installation created in each room. A skylight with shutters, controlled by ropes and pulleys from the central space, illuminated each space in turn.


Theseus' Boat (Maria Michaels-Posidis)


a sculpted figure with pendulum head (Angela Thomas)

CONCLUSION

This process was a true learning experience for the Asterion team. They were not fully prepared for the sheer weight of the workload involved in this process. The project took longer than anyone expected, and required long days of back breaking physical labour in the hot sun. The upper, wood-framed portion of the building meant that costs were not as low as had been originally hoped, since these materials are expensive.

In spite of the drawbacks, there are many situations where this could provide an ideal solution. On a building site that is isolated or inaccessible, where bringing in heavy machinery and large quantities of building materials is impossible, earthbag building might be the most feasible. Feed bags in and of themselves are extremely light and fold flat when they are empty. They transform into building materials by nature of their interaction with the landscape itself – the existing earth. In a situation with a surplus of willing volunteers, but a lack of capital, earthbag could be the solution; the materials required to build an earthbag construction are minimal and the cost basically negligible compared to other techniques. If your labour is free, this could be perfect for you. A design that calls for wide, curved walls, archways, and rounded windows could benefit from the earthbag technique. The ability of this method to create curved wall and ceiling shapes is inspiring and unique.

The use of existing materials was a defining factor in the decision of the Asterion team to build using earthbags, and worked to their advantage. The structure was very strong, and built to last. The technique was particularly suited to underground building, since the earth used in construction is not vulnerable to moisture damage or variation in the temperature of the ground. The interior of the structure remained cool in hot weather. The acoustics within the building were quiet and somewhat muffled or muted, creating a distinct ambience, which enhanced the performances there.


The buried Tetrad structure seen from outside

Bibliography

Geiger, Owen. Earthbag Building Guide. 2011. PDF file,
www.earthbagbuilding.com

Performance Credits

Artistic director: Jerrard Smith
Visiting artist/Tetrad: Angela Thomas
Lighting: Chris Clifford
Costume: Denis Huneault-Joffre
Hermes Trismegistos played by Tony Bergamin

Tetrad Construction Crew

Max Evans
Simon Zaborski
Jonas Bonnetta
Jenny Balch
Aidan Shenkman
John Gunner
Gabriel Baribeau
Craig Spence
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