EXPLORING THE CRAFT OF SEWING MACHINE-FACILITATED NOVEL EARTHBAG GEOMETRIES

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The earthbag, or flexible-form rammed earth wall system, is a low-tech building system that can be used to quickly erect emergency shelters for disaster relief or, alternatively, to construct "do-it-yourself" homes within the context of self-building construction. Because the required building materials are affordable and the construction method easy to replicate and teach, earthbag construction is more accessible than comparable building systems that require certifications. This study aims to explore the impact of machine-facilitated bag craft on earthbag building processes, with regards to bag production, sewing craft and reducing on-site tooling. Following a literature review, a design-as-research methodology approach with a sewing machine is used to replicate existing earthbag geometries and generate novel geometries, varying in bag material and production process. The first part of the study catalogs bag fabric material behavior when sewn, instructions for sewing existing and new geometries, and selects one novel bag prototype, the Surprise-Star, as a case study for preliminary stacking assessment. The second part of the study catalogs the craft experience of modified earthbag geometries intended to substitute existing tools used on-site, which culminates in an assessment of the feasibility of sewn novel earthbag construction.

Keywords: Earthbag construction, sewing craft, do-it-yourself, earthbag production.

1. FRAMING THE RESEARCH

1.1. BACKGROUND AND RATIONALE

Earthbag construction is a type of rammed earth building method that utilizes the earthbag's material flexibility and capability to support earth as it is transported, stacked, compressed, and hardened on site. The conventional earthbag wall system consists of earth-filled bags that are tamped and strengthened with barbed wires between each course that strengthen the wall's tensile strength (Khalili & Vittore 1998). The bag itself serves as an alternative to traditional wood forms and is easier to replicate and mass produce. In addition to their inexpensive cost, earthbags often utilize locally sourced earth, effectively reducing or eliminating energy use when transporting materials to the building site (Wojciechowska 2001). Due to the simplicity of its construction process, earthbag construction is an affordable and easily replicable building system that can be erected quickly (Geiger 2009). Its quick and simple building methodology makes earthbag construction suitable for responding to disasters. Within the context of craft, earthbag building techniques are passed down by experts in training workshops and "do-it-yourself" guides, making it more accessible than building techniques that require certifications.

Because the earthbag is primarily considered as a container for carrying earth, it is underdeveloped as an architectural element with regard to spatial expression and quality. Currently, earthbag geometries can be categorized into two types: single-unit bags laid in a stacked course, and tube bags that coil in layers (Hunter & Kiffmeyer 2004). The flexibility of the bag material, which varies between burlap and polypropylene fabric, allows the earth to be sculpted into organic forms and domes (Khalili & Vittore 1998). With the aid of external forms, earthbag geometries can be manipulated into curves and keys for arched openings. Sculpting earthbags in this way, however, occur on-site and after the bags have been filled and begets the question: is there a way for the earthbag to be transformed off-site and before the bags are filled? Could this eliminate the need for additional tools, forms, or materials used to construct the earthbag wall on-site?

As a form of craft that is also democratically accessible, machine sewing, in this study, is regarded as the fastening of textile objects together with needle and thread, and the hand-making skill associated with it. The sewing machine is considered in this study as a vehicle of craft accessibility that shares parallels with conventional earthbag construction: (1) both incorporate standardizing tools for democratized use among many types of users, (2) increased usability through adaptive design, (3) teachability to the less-skilled, (4) material variability in craft, and (5) celebration of the user's capacity in hand-operated crafts. This research aims to explore how machine-facilitated earthbag crafting can impact earthbag building processes, with regards to bag production, sewing craft and reducing on-site tooling through the creation of alternate bag geometries.

1.2. METHODOLOGY

Following a literature review of existing earthbag construction guides, which include "do-it-yourself" and emergency applications, explorations on sewing machine-facilitated earthbag geometry were conducted in two parts. The first part focuses on understanding the behavior of fabrics, both conventionally and unconventionally used in earthbag construction, when sewn with a machine. Primary design explorations intended to increase tactile experience in bag-making involved replicating existing earthbag geometries with alternate materials, such as cotton fabric, canvas tarp, medium-duty woven polypropylene fabric, and spandex. Conventionally-used materials, such as low-duty woven polypropylene fabric and burlap are examined in the same manner. After replicating existing earthbag geometries and understanding shape relationships during the bag sewing process, a novel Surprise-Star geometry was generated and selected for further examination for potential application in bag-to-bag stacking relationships, with a focus on understanding how changes in geometry can begin to impact the building construction process and the resultant wall. The second part of the research focuses on earthbag modifications and their feasibility within the scope of "do-it-yourself" construction, with regard to craft difficulty, material consumption, and replicability. Preliminary prototype bags were designed and replicated with a sewing machine, with the goal to specifically reduce on-site tooling, such as eliminating a bag stand, during the construction building process.

2. CRAFTING ALTERNATE EARTHBAG GEOMETRIES

Since fabric weaves perform differently due to variations in thread size, material, directionality, and shape, it was essential to first understand the behavior of the different fabrics when assembling earthbags on the sewing machine. Differences in the physical characteristics of the weave impact how the fabric is cut, handled, and stitched during the sewing process. Within the scope of conventional earthbag construction, earthbags are made from woven polypropylene or burlap fabric (Hunter & Kiffmeyer 2004). Each material possesses its own advantages and disadvantages that impact the construction of the earthbag wall and stitch depending on the fabric weave. For example, the flat weave of woven polypropylene makes the fabric more durable to abrasion than burlap fabric, which is woven from twisted jute string. While burlap fabric is natural and biodegradable, its rounded threads and loose weave makes the fabric unsuitable for holding fine particulate earth fills (Wojciechowska 2001). For the research, conventional materials handled include burlap and low-duty polypropylene fabric. Unconventional fabric materials handled in the research are medium-duty polypropylene and painter's tarp fabric.

2.1. HANDLING AND SEWING EARTHBAG FABRIC MATERIALS

As mentioned previously, burlap fabric is woven from jute string, which is an organic and sustainable material. The loose weave makes single-line stitching less ideal when attempting to sew burlap fabric together. Instead, zig-zag stitching is more appropriate for making burlap fabric earthbags. Compared to polypropylene, burlap fabric is heavier and more expensive (Wojciechowska 2001); the bulkiness of the fabric makes sewn hems and folds thicker and comparably less precise than sewing similar folds on polypropylene.

Low-duty woven polypropylene when cut is easy to unravel, and the material loses its weave when the cut edges have not been sealed. The resulting instability of the fabric's cut edge complicates the sewing process because a consistent stitch cannot be applied to the loosened material. To properly seal the edge, an adhesive layer should be applied to the weave and pressed with heat. Heat must be applied through a flat-press method to hold the weave while the adhesive bonds them together because the polypropylene material tends to contract and crinkle when exposed to heat.

Medium-duty woven polypropylene is the same material as the low-duty material with the addition of an adhesive layer on both sides of the fabric. Because it is made from three layers—woven polypropylene bonded between two plastic adhesive layers, the fabric is more durable when cut and easier to sew together. When cutting with a straight-edge scissor, a seamstress can glide the tool across the fabric with less resistance and catch than the more unstable low-duty version. The flat weave allows many stitches to be applied to seams—for simple sewing, single-line stitches were primarily used when handling this material.

The canvas tarp or painter's tarp is a woven rough cotton fabric with a plastic membrane underside that prevents moisture from seeping through the fabric. The cotton weave is also treated to reduce unraveling and adhere to the plastic membrane, allowing it to maintain its shape when cut. The fabric is easy to sew, lightweight, and, due to the plastic membrane, can hold its shape slightly better than plain woven cotton fabric. This material, however, does not hold its shape as well as polypropylene. Compared to the burlap, the canvas tarp has a tighter and thinner weave, making single-line stitching suitable for sewing it together.

2.2. RE-CONSTRUCTING THE EARTHBAG SHAPE

Another element of the bag construction is the shape of the earthbag, which in this study was geometrically deconstructed and assessed for material consumption. Prior to assembly on the sewing machine, individual parts were measured and cut from larger material sheets. Similar bag geometries were observed to vary in sewing complexity and material consumption, despite having the same dimensions, material, and size. The bag geometries were reproduced at 1:4 scale and the bag dimensions mentioned in this paper will refer to the intended full-size earthbags for the purposes of instruction. Dimensions and same-shape pieces were limited to 45cm (18in) widths and 76cm (30in) lengths, which are derived from the conventional 50lb polypropylene earthbag sizes noted by Hunter and Kiffmeyer (2004) as well as common hessian-bag width by Wojciechowska (2001). Variables include the number of pieces and edge-to-edge connections for each geometry.

The Sack or Pocket geometry consists of two rectangular pieces that are overlayed on top of each other and sewn along three edges. This geometry is the conventional geometry that is used in earthbag construction, both in off-the-shelf products and repurposed items of similar shape (i.e. – animal feed bags or rice sacks). Alternatively, it can also be constructed from a singular rectangle piece that is double the length; a piece that has a 45cm (18in) width and 152cm (60in)

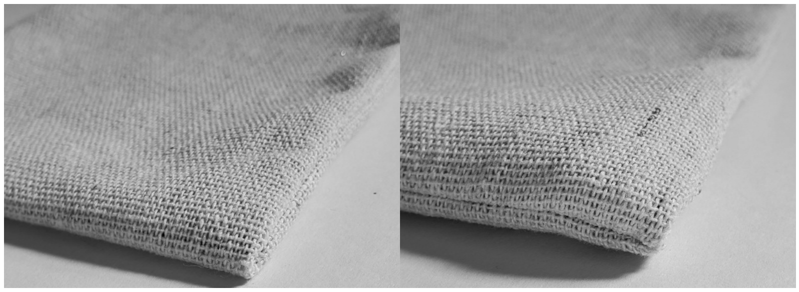

Figure 1: Side-by-side photographs of folded end (left) and two-piece (right) end condition. Source: Author 2022.

length can be folded in half lengthwise and sewn along the two edges adjacent to the fold. Each version results in a two-sided bag that is flat when empty, as shown in Figure 1. Although both sewing processes yield the same bag geometry with the same amount of fabric material, the single-piece version requires fewer cuts and less sewing thread.

The U-panel geometry, which is derived from construction methods used in polypropylene factory-packing bags, is constructed from overlapping two 45cm (18in) width by 197cm (78in) – subdivided by a 76cm (30in), 45cm (18in), and 76cm (30in), length rectangle pieces perpendicularly in cross orientation. The total overlapped area in the center is a 45cm by 45cm (18in by 18in) square. A single-line is stitched diagonally on the square, running from corner to opposite corner. Another line is stitched on the remaining corners to create an X that fixes the rectangle pieces together, as shown in Figure 2. The remaining 76cm (30in) edges are sewn together so that the resulting geometry is a five-sided rectangular prism with an open top.

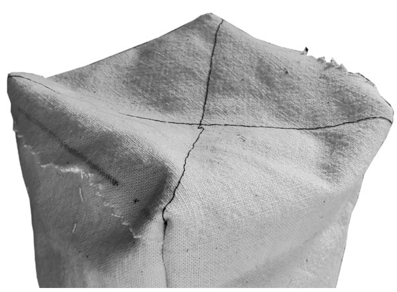

Figure 2: Crossing two single-line stitches to attach planar surfaces together. Source: Author 2022.

The Four-panel geometry, derived from another polypropylene factor-packing bag variant, is constructed using four 45cm (18in) width by 76cm (30in) length rectangle pieces, or panels, and one 45cm by 45cm (18in by 18in) square bottom piece. Each rectangle piece is sewn to another rectangle along their 76cm (30in) long side to create a four-sided open rectangular prism shape. The square bottom piece is sewn to close one of the sides, creating a five-sided rectangular prism with an open top. Compared to the U-panel geometry, which possesses identical surfaces, this geometry utilizes less material, but requires more total parts.

2.3. CASE STUDY OF THE SURPRISE-STAR DERIVATIVE GEOMETRY

To reiterate, the first part of the research sought to explore the manipulation of same-shapes to create different earthbag geometries. As hinted before with the Sack/Pocket, U-panel, and Four-panel geometries, the same and nearly-similar rectangle and square shapes can be used to generate different configurations or methods of sewn bag construction as long as they share the same measured edges. Following the logic of same-measured edges, the 45cm (18in) measurement was adjusted to be a factor of all measured edges to allow for all edges to be sewn proportionally. One possible geometry resulting from this change is the Surprise-Star geometry. The prototype is 1:4 scale, but the following measurements will refer to the intended dimensions for full-sized earthbags.

The Surprise-Star geometry is constructed from two 45cm width by 90cm length (18in by 36in) rectangle pieces and uses the same amount of material as the Pocket geometry. Each rectangle piece is folded in half along its 90cm (36in) edge and sewn along one of the newly generated 45cm (18in) edges, from the fold to the corner. This transforms the rectangle pieces into pinched cone geometries that have an opening profile of two 45cm (18in) edges and one 90cm (36in) edge. One cone is then partially inverted in a manner so that the unsewn edges perfectly overlap with the inside edges of the other cone. Then one 45cm (18in) and 90cm (36in) overlap is sewn, leaving a 45cm (18in) opening. The resulting geometry is an eight-sided polyhedron that can be manipulated once more to form a six-sided polyhedron, as shown in Figure 3.

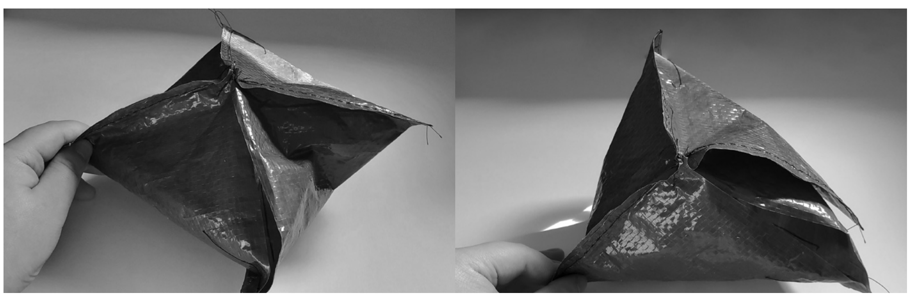

Figure 3: *Surprise-Star* transformation from four-points (left) to three-points (right). Source: Author 2022.

In conventional earthbag construction, when stacking Sack/Pocket bag geometries, the stacking surfaces are aligned relatively parallel to each other and tamped so that the top surfaces are even and level. When transporting U-panel and Four-panel geometries, the bags, which are rectangular and orthogonal, can be stacked on top of each other evenly. In contrast, the generated Surprise-Star geometry does not have a continuously flat surface for parallel stacking. Therefore, to observe the relationship between Surprise-Star earthbags and potential reductions of on-site tooling, additional Surprise-Stars were produced, filled with the same medium, and arranged in various wall configurations at a rudimentary level. In this case study, the medium-duty woven polypropylene Surprise-Star earthbags were selected for study and replicated following the described instructions.

To understand how this geometry can influence the building process, the Surprise-Star earthbag courses were laid in a manner to take advantage of the geometry of the individual bag. The pyramidal top of the eight-sided Surprise-Star earthbag, when arranged side-to-side with an identical bag generates a valley surface condition that can potentially serve as a pseudo form (a three-dimensional template of sorts) for a sequential course. If lower earthbag courses could support and isolate upper courses in a manner that prevents slippage, could a Surprise-Star earthbag wall eliminate the use of barbed wire and rebar within the construction? Simple stacking exercises were used to assess the feasibility of the geometry in various wall configurations: line, L-shape corners, T-shape perpendicular joints, and 2 by 2 squares.

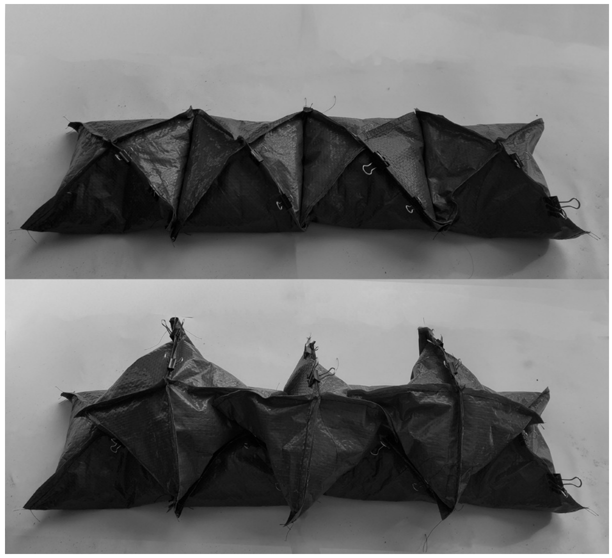

Figure 4: *Surprise-Star* valleys can support other *Surprise-Star* earthbags. Source: Author 2022.

When arranged orthogonally in a line, the Surprise-Star bags create a valley-and-hill form along the top surface of the earthbag wall course. The valleys can serve as a supporting form for the next course, albeit in a different orientation; the second course in the line arrangement features Surprise-Star bags that are rotated 45 degrees to fit into the valleys, as seen in Figure 4. In the third course, the bags are rotated 45 degrees again to create an orthogonal arrangement like the first course in the wall. To summarize, the odd courses, as a result, are orthogonal while the even courses feature bags rotated 45 degrees in the wall.

When arranging the corner in an L-shape, the first course of the Surprise-Star earthbag stack can be neatly arranged because the profile of the bags in the plan is rectangular. In the following course, the Surprise-Star bags are not able to fill in the corner of an irregular valley condition there. As a result, by the third course, the corner of the wall begins to deviate from the layout of the first course. A rigid corner material to support the Surprise-Star as a filling medium or increasing the thickness of the wall to two Surprise-Star bags can give the corners more stability. Alternatively, when arranged in a T-shape, the presence of a perpendicular wall provides the primary wall with stability when stacking, despite the upper layer deviation observed in the L-shape array. Similarly, the corners can be strengthened with a supporting material, such as chicken wire or metal mesh, or with wall thickening (Geiger & Zemskova 2015).

The Surprise-Star earthbags, when stacked in a 2 by 2 square, are comparably more unstable the further the layers rise above the ground. The uneven distribution observed in the L-shape array is multiplied with the introduction of three more corners in the square, causing more slippage between earthbag layers, as seen in Figure 5. This slippage aligns with stacked sandbag behavior, particularly in structures lacking tensile strength (Khalili & Vittore 1998). On that note, the eight-sided Surprise-Star sewn from polypropylene is not ideal for a 2 by 2 formation. The pile can be strengthened with the addition of supporting rigid material or with buttressing elements (the former option distorts its spatial identity as a column, however).

Reflecting upon the Surprise-Star geometry, the undulating polyhedral form of the Surprise-Star wall contrasts greatly with the smooth planar surfaces of conventional earthbag walls, offering a different spatial expression with regard

Figure 5: Gradual slippage of *Surprise-Star* earthbags in a 2 by 2 square alternating stack sequence (left to right). Source: Author 2022.

to contrast and texture. Yet, as the Surprise-Star wall is built vertically, the layers deform in a manner that increases irregularity within the wall, particularly with regard to unfilled space and slip-prone surfaces. This could be remedied with a different fabric material, earthbag fill, or a secondary supporting system, such as mesh or ties, to hold the bags in place, as suggested by Geiger and Zemskova (2015). This shows that the combination of the Surprise-Star geometry, medium-duty woven polypropylene fabric, and dirt medium is not effective in eliminating barbed wire, rebar, or similar supporting components from the earthbag construction. However, arising from the Surprise-Star exploration was not only a novel earthbag geometry as a product, but also an altered earthbag construction process that was expanded to include bag-making and sewing craft.

3. EARTHBAG MODIFICATION AND DIY CRAFT FEASIBILITY IN CONSTRUCTION

The next phase of the research sought to understand the significance of earthbag craft and production within the context of “do-it-yourself” making processes by cataloging novel prototypes derived from manipulations of conventional earthbag geometry. In “do-it-yourself” earthbag construction, earthbags are often purchased off-the-shelf or recycled from approximately 45cm by 76cm (18 inch by 30 inch) sack-shaped bags (Geiger 2009). Prospective builders are recommended to acquire misprinted commercial bags or recycled feed bags to save money prior to the building construction (Hunter & Kiffmeyer 2004). “Do-it-yourself” earthbag building construction has a frugal and resourceful connotation associated with the act of self-building. Therefore, the cost of materials and the effort invested in hand-making the earthbags are considered in bag production. All the prototypes share the same starting 45cm by 76cm (18 inch by 30 inch) dimensions, TERA 80 sewing thread, and single-stitch seams. The variables will be the supplementing material used to modify each earthbag prototype and two types of polypropylene fabric. The introduction of modifications to the base 45cm by 76cm (18in by 30in) earthbags sought to explore ways in which tools could be eliminated during the on-site building process. The earthbag prototypes were constructed at 1:2 scale but the paper will refer to the intended full size for purposes of instruction.

3.1. REDUCING TOOLS

The Drawstring modification requires open edges of the base geometry to be folded and sewn around a string, which can be jute, nylon, or any alternate material, that is free enough to pull and cinch the edges closed. The addition of a drawstring part allows the earthbag to carry more amounts of earth, and be sealed and resealed. Prototypes using the Drawstring modification could reduce the number of earthbags used in the wall in exchange for generating heavier and more packed bags.

Figure 6: An emptied *Bi-Cinch* prototype opening detail (left) and filled side view (right). Source: Author 2022.

Alternatively, while the Drawstring modification requires an edge to create a string-wrapping hem, the edge of the base geometry can be cut freely on the earthbag. One example of an alternate design is to reposition the bag's opening to run midway across the 76cm (30 inch) length, bisecting the geometry. The addition of Drawstring modifications in the bisecting center of the bag geometry transforms the conventional Sack/Pocket geometry into a folded one, named Bi-Cinch, as shown in Figure 6. The centered fold allows the earthbag, particularly if sewn from a semi-rigid material such as woven polypropylene fabric, to stand up by itself or hang on a rigid line or pole. As a result, this geometry simultaneously eliminates the need for a bag stand and allows the earthbag to be supported by a simpler supporting apparatus. Additionally, since this geometric manipulation involves the Drawstring modification, the Bi-Cinch prototype is also capable of containing more earth.

The Corner-stitch modification is created by stitching two adjacent corners along a closed 45cm (18 inch) length to create a folded loop, as shown in Figure 7. Fixing two corners of the geometry together curves the end while also creating a handle on the earthbag without adding supplementary materials. Furthermore, the creation of a handle or loop on the geometry eliminates the need to puncture the earthbag with rebar when reinforcing the wall. Instead, vertical supports can be inserted into the loops to hold multiple bags in place; the introduction of vertical support around the Corner-stitch modifications also allows the earthbags to be stacked axially.

The Embedded stick modification is characterized by sewing hems along the surface of the base earthbag geometry and threading dowels inside them. The hems are sewn to be at least twice the diameter of the dowels to allow

Figure 7: A schematic *Corner-Stitch* modification on a commercial low-duty woven polypropylene earthbag. Source: Author 2022.

enough space for the new materials to be embedded into the fabric. The insertion of dowels within the surface of the geometry adds rigid edges to the earthbag that will not deform when packed with earth. Depending on the placement of the dowels, an earthbag surface can be modified to reduce slippage between layers.

3.2. MATERIAL CONSUMPTION AND HANDICRAFT

In exchange for the prototype's potential to reduce or eliminate on-site tool use in earthbag construction, the new geometries, as mentioned previously, add materials to the earthbag. The Drawstring prototypes, for instance, require one or two strings to pull the earthbag shut. Supplementing strings, not only need to be measured to an appropriate length, but they need to be threaded into the earthbag either during or after the sewing process. When threading the drawstring post-sewing, a needle or threading tool, such as a hook or straw, needs to be used; depending on the tool, the hem dimensions need to be adjusted accordingly, as shown in Figure 8.

The Bi-Cinch prototypes, because they use two Drawstring modifications, require double the amount of string. Doubling the material doubles the amount of time required to assemble that part, meaning more time spent threading the string through the added hems. Conversely, the Corner-stitch prototypes, because they only require sewing the corners of the original bag geometry, only consume a minute amount of thread during the sewing process.

The Embedded stick prototypes, on the other hand, require multiple hems to be sewn into the surface of the earthbags and a proportionate number of supplementing dowel materials. Depending on the number of modifications within each earthbag, the Embedded stick prototypes consume a lot of material, time, and effort in precisely sewing the correct lengths and threading dowels. Furthermore, the Embedded stick modifications, if intended to reduce slippage, do not outperform the conventionally used barbed wire, and can also be substituted by changing the bag material with a more frictional surface.

3.3. REPLICABLE CRAFT FEASIBILITY

All the earthbag prototypes in this study were mass-produced with the sewing machine and followed defined instructions for replication. To increase accessibility by providing instructional flexibility, there were two versions of bag-making guidelines for each prototype: 1) from sheet fabric and, 2) modifying existing bags; all earthbags were modified from existing off-the-shelf polypropylene sandbags or from pieces measured from sheet material using a template. Within the scope of replicable "do-it-yourself" craft, using a template allows non-polypropylene materials to be used for sewing new earthbags while repurposing off-the-shelf products allows quick minute changes via modifications. Using a template

Figure 8: Photo of a commercially available threading tool, or straw, threading an earthbag hem. Source: Author 2022.

facilitates easier marking, cutting, and trimming of earthbag fabrics and increases the craft accessibility of sewn earthbag production to less-skilled hands.

With regards to the individual prototypes and modifications, instructions that had simpler steps and fewer supplementing materials were easier and faster to replicate. For example, the Corner-stich prototypes did not require many additional materials to be inserted into the earthbag. This meant that not a significant quantity of materials needed to be handled during the bag crafting process, which is notably less than the Embedded stick prototypes, which require more finesse in handcrafting. Similarly, the Bi-Cinch prototype, because it is essentially a combination of two Drawstring prototypes, requires builders to make the modification twice on the same geometry.

Complications during the crafting process were linked to material properties. For example, when repurposing off-the-shelf sandbag products, which are optimized for cost and disposability, difficulties in sewing the polypropylene resulted in more time being spent attempting to prevent the fabric from unraveling. While it is possible to apply and heat adhesive layers to stabilize the low-duty woven polypropylene fabric, it is simpler to purchase or use medium-duty polypropylene fabric. The option to select more durable fabrics, while more expensive than repurposing bags, makes crafting the bags easier and more manageable.

To clarify, this does not delegitimize low-duty polypropylene, however. Instead, the instructions sampled in Chapter 2.2 Re-Constructing the Earthbag Shape, by explicitly only defining fabric parts and shapes, leave the possibility of using fabrics not mentioned in this paper. The act of sewing earthbags by hand is a more intimate way for builders to process their materials; through continuously selecting, feeling, interacting, and working with fabrics, the sewing machine, and geometries, builders increase their knowledge and crafting skills with each sewn bag.

4. CONCLUDING REMARKS AND FOLLOWING RESEARCH

This paper sought to investigate how using the sewing machine to create novel earthbag geometries can change the earthbag construction process in terms of bag production and reducing the use of tools on the construction site. The sewing machine served as a vehicle for creating geometries that replaced on-site tooling with off-site bag modifications that added value to earthbag craft, reflecting a direct impact of the sewing machine on the construction of the resultant wall. Added value to earthbag craft includes the handicraft experience associated with experimenting and handling different materials, testing stitches, and planning how to construct individual bags. Sewing alternate earthbag geometries gained value within tactile craft-learning while simultaneously attempting to improve on-site earthbag construction.

The primary focus of this research sought not to explicitly improve the performance of the resultant earthbag wall, but rather explore how changes in on-site construction processes can be facilitated through the craft of actively manipulating earthbag geometries. Production of the novel earthbags generated in this research also sought to increase accessibility through the tactile understanding of materials, sewing craft, and knowledge formulation within the context of "do-it-yourself" earthbag building and bag-making that can be shared with others, hence the initial abstraction of earthbag geometries to assembled sheets.

In terms of open questions, while the research investigated preliminary considerations of earthbag craft, geometric manipulations, and tool substitution, it did not investigate another core component of earthbag construction: namely, the earth medium used to fill the bags. In conventional earthbag construction, the earth varies depending on the site, making each earthbag building intimately related to the environment it is placed. The stability of a compressed earthbag unit depends on the stabilization of the earth mixture, which can be strengthened with cement or clay. Furthermore, the presented research did not include tamping or discussion on compressive forces on the earthbag geometries. Future stages of the research, therefore, incorporated filling the novel earthbags with naturally stabilized earth that was available locally and tested varying tamping strategies during wall-building construction processes (Leung 2022).

The methodology for future work included a framework that compared the on-site construction parameters of conventional earthbag and similar wall systems, which was used as a benchmark for evaluating the suitability of novel earthbag prototypes as modular units intended to support compressive forces. This framework included the conventional earthbag system, SuperAdobe coiled earthbag system, hybrid earthbag systems, and rammed earth. Taking into consideration an expanded building process that includes machine-facilitated earthbag production, sewing craft and earthbag replicability of the earthbag prototypes were assessed; this included strategies used to improve bag production and efficiency, such as alternate sewing techniques and the use of standardized templates. Then, physical simulations of subsequent novel prototype-walls were built to include a stabilized earth mixture and ramming. During the construction of each wall, it was important to document how the geometry changed in three parts: (1) immediately after being filled with earth, (2) after ramming within the wall, and (3) while supporting the weight of earthbags on top. Most importantly, the research conducted outside of the work presented in this paper assessed prototyped earthbags, not in terms of modular earthbag performance, but in terms of improving safety and labor during on-site earthbag construction

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