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Re-Fashioning Earthbag Construction: Engaging Textile Waste Through Flexible-Formed Modular Rammed Earth Construction

To reduce the reliance of earthbag construction on polypropylene, an environmentally detrimental material, and simultaneously address the urgent issue of fast fashion waste, this research explores the suitability of using earthbag construction to reduce postconsumer clothing waste in landfills. Three approaches to generating new earthbag geometries were explored using sewn domestic craft: alternate modular arrays, free orientation in the wall, and recycling from existing forms. Prototyping led to refining a methodology for sewn earthbag production and developing five new earthbag wall textures. The paper concludes with suggestions for advancing earthbag research beyond the coiled tube and running sack typologies, highlighting the performance and parametric potential of modifying earthbag containers and potential applications in areas where formal textile recycling infrastructure is lacking.

◁ Opening Figure. Top view of the Surprise-Star prototype earthbag aligned in a grid, sealed with clips. (Credit: Tiffanie Leung for all figures unless otherwise noted.)

Keywords: Do-It-Yourself Construction, Sewn Earthbag Construction, Domestic Craft, Alternative Earthbag Containers

Introduction

Earthbag construction—low-cost, low-skilled local construction—desperately needs innovation. Unlike Nader Khalili's CalEarth constructions, which utilize continuous tubular earthbags, conventional earthbag construction has not evolved as rapidly as other construction materials. On the other hand, the field of fabric, bags, sewing, and textiles is constantly changing in the form of clothing and shoes, as well as architectural textiles and lightweight construction. Contemporary earthbag construction utilizes tubular forms, such as Superadobe, which coils upward during the erection of a dome made from compressed earth, contributing to its resilience against earthquakes and fire (Hunter and Kiffmeyer 2004, 9). It has been compared to additive manufacturing in terms of the manual placement of material in a single line, also known as "manual 3D printing." Despite this, the architectural form of earthbag construction has not expanded beyond rectangular structures and corbelled domes, resulting in a copy-and-paste approach to earthbag structures worldwide. While infill earth mixtures vary depending on geography, the form remains the same, resulting in aesthetic and structural redundancy in earthbag construction. Consequently, the resulting forms are not appropriate for different contexts. For instance, the Aga Khan Award for Architecture recognized Khalili's Superadobe dome shelter design as a potential temporary housing prototype in 2004—the proposal identified that domes have an "Islamic" sensibility (Kamal and Rahman 2018, 15) and can be suitably used by refugees, but this is not the case universally (Bejtullahu and Morishita-Steffen 2021, 268–69). The resulting forms are redundant and contradict the inherent flexibility and crafty spirit of the earthbag construction practice. The research presented in this paper begins to challenge conventional earthbag construction field assumptions by proposing alternative geometries and materials that can be more sustainable and flexible than the norm. The reduction of earthbag scale and expansion of container shapes facilitate an evaluation of alternative wall assembly methods, while substituting textile waste as bag material recalibrates earthbag construction's circularity away from plastics and towards reducing the amount of used clothing that ends up in landfills.

What is Earthbag Construction?

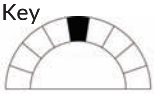
Earthbag construction is a stack-building system that utilizes virgin plastic bags (such as sandbags or similar flexible containers) for modular stacking, compression, and in-place curing of earth mixtures. Barbed wire is laid between each course to enhance the tensile strength between bag-to-bag interfaces (Khalili and Vittore 1998, 26). Also recognized as sandbag technology, earthbag construction conventionally uses two types of bag geometries: rudimentary sacks and CalEarth's coiled tubular bags, shown in Figure 1. Filled earthbags vary in weight from 50 to 100 lbs. (22.6 to 45.3 kg) and are often stacked in a running course (Hunter and Kiffmeyer 2004, 21–22). Notably, 50 lbs. (22.6 kg) is the maximum lifting limit suggested by OSHA, highlighting how the earthbag's weight makes construction less accessible to builders of all body types. The bag itself gives form to earthbag structures, oftentimes wrapping around or over spacers in the wall for window and door openings. Unlike other modular earth systems, earthbags are malleable and do not need to last within the wall (Khalili and Vittore 1998, 26).

Existing bagging techniques in earthbag construction utilize the plasticity of soil and earthbags through molding, as highlighted in Table 1. In conventional earthbag construction, additional tools are used to manipulate the bagging geometry: a wedge box is used to compact bags into wedges for arches, and forms fill in the negative space for openings in the wall (Hunter and Kiffmeyer 2004, 41). Alternate non-bagging materials conventionally used in earthbag construction are earth infills that vary depending on the environment (Hart 2018, 15–21), barbed wire to improve tensile strength, rebar for securing earthbags together for improved seismic stability (Geiger and Zemskova 2015, 87), and chicken wire to improve plaster adherence on the wall (Hunter and Kiffmeyer 2004, 26–27).

In a contemporary context, earthbag construction addresses three key issues: the global housing deficit, displacement of people, and resource scarcity (Geiger and Zemskova 2015, 81). It has also found traction in do-it-yourself construction communities as an easy-to-pick-up building method (low-skilled, high labor). Compared to other wall systems, such as wood frame, steel, and concrete, earthbag construction is more affordable—plastic earthbags are inexpensive in bulk, and earth is typically available for free on the building site. Economically, earthbag buildings can serve as an affordable housing option. Likewise, as reflected in CalEarth's Aga Khan proposal, earthbag construction can be a temporary shelter in humanitarian relief efforts. Assembly is quick and simple (albeit labor-intensive), and the bags can be just as easily disassembled at the end of their use. If cement isn't used to stabilize the earth's infill, emptying the earthbags upon disassembly will return the earth's material to the planet. The longevity of earthbag structures can be extended through regular maintenance, particularly with mud plasters that adhere to the bag surface and can be easily reapplied or repaired, as shown in Figure 2.

According to Merriam-Webster, *fashion* means giving shape or form, usually with careful attention or using imagination and ingenuity. The bags can be molded and shaped using conventional earthbag construction methods to mimic traditional masonry geometries, such as blocks and keystones. Additional forms—primarily constructed frames or creative bucket substitutes for openings and pre-tamping bag finishing techniques to smooth bag corners (also known as "diddling")—are common in earthbag construction. All these elements can be considered a part of the fashion and fashioning of earthbag construction. *Fashion* (n.) also means the prevailing custom, usage, or style of

Table 1. Existing bagging techniques in conventional earthbag construction practice.

Geometry	Weight	Stacking Methods	Bagging Material	Tools used to create geometry	Purpose in the building methodology
"Block" 	90-100 lbs. (40-45 kg)[1]	Running bond	Woven polypropylene	Tamper	To stack and level each layer
Key 	Less than 90-100 lbs.	Molded (formwork)	Woven polypropylene	Wedge box and Arch form	To secure composite arched openings
Curved 	Greater than 90-100 lbs.	Molded (formwork)	Woven polypropylene or polyethylene[2]	Arch form	To create continuous arched openings
Coil 	Greater than 90-100 lbs.	Coil	Polyethylene	Tamper	To reduce total bag usage and create continuous curved surfaces

Notes: (1) Average weight of a filled and tamped standard 50-lb. bag measuring 17 in. wide by 30 in. long (42.5 cm by 75 cm). A 100-lb. bag would weigh 180-200 lbs. (80-90 kg) (Hunter and Kiffmeyer 2004, 22). (2) Tube-shaped Hyperadobe and Superadobe earthbags are manufactured from woven polyethylene (Hart 2018, 14).

something. Within the context of earthbags, the current trend in earthbag buildings, which has persisted since their conception, is the use of one-story corbelled domes and buttressed box structures stabilized with cement. Fashion can also refer to the fashion industry, encompassing the production, commercialization, and aesthetic trends that shape the former. This research suggests placing earthbag construction at the intersection of these "fashions" and transforming fashion waste into upcycled earthbag construction.

Motivation

The primary motivation of the research presented in this paper is to explore and celebrate the geometric flexibility of earthbag construction (Figure 3). As noted previously, earthbag construction parallels masonry. Blocks, even those that are standardized, come in different shapes, sizes, and materials. They can be pushed and pulled in a wall assembly and are form-giving. Earthbags, historically, come in various sizes and shapes, outside of the conventional 18 x 32 in. (45.7 x 81.3 cm) 50-lb. bag, notably tubes and large mass bags used for military entrenchments (Hart 2001). Textiles in nature can be twisted, folded, compacted, and pulled into shape. Clay, a natural binder, enables earthen mixtures to exhibit remarkable plasticity. With the bag, earth mixtures can be easily shaped into non-block geometries. Earthbag construction favors bodies with greater physical strength—a smaller module for lifting, carrying, positioning, and handling on-site would extend its purported accessibility beyond the constraints of a coffee can or scooping implement (Leung 2022). By emphasizing the flexibility of textile earthbags, earthbag technology can be refined into a truly accessible building practice that can be integrated into existing waste streams (Figure 4).

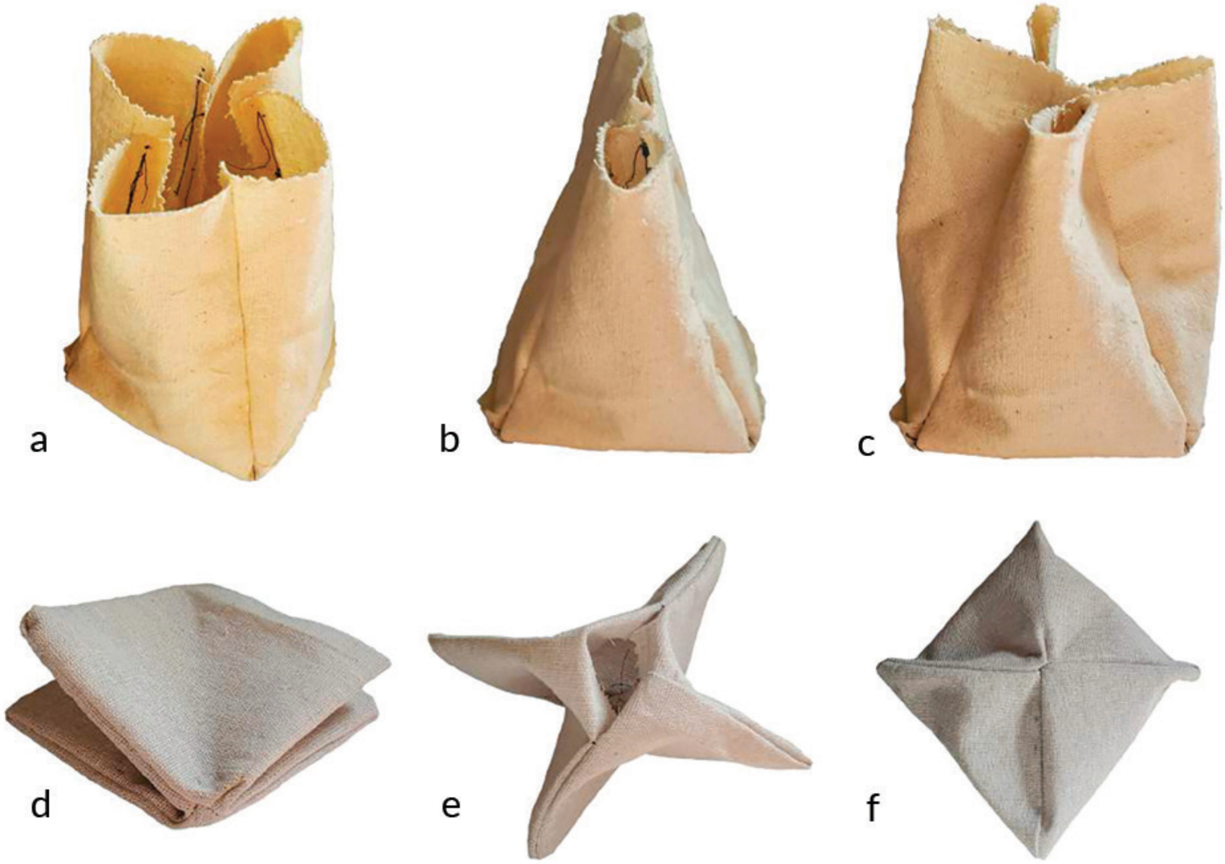
Methodology

In the research presented in this paper, various materials and bag components were recycled from flexible sheets and supplementary parts, such as tarps, textiles, and strings. The materials were medium-duty polypropylene tarps with double-layered heat-adhered layers and twine. More recent prototypes were recycled from post-consumer clothing and sewn into new geometries. Depending on the quality of the materials acquired secondhand, they required post-collection treatment or cleaning to ensure sterility. The materials were then classified by fabric type and organized to produce bags. To reduce the total lifting weight of earthbags, preliminary prototypes of smaller scale and weight than the conventionally used 50-lb. (22.67 kg) and 100-lb. (45 kg) dimensions were prioritized. Weight, ease of bag assembly, and adjustments to the earthbag construction methodology were noted.

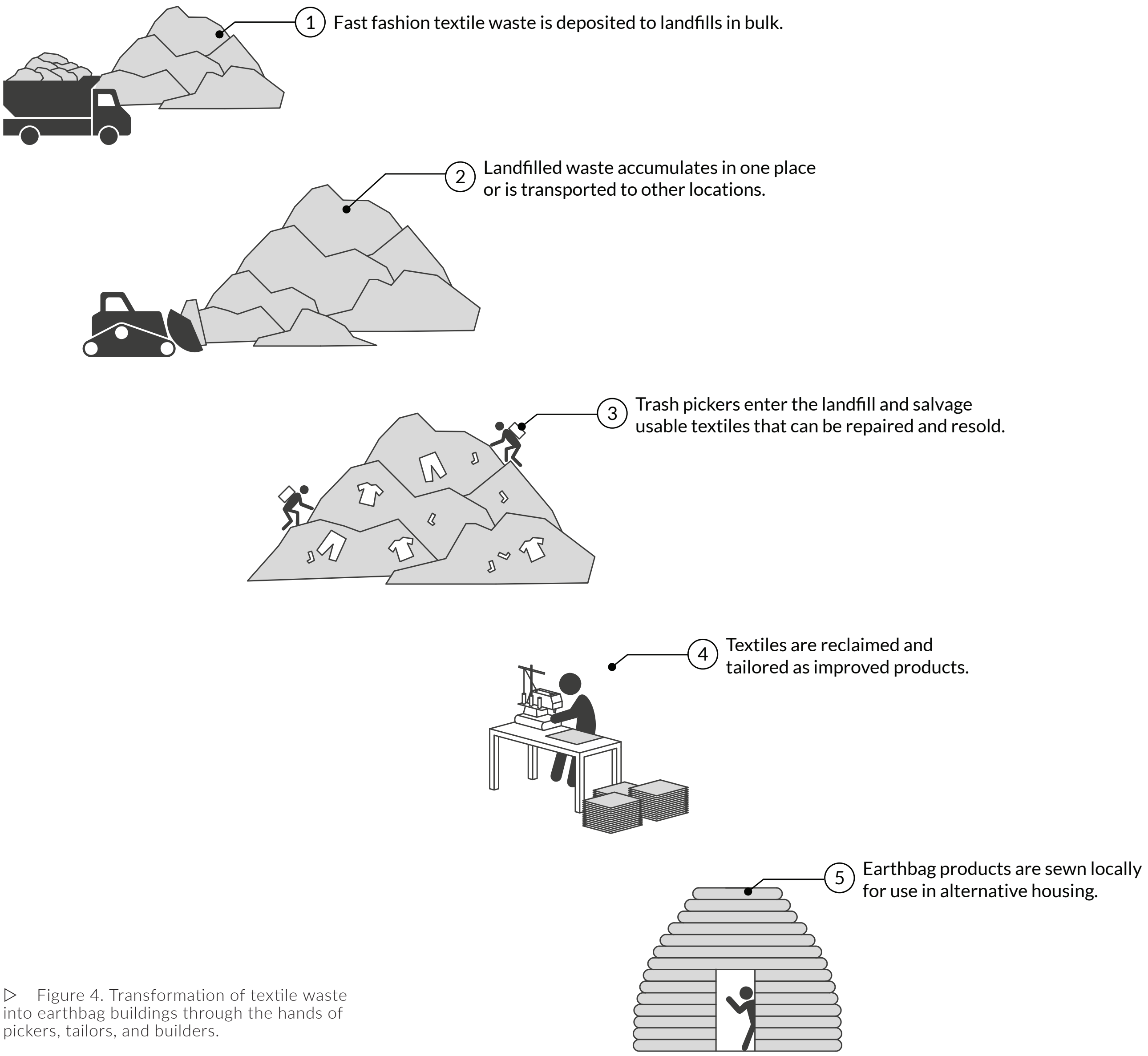
Modifications to the existing earthbag geometry involved a series of geometric adjustments, or "tailoring," to the unfolded form and prototypes of additional parts, such as drawstring and handle components. Changes to the existing earthbag into new geometries encouraged adjustments to the earthbag construction methodology—for example, adding a handle or a noninvasive opening for vertical reinforcement that does not penetrate the earthbag protective layer. Likewise, such additions essentially embedded practice into the bag—changes explicitly responded to existing earthbag construction methodological conditions. Downsizing the earthbag decreased the weight lifted above a builder's head and/or made lifting less laborious. Also included in this category is the introduction of parts to eliminate or optimize specific steps in the earthbag construction process. For instance, a Bi-cinch bag prototype was modified to self-seal using its weight and be actively flipped into different configurations on the wall; this is contrary

△ Figure 1. Construction of the Eco-Dome. (Credit: CalEarth Institute.)

△ Figure 2. Applying plaster to an earthbag home. (Credit: Kelly Hart.)



△ Figure 3. Bag container geometry studies, playing with configurations of standard (a) four-sided box shapes, as (b) wedge and (c) pinched with cotton material. Canvas tarp variants of the Surprise-Star prototype explore (d) the module in a flattened state, (e) pinched openings, and (f) expanded in plan.



① Fast fashion textile waste is deposited to landfills in bulk.

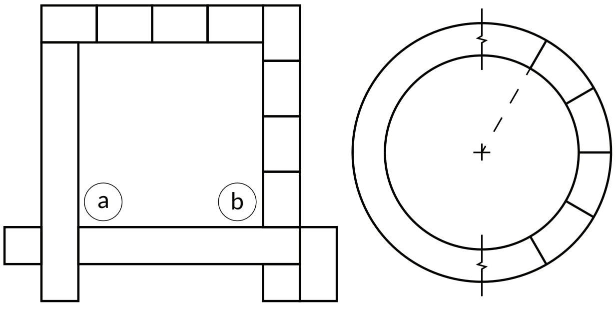
② Landfilled waste accumulates in one place or is transported to other locations.

③ Trash pickers enter the landfill and salvage usable textiles that can be repaired and resold.

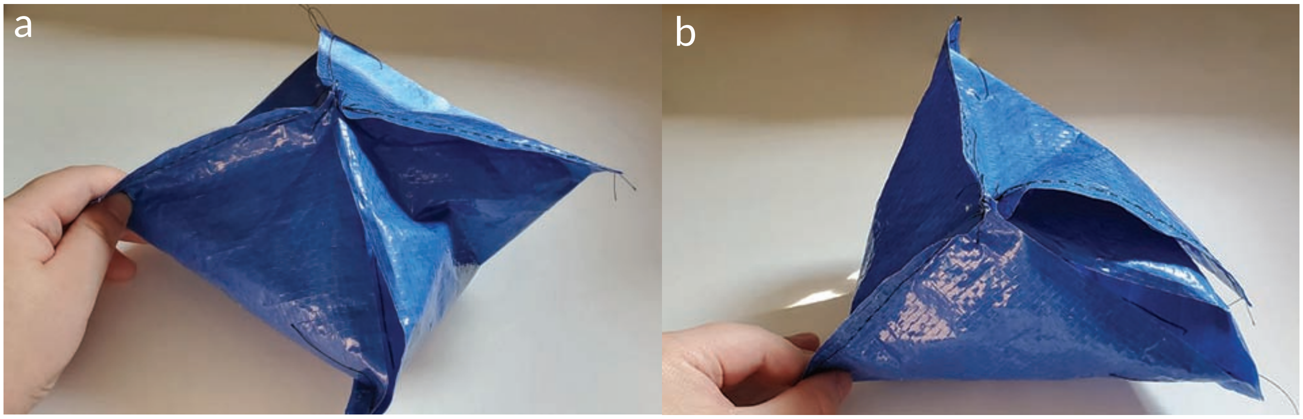
④ Textiles are reclaimed and tailored as improved products.

⑤ Earthbag products are sewn locally for use in alternative housing.

▷ Figure 4. Transformation of textile waste into earthbag buildings through the hands of pickers, tailors, and builders.



△ Figure 5. Conventional earthbag building layouts use bag and tube geometries. (Left) Corner reinforcement for rectangular structures includes (a) interlocking and (b) padded corners. (Right) Circular layouts for domes can consist of discrete bags or continuous coils.



△ Figure 6. Earthbag prototypes: (a) (S-4) Four-pointed star geometry bag prototype, (b) (S-3) Three-pointed star geometry prototype.

to conventional earthbag construction, which staples, stitches, or overlaps the earthbag in a particular configuration.

New Geometries

These investigations produced three approaches to alternate earthbag construction geometries, each focusing on addressing changes to stacking and earthbag materiality. The first prototype examines modifications to the planar array of earthbag modules, diverging from conventional courses and curves in sack-shaped and coiled earthbags. Earthbag structures are conventionally circular, rectangular, or a hybrid of these geometries in plan, tamped flat, as shown in Figure 5. Bags are laid in a line that makes up the perimeter of the building (Wojciechowska 2001, 33–34). Exceptions to the single-bag layout include corner configurations that utilize additional layers of earthbags to enhance the wall's mass for reinforcement (Geiger and Zemskova 2015, 88). The first prototype replicates old configurations with an octahedron bag and explores new arrangements.

The second prototype explores freedom in in-wall configurations and enables the earthbag placements to be rotated. In conventional earthbag walls, bags are dominantly arranged in a running bond for stability (Wojciechowska 2001, 54) and to prevent soil spillage—the ends of the bags are folded, pinned, and butted against existing bags to seal the earth on each layer. Hyperadobe and Superadobe earthbags, which utilize tube earthbags, are stacked in an elongated formation (Hart 2018, 37). The second prototype explicitly introduces an alternative method of sealing the bag, allowing builders to rotate the geometry freely.

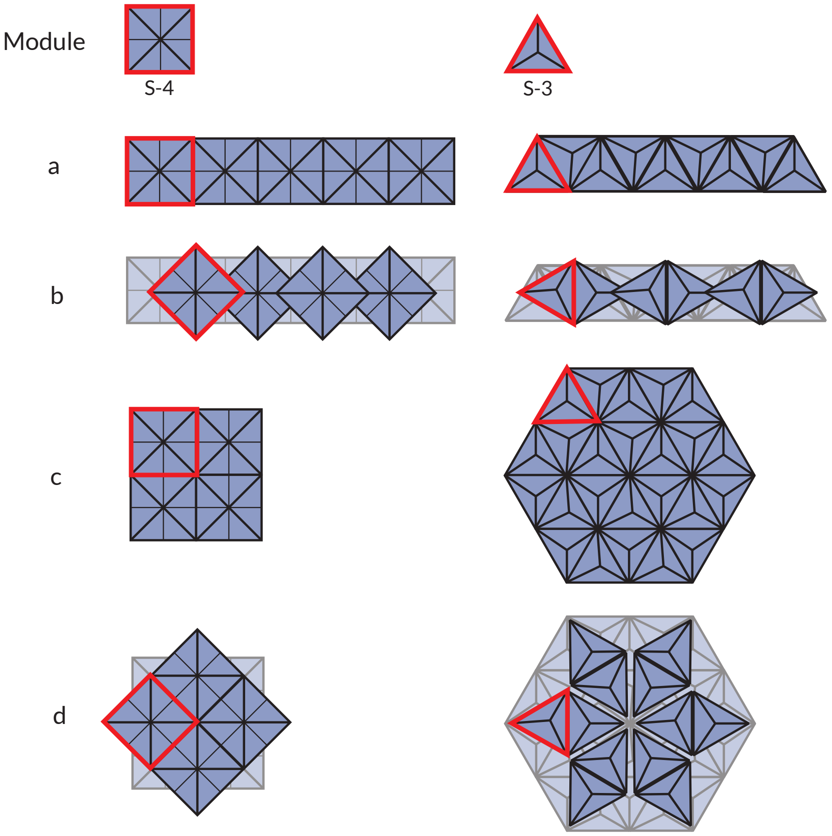
The third prototype concept investigates new earthbag geometries that respond to the material from which they are derived, which may or may not be a sheet or conventionally bag-shaped geometry. As discussed in Table 1, conventional geometries are typically polypropylene or polyethylene bags, which are manipulated with tools and external forms. The third prototype investigates earthbags derived from recycled clothing and the subsequent irregularities in shape, size, and material behavior associated with worn garments and apparel.

Prototype One: Surprise-Star Earthbag Arrangements

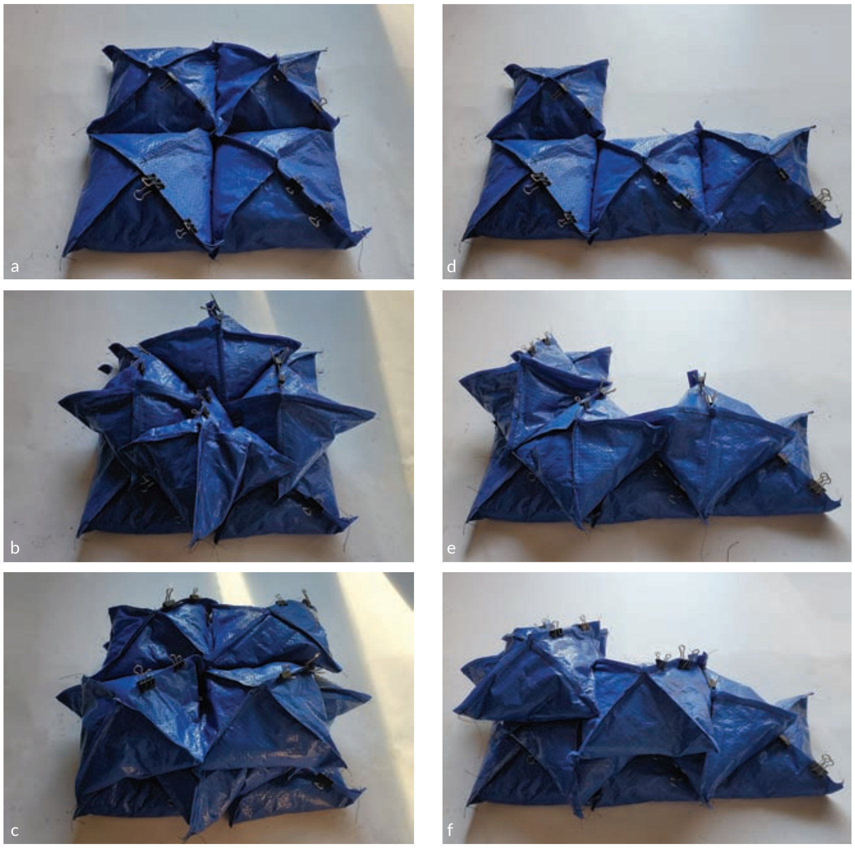
The Surprise-Star prototype is an earthbag that can be configured into a three-point (S-3) or four-point (S-4) star geometry, taking advantage of the flexibility of the bag material to freely manipulate the bag using folds and overlapping sheets, as shown in Figure 6. The basic four-point shape can be constructed by sewing adjacent sides of a rectangular sheet, resulting in a flexible container cradling subsequent earthbags in a stack. Initial Surprise-Star prototypes were sewn from medium-duty polypropylene sheets commonly used in outdoor-rated tarps. When filled with earth, the bags puff out to form a rounded square or triangular profile, allowing them to nestle new earthbags in the valleys of adjacent bag-to-bag connections, as shown in Figures 7 and 8. This result contrasts with the conventional pattern of laying earthbags, which involves running bonds or coils and changing the module of the earthbag both in the plan and top-down earthbag interactions. Not only does this alternate form shift how the modules are placed side-to-side, but it also suggests an alternative way of interlocking earthbags on top of each other—the polyhedral shapes of the S-4 and S-3 geometries indicate a means of securing earthbags between earthbags and reduce reliance on barbed wire during the wall assembly process (Figure 9). Although the shape of the disengaged earthbags will warp out from the forces of the earth inside the bags, if compacted and cured within the negative form of these shapes, the earthbag can be hardened into such geometries, much like keystones and wedges in conventional earthbag construction. The Surprise-Star geometry was fabricated at a quarter of the traditional scale of the earthbag.

Prototype Two: Bi-Cinch Earthbag Wall Textures

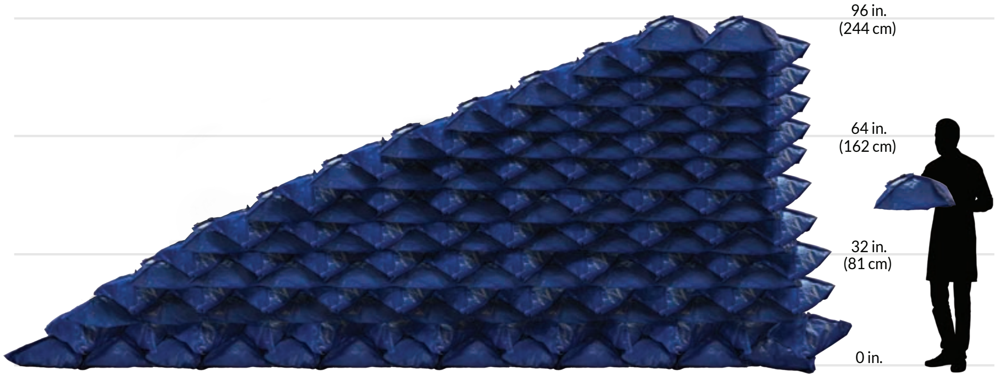
The Bi-cinch earthbag is a conventional earthbag sack shape modification created by introducing a crease at its midpoint. When sewn from moderately stiff fabric, such as polypropylene tarp (Figure 10), the Bi-cinch prototype can be propped open on the ground or hung from its center to make it easier for builders to fill the bag without the use of a conventional bag stand, which must be constructed separately. Instructions for welding and building a bag stand are available in earthbag guides; it requires technical skill supplementing the earthbag construction method, falling outside of the scope of simply digging, filling, and stacking bags of earth (Hunter and



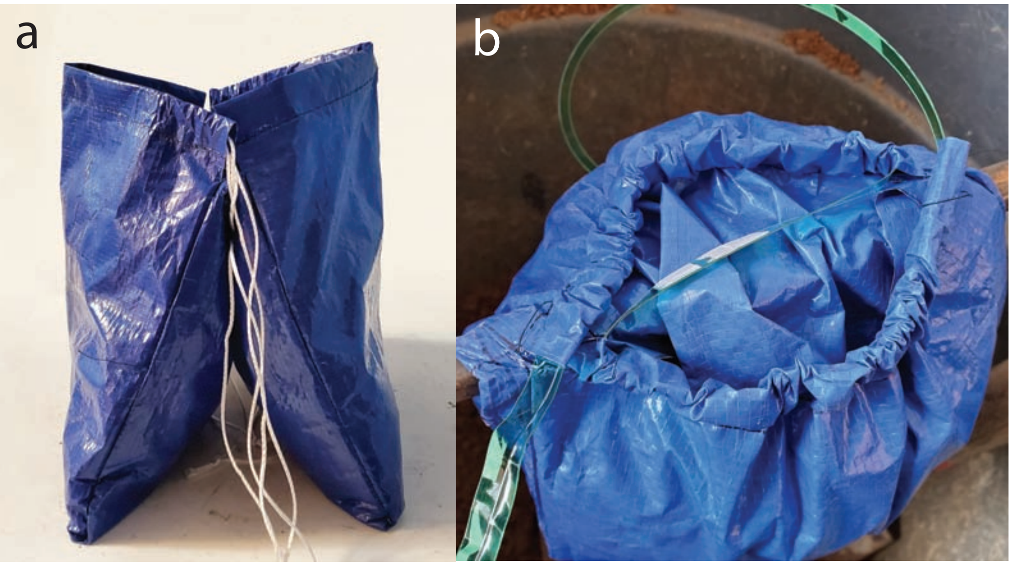
◁ Figure 7. Plan configurations of four- and three-sided earthbag modules (red) in a line and grid layout: (a) one-course line, (b) two-course line, (c) one-course grid, and (d) two-course grid.



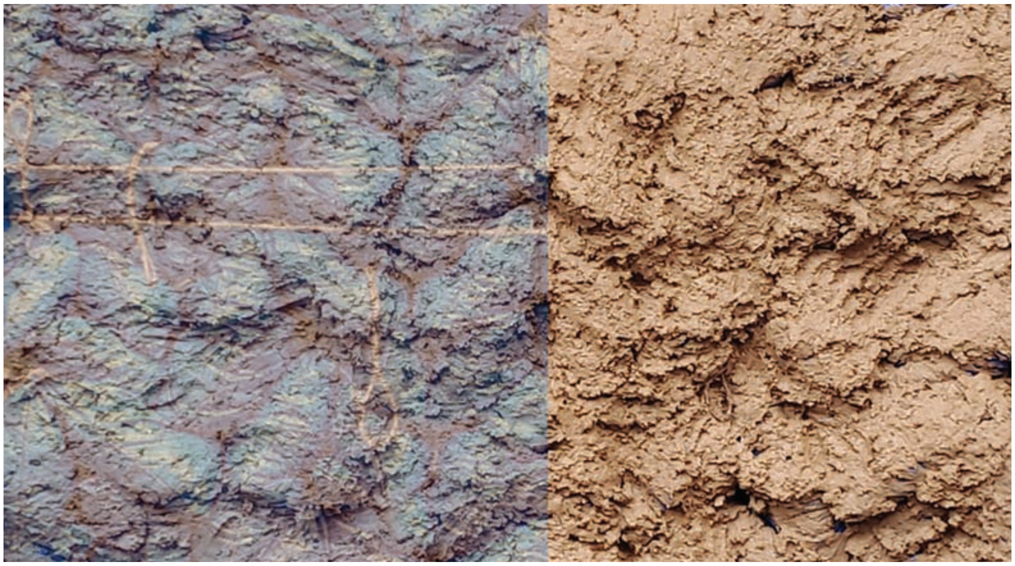
◁ Figure 8. S-4 earthbag displacement in box and corner configurations: (a) one-course box, (b) two-course box, (c) three-course box, (d) one-course corner, (e) two-course corner, and (f) three-course corner.



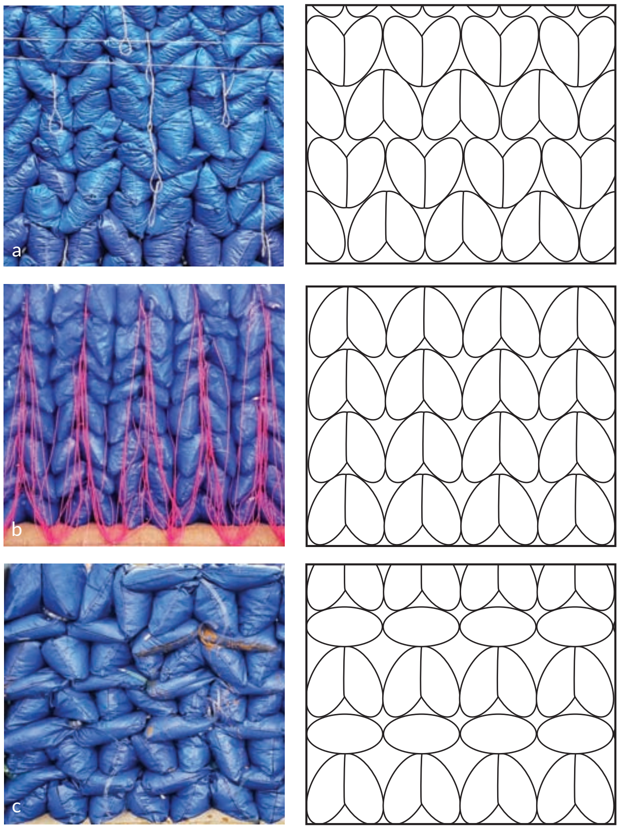
◁ Figure 9. (S-4) Conceptual wall elevation and texturing.



◁ Figure 10. Bi-cinch bag prototype: (a) can stand on its own without the use of a bag stand, and (b) self-seals when modified with an extra flap for the opening.



◁ Figure 11. The alternate earthbag geometries in the Bi-cinch wall resulted in a bumpy textured earth surface when rendered with clay plaster.



△ Figure 12. Wall textures from the Bi-cinch prototype in (a) running bond with upside-down courses, (b) stack, and (c) unfolded orientations.

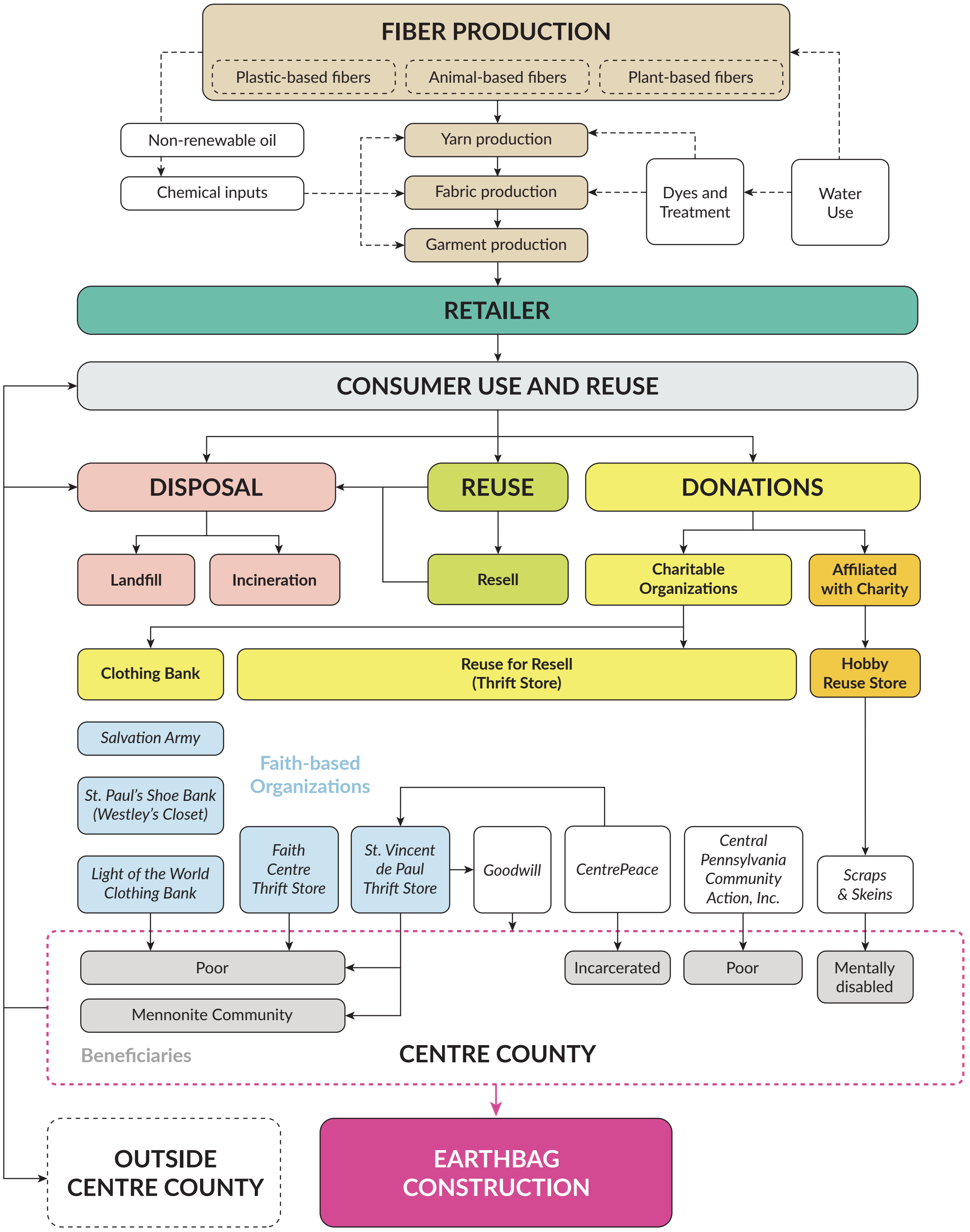
Kiffmeyer 2004, Ch. 3). The addition of a drawstring in the new opening allows the bag to be lifted by the string and simultaneously sealed. A flap material can cover the opening and effectively seal the bag, allowing no earth infill to spill out when it is rotated and turned upside down. In conventional earthbag construction, bags are either sealed by folding the ends underneath other bags, twisted, stapled, or nailed shut. As a result, the earthbag's performance as a container depends on its orientation in the wall and the existing modules in the assembly. The ability to freely manipulate the earthbag container within the wall opens the façade design of earthbag structures to be more creative, as shown in Figure 11. When folded and filled, the Bi-cinch earthbag transforms into an earth container that can be manipulated into an A, V, or unfolded flat orientation. Bags can be placed between the crowns of previous layers and nest in the valleys within each course, as shown in Figure 12. Given the earthbag's flexibility, the modules can also be treated as space-filling containers to fill in gaps, offering alternative textures to the earthbag wall that cannot be observed in earthbag structures made from coiled tubes and sack geometries.

Prototype Three: Earthbags Made from Postconsumer Clothing

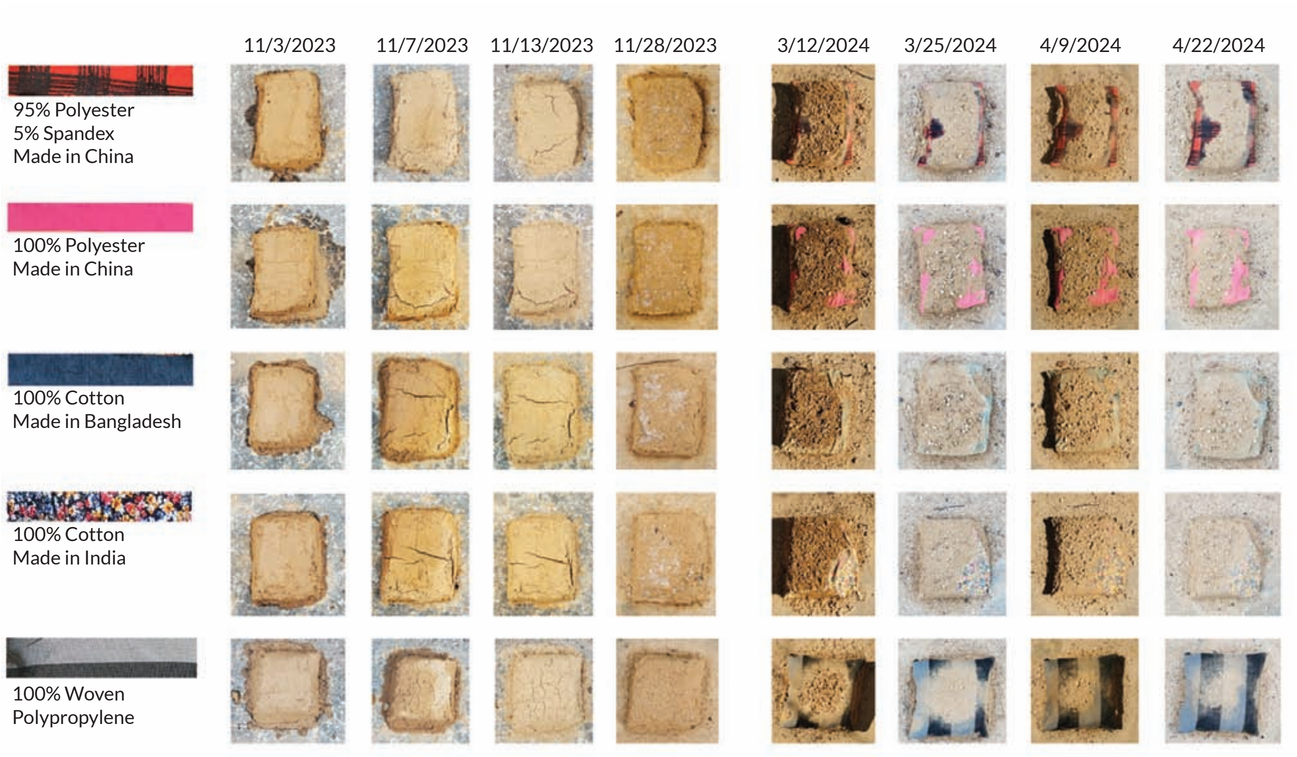
The third geometry innovates the earthbag's materiality while addressing the wastefulness of the global clothing industry. In a study by the Environmental Protection Agency, the United States generated 17 million tons (15.4 metric tons) of textile waste in 2018, recycled only 14.7% of this quantity, combusted 18.9%, and disposed of the remaining 66.4% in landfills. Considering that approximately 3,000 liters (792.5 gallons) of water are needed to produce one cotton shirt and around 8,000 liters (2,113.3 gallons) for a pair of jeans (Rao 2019), a significant amount of our natural resources is wasted when clothing is discarded. Framed within an overabundance of textile waste generated by fast fashion and an urgency to salvage the wasted resources of clothing production (such as water), earthbag prototypes recycled from post-consumer garments necessitated an earthbag production methodology that leverages the clothing's existing geometry rather than fashioning new geometries from scratch. Conceptualizing clothing as containers for the human body, it is not a stretch to consider clothes as alternative containers for the earth. Pants, for instance, possess two tubes to cover the legs, which can be separated (or not) into long earthbag geometries. Depending on their size and dimensions, the shirts and tops can be sewn shut or divided to create earthbags by simply sewing the ends together. This process is more straightforward than cutting out a specific earthbag shape from a sheet and reduces the amount of unused textile waste from cutting out pieces of cloth.

Circularity is celebrated in earthbag construction, not only in the use of earthen materials but also in the bag itself—for economic considerations, using misprinted feed bags or burlap containers are suitable alternatives to purchasing commercial store bags (Wojciechowska 2001, 43–46; Hunter and Kiffmeyer 2004, 21–24). Likewise, expanding the scope of alternative earthbag containers to clothing builds upon the adaptability of earthbag construction practices and addresses an urgent need to reduce textile waste in landfills. The same qualities that make nondegradable postconsumer fabrics ecologically problematic in landfills can be seen as positives in an earthbag wall section. The fabric materials were reclaimed from a grassroots textile recycling system in Centre County, Pennsylvania, shown in Figure 13. The mud render sampling shown in Figure 14 highlights the variety of recycled textile materials. It provides a brief glimpse into the global sourcing of textile materials, with some clothes being manufactured overseas.

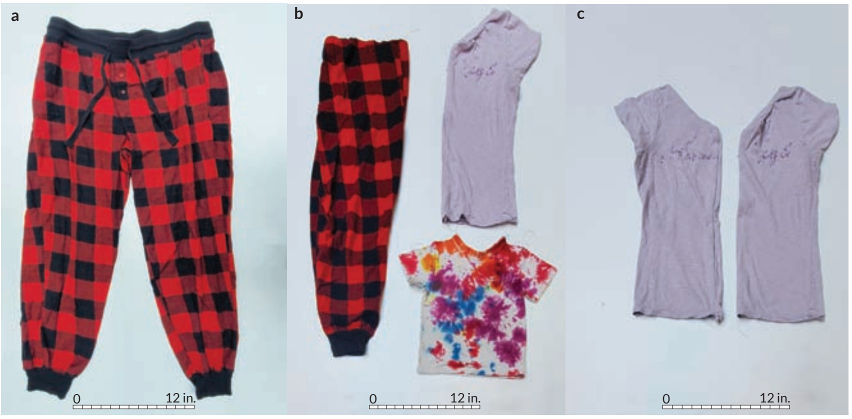
The garment earthbags ranged in width from 8 to 10 in. (20.3 to 25.4 cm) and had varying lengths, depending on the size of the original garment, as shown in Figure 15. An initial earthbag wall prototype was filled with Hagerstown soil, which has a texture of 60% sand, 10% silt, and 30% clay. The ideal sand-to-clay ratio is 70-75% sand to 25-30% clay (Hunter and Kiffmeyer 2004, 15), so sand additives were mixed into the earth and moistened before compaction. The first two rows, which totaled 4 in. (10.1 cm) in height, were filled with gravel to account for the wet climate. Earth-filled earthbags made from garments measuring 10, 20, and 30 in. (25.4, 50.8, and 76.2 cm) in length weighed 9.3, 28.3, and 42.5 lbs. (4.2, 12.8, and 19.3 kg) respectively, which is lighter than the average weight of conventional bags at 90–100 lbs. (40.8–45.3 kg). Each layer was tamped to a 2 in. (5.08 cm) thickness and exhibited varying degrees of stretch when compacted. As shown in Figure 16, a strand of four-pointed barbed wire was laid between each row and held down with cords made from salvaged waistbands from pants.



◁ Figure 13. Texture circularities in Centre County, Pennsylvania, modified from Weber (2015, 28). Clothing is not included in the municipal recycling mandate and is categorized as solid waste in the region.

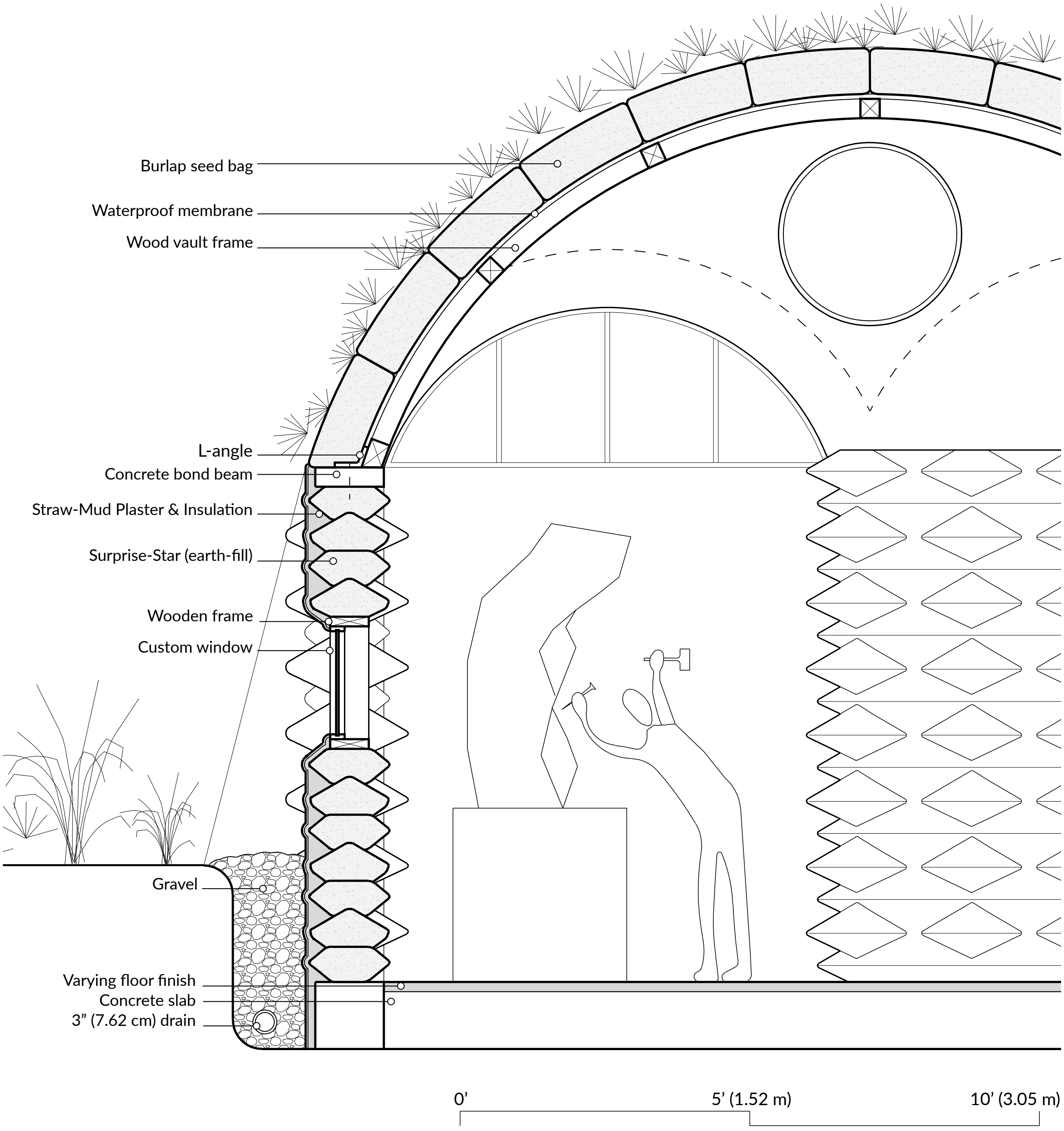


△ Figure 14. Weathering samples of clay plaster on various textiles salvaged from postconsumer garments.



△ Figure 15. Size comparisons between: (a) adult large pants, (b) medium top, and (c) child small shirt.

△ Figure 16. Pillow Earthbag wall prototype featuring an earth-infill with a sand additive. Recycled elastic waistbands tie down the barbed wire in between each layer, using bricks as weight.



△ Figure 17. Conceptual section drawing of S-4 earthbags used to accentuate the walls of an artist’s work residence.

◁ Figure 18.
3D models of alternate earthbag geometries and materials through photogrammetry.

Broader Impact

In the early stages of the research, machine-facilitated sewing techniques were used to manipulate the earthbag form before it was engaged with the earth and during the wall assembly process before on-site practice. Developing the aesthetics of earthbag structures beyond the box, vault, or dome aims to shift the perception of earthbag construction from a cheap and undesirable alternative for the poor to a refined and visually interesting construction methodology. Barriers to earthbag adoption in new contexts include this negative perception, unawareness of the method, and lack of governing support (Adetooto and Windapo 2022, 13). Pushing earthbag construction into more complex forms proposes a shift in the conceptualization of the "earthbag" shape and material, which has long been constrained by the traditional bag or tube. As shown in Figure 17, changing the bag's shape provides a distinct spatial experience by introducing unique texturing not previously seen in earthbag construction. Different earthbag shapes also open considerations for using recyclable textile materials in various forms. Despite most research focusing on using woven polypropylene or sandbag technologies made from plastic, alternative materials for earthbag construction offer a more sustainable and environmentally friendly option for earthbags, envisioning more environmentally conscious earthbag structures. An earthbag production process that transforms secondhand clothing into bags suggests integrating earthbag construction into circular streams for textile disposal or recycling. Can textile waste and/or post-consumer clothing be used for earthbag construction? Can earthbags be a suitable alternative to unwearable textiles, rather than bundling them with municipal waste and filling the landfill? Could earthbag construction respond to the unsustainable production of fast fashion products, thereby preventing wearable yet out-of-fashion textiles from entering landfills?

An earthbag construction methodology that uses post-consumer textiles to build spaces has the potential to reclaim usable textiles from our waste streams. Recall that the United States landfilled 66.4% of its textile waste in 2018, totaling approximately 11.2 million tons. To break down this amount even further, according to the EPA Office of Solid Waste, 68 lbs. (30.8 kg) of clothing and textile waste are discarded per person per year in the United States (Claudio 2007, A451). Assuming their reusability, converting textile waste to earthbags would suggest that 68 lbs. (30.8 kg) of earthbag material can be supplied per person in the country. Additionally, recall that 14.7% of the United States textile waste was recycled or

Table 2. The mechanical properties of polypropylene, polyester, and cotton.

Material	Ultimate Tensile Strength (MPa)	Yield Tensile Strength (MPa)	Elongation at Break (%)	Modulus of elasticity (MPa)
PP (fiber grade)	17.8 - 312[1]	15 - 45[1]	15 - 72[1]	650[1]
PP (fabric sheet)	-	28 ± 1.5[4]	75 ± 4.75[4]	338 ± 25[4]
Polyester	22 - 95[2]	55 - 260[2]	5 - 120, 2 15[3]	15, 6.9 - 20.7[3]
Cotton	20 - 41[2]	287 - 597[2]	7, 6 - 13.5[3]	8, 7.1 - 15.7[3]

Notes: (1) MatWeb n.d. (2) Xometry n.d. (3) Wang and Salmon 2022 (4) Hoque et al. 2018

Table 3. Computational framework for digital earthbag modeling defined by Santos (2020) and López Gómez (2021).

Research	Hybrid dome and linear structure (Santos 2020)	Dome structure (López Gómez 2021)
Data inputs	Bag size Curvature arch Dome radius Quantity of apses Apses distance to center Angle location Rotate Apses Calculus logic	Sack dimensions Radius of roof (external compass) Radius of base (internal compass) Radius of skylight Dimension of openings Mean specific weight Mean material elastic modulus Mean friction coefficient between rows
Desired outputs	Quantity of the compound Mixture of earth Quantity of bags Total length of barbed wire Total surface to plaster	Dimensions Building height Interior habitable area Proportion of rows resting above previous rows Total building weight Maximum shear force amongst all rows Axial stresses
Technical basis	Hunter and Kiffmeyer 2004 Hart 2018 Geiger 2011 Hart 2015 Wojciechowska 2001	Jain 2013 Canadell et al. 2016 Santos and Beirão 2019 A series of online and practical workshops by *Rammed Earth Solar Homes*, *Domoterra*, *EcoNest*, *CobWorkshops*, and *CalEarth*

entered circular material streams, totaling approximately 1 million tons. Considering that 20% of donated clothing is generally reused or resold in shops (Claudio 2007, A452), the remaining 80% of recycled textile waste, namely 800,000 tons of reusable materials, can be recovered for earthbag construction.

Changing the bagging material also has implications for a more sustainable earthbag construction practice. For example, the Pillow Earthbag wall prototype uses garments made from 100% cotton and is filled with an earth-and-sand mixture that relies on clay as a natural stabilizer rather than cement. In an ideal circularity, the cotton shirt will degrade in the sun after the mud plaster falls off or the wall collapses. Because cotton is made from organic fibers, the garment will decompose into biodegradable material, contributing to the organic material stock and benefiting the soil. Without a roof or moisture protection, the earth infill will eventually crumble and return to the earth, giving nutrients back to the topsoil. The remaining material is the barbed wire between the courses, which will rust over time.

Moreover, cotton has greater tensile strength than the polypropylene fabrics commonly used in conventional earthbag construction, as well as polyester, one of the most abundantly produced textile materials in the world, as shown in Table 2. There are also 40 different types of cotton fabrics, varying in density, weight, and weave, that contribute an additional structure not seen in the plastic sandbags commonly used in earthbag construction. Not only would postconsumer fabrics reduce textile waste in landfills, but they could be stronger alternatives to plastic earthbags, which are unsustainable in the long term.

There is also potential for incorporating unique earthbag geometries into current digitization and computing methods for earthbag construction. Current digital modeling research of earthbags includes the integration of BIM and generative design through the CICERO tool (Santos 2020, 128–29) and the mathematical definition of the Superadobe coil-building methodology (López Gómez 2021, 90–91), compared in Table 3. New earthbag geometries, such as those presented in Figure 18, can be captured via 3D scanning technology, replicated, and rearranged in digital wall assemblies. Existing computational earthbag frameworks can be amended to incorporate data inputs for new bag geometries, offering parametric flexibility in designing earthbag structures. Scanned earthbag models can be refined using the dimensions of the sewn sheet components to generate unique geometries (Leung 2023). There is ample opportunity for methodological innovations in earthbag construction within the computational field and in do-it-yourself practices that center on using the earthbag module as a geometrical basis for developing the wall.

Discussion

Investigations into alternative earthbag geometries with various textile materials yielded several expected and unexpected challenges that can be improved or addressed in future stages of research. For instance, when filled with different earth infills, a fabric's elasticity impacts an earthbag's ability to support compaction forces and affects its geometry's distortion beyond its resting state. The Surprise-Star prototypes tended to sink into a flat pack when filled with fine sand, whereas a mixture with more clay, on the other hand, could adhere to the inner walls of the bag, which helped it retain its shape better before being tamped. Regarding tamping, specific geometries and orientations were more conducive to improved translations during downward compaction on the wall. For example, the A and V configurations of the Bi-cinch prototype allowed the halves of the bags to be wedged together.

Meanwhile, a space-packing method using bags to level the course resulted in the ends of the Bi-cinch being more flattened. Both the Surprise-Star and Bi-cinch prototypes were derived from conventional earthbag geometries and, therefore, can be integrated into existing parametric frameworks for digital earthbag design. Parametric tools can optimize future investigations by modifying the data inputs for dome, linear, and hybrid structures. Furthermore, additional research is needed to assess different types of fabrics in terms of their moisture absorption and ability to retain shape. The type of earthbag fabric used affects the wall's breathability and the type of earth used as infill in construction. Burlap bags with coarse weaves were unsuitable for infills containing fine aggregates, such as sand. Polypropylene is moisture-resistant but less breathable (Wojciechowska 2001, 45). The research presented in this paper explored the impact of novel earthbag geometries on stacking patterns and on-site filling practices. Still, it did not consider their effects on the curing period of earthbags during the construction process. The curing period, which ranges from three to four days depending on the climate, influences the stability of the bags as the wall is assembled, as premature exposure to water can degrade the compaction of the earthen wall mass. Understanding how different textile materials, which have varying moisture absorptions, aeration, and wicking properties, can impact earthbag stability would provide insight into a more comprehensive selection of alternative earthbag materials for future research and comparisons.

Data Availability Statement

The authors confirm that the data supporting this study's findings are available within the article or its supplementary materials.

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