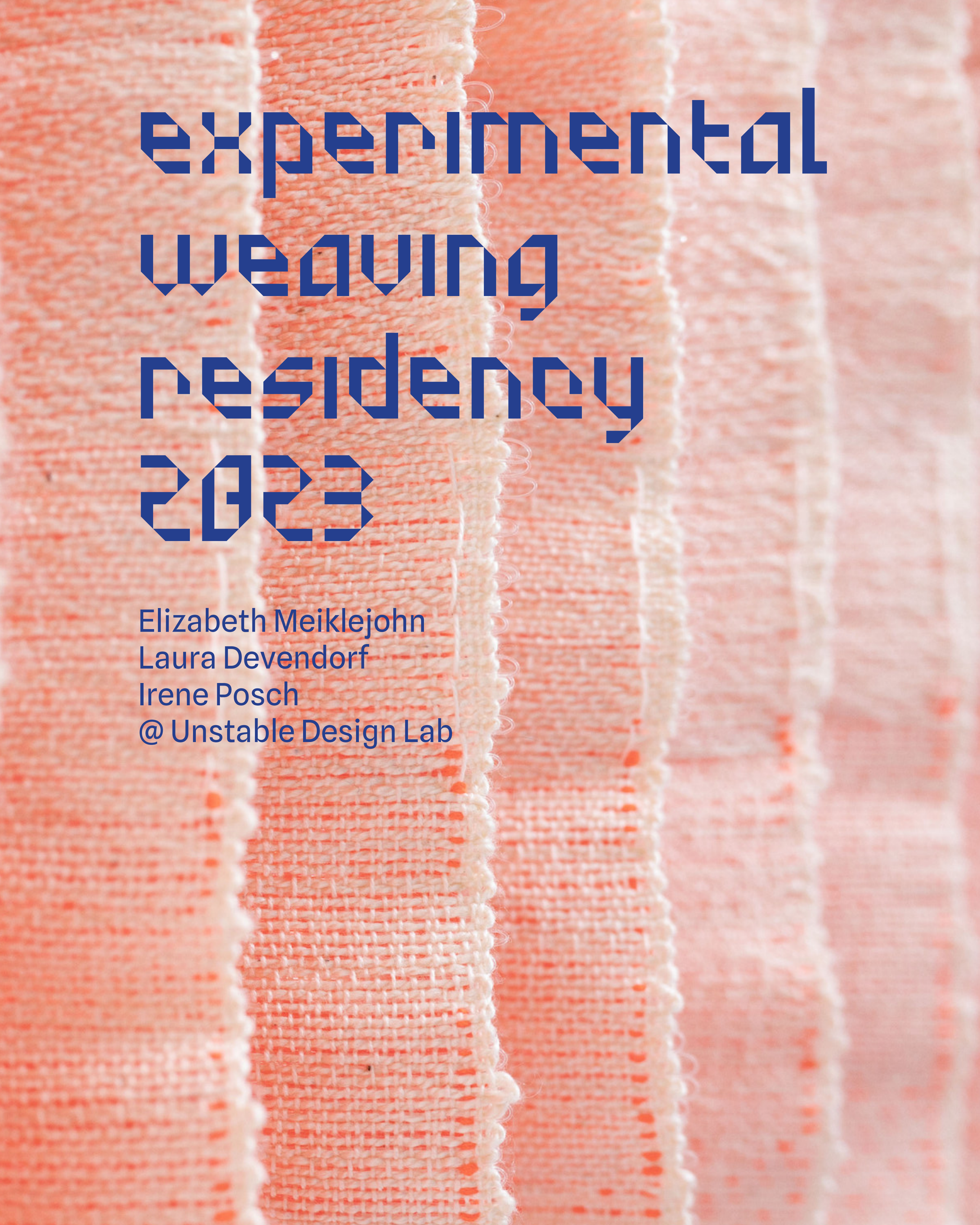
Making Magnetic Reverberations



experimental weaving residency 2023

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introduction

In the spring of 2023, Elizabeth Meiklejohn joined the Unstable Design Lab for 12 weeks as the lab's Experimental Weaver-in-Residence. The Experimental Weaving residency was started in 2019 to foster exploration and collaboration between textile designers, artists, programmers and engineers with a focus on identifying and open-sourcing new techniques in textile fabrication.

Documenting these techniques enables researchers within the lab and across the university to adapt them to their own work, and sharing them publicly strengthens the growing community around experimental weaving that exists at the intersections of craft and technology. This commitment to making methodology accessible has in the past been realized through publications, workshops and lectures that address broad audiences of weavers and HCI researchers to eager students and non-experts. In presenting the process work, notations and reflections created alongside the finished woven pieces in this residency, we aim to de-mystify some of the complexities inherent to multi-layer, Jacquard and hand-manipulated weaving, and encourage others to adapt and remix these strategies within their own experimental weaving practices.

Elizabeth came to the residency with a focus on textile movement and behavior, which can be closely controlled by modifying the weave structure and yarn composition of the fabric. Together with lab director Laura Devendorf, she discussed several ideas for potential residency projects that quickly resolved into a few broad categories, including "sensing" and "actuating." The sensing category was a direct response to the lab's previous work developing conformable low-profile woven resistive pressure sensors. Within the scope of actuation, there are many existing ways of making fabrics move: shape-memory alloy (SMA) wire, thermoplastic yarns, magnets, pneumatics and mechanical linkages. This category was deliberately left open, encouraging simultaneous exploration of both the existing solution space for textile actuation and the range of textile architectures that can transition between multiple states.

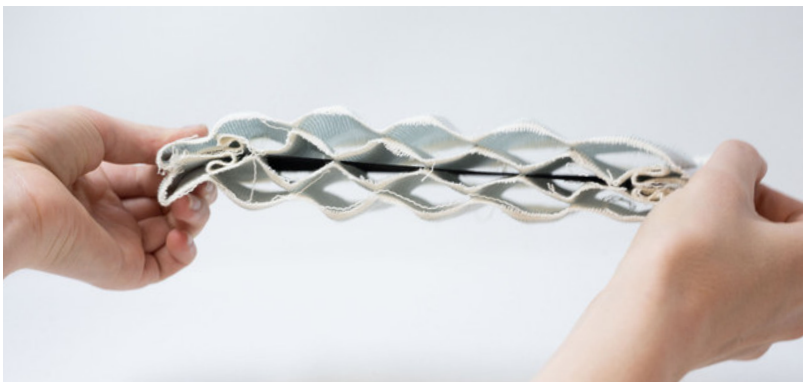
As the residency progressed, we produced a suite of samples to inform the design and fabrication of a final, interactive textile piece called *Magnetic Reverberations* in collaboration with Irene Posch. This work was developed to showcase the potentials of weaving as an inherently three-dimensional, sophisticated fabrication strategy; the integration of complex systems into fabric as a process that is both embodied and precise; and a unique optical effect made possible by a combination of textile structure and actuation. Accompanied by a collection of sketches, drafts, diagrams and notes-to-(future)-self, *Magnetic Reverberations* is a synthesis of methodologies applied during the residency and a testament to the interdisciplinary knowledge transfer through which they were developed. In the catalog that follows, Elizabeth offers her first-person account of the prototyping and development.

sampling

The first phase of the residency was dedicated to sampling, quick iteration and discovery. By making deliberate space and time for semi-structured exploration, we hoped to identify potential directions for a more formalized final project among the growing array of specimens. Starting with broad prompts, (ie. sketching imagined mechanisms for textile movement and then attempting to weave them), we generated a collection of samples full of sub-groups and related artifacts, taking multiple approaches to solve specific, spatial questions.

Many of these samples are multi-layer wovens utilizing up to four layers—often in conjunction with elastic or shrinking yarns—to create self-supporting three-dimensional wovens. Some are more successful than others: samples 7a and 7c use an extra set of elastic weft floats running vertically to tie outer layers together, resulting in a flattened final fabric rather than the intended bistable mechanism. This family of samples represents multiple approaches (or educated guesses) towards achieving a stated goal.

Sample 4b is a version of a spacer fabric with square cells and elastic floats at the corners. It uses a partial-weft technique to create parallel vertical walls between the upper and lower fabric layers.



Sample 7b is a four-layer construction with weft exchanges between layers to join them together at select intervals. Black elastic floats run through the middle of the stack, compressing it into soft accordion folds.

Sample 7d is another four-layer design with offset joining points between layers and a heavy-duty polyester weft.

Sample 7a resulted in smaller peaks and valleys due to internal elastic floats joining layers together more often.

In other cases, a single sample represents a thread of an idea that was tested but not pursued further. Sample 5 (see page 6) has long weft floats and short warp floats, interlocking loosely between two layers that allow the fabric to slide laterally between two distinct formations. This type of movement is not present in any subsequent samples - not because it was deemed impractical or a failure, but more likely because in the intervening time between weaving, cutting off and assessing (weaving often involves not only an initial time investment, but also a persistent time delay), several more interesting ideas had arisen.

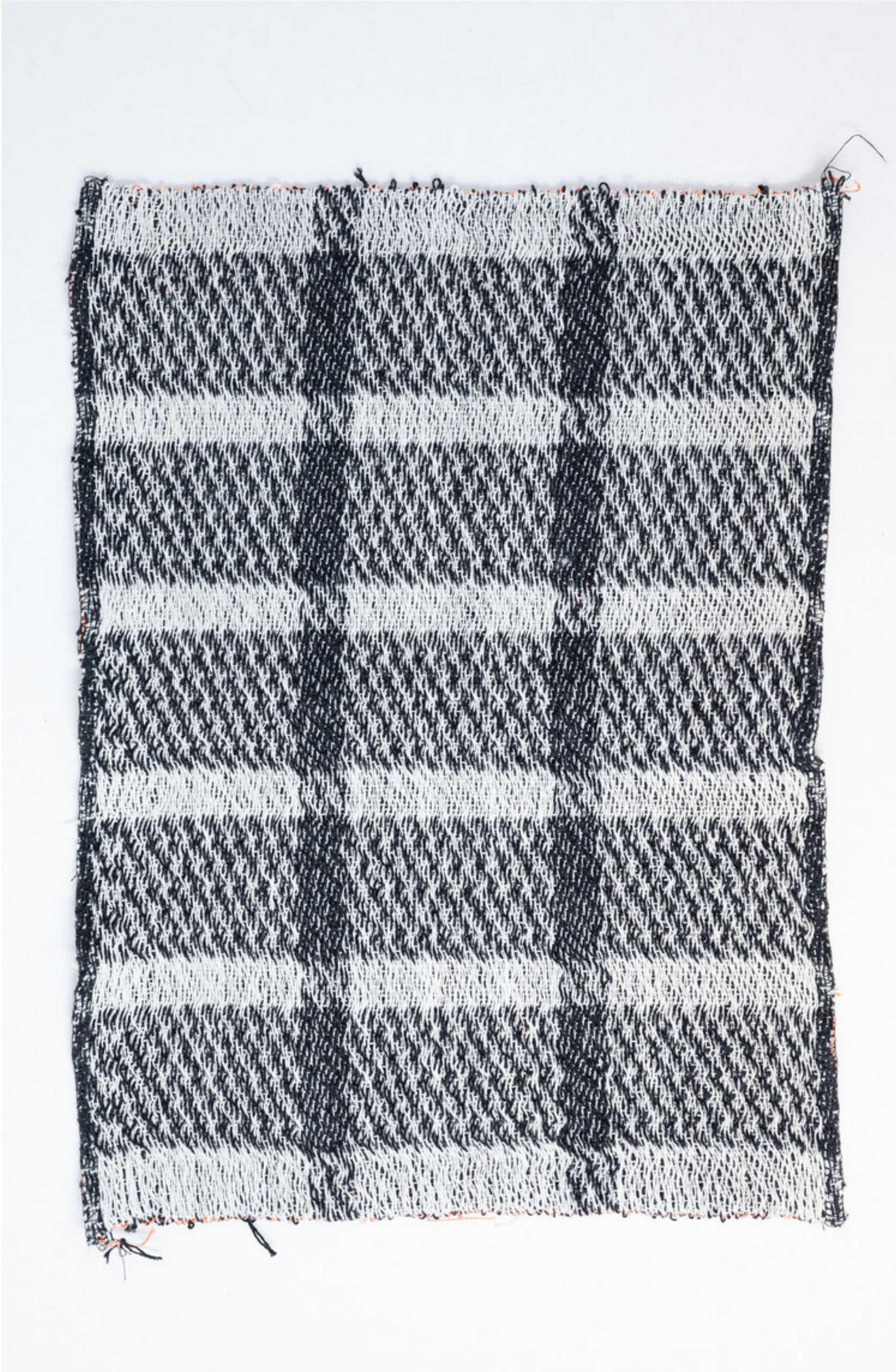
Other woven studies from this phase investigate the outcomes of "partial-weft" weaving: a technique in which the shuttle travels partway across the cloth during each pick, tracing a circuitous path that can create extra layers and free edges. While this technique was by no means developed during the residency, and borrows basic concepts from tapestry and manual pickup methods, the hand-operated, computer-controlled nature of the TC-2 loom inspired us to weave with partial wefts for the first time and enabled the creation of fabrics with highly complex cross-sections and surface features. Structures that would otherwise be impossible to weave or require extensive cutting and separation - such as "weft-spacer" fabric, in which stiff weft yarns travel vertically between two woven layers - can be fabricated in a slow but optimally choreographed manner using these strategies. While we numbered the samples chronologically, we present the remaining samples out of order to group them by theme.

Sample 1 is the first Jacquard-woven fabric made during this residency. It combines self-folding techniques with partial weft passes, which are a unique capability of hand-operated Jacquard looms.

Sample 4a is a lightweight, crisp square-cell spacer fabric made with partial weft passes in a single material: bonded nylon thread. It was woven flat on the loom and its cells have a tendency to collapse to their original state.

Sample 5 uses long weft floats interlinked with short warp floats to create a system of layers that can slide sideways relative to each other. Elastic floats give the layers an accordion-pleated and slightly crumpled look.

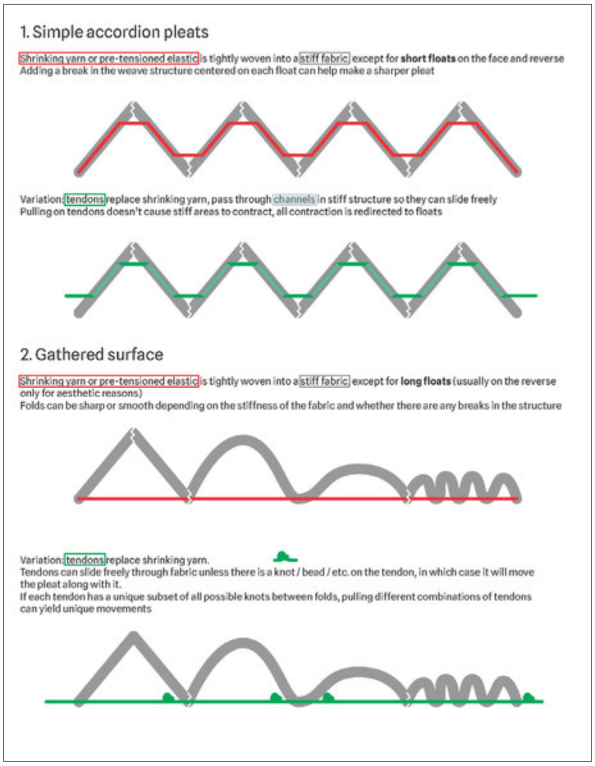
Sample 0 was the very first fabric woven during the residency, on an 8-shaft table loom. Similar to sample 7b, there are 4 layers joined at regular intervals to form a lattice, but in this fabric, both warps and wefts exchange positions at each joining point, creating the appearance of multiple fabric planes intersecting.

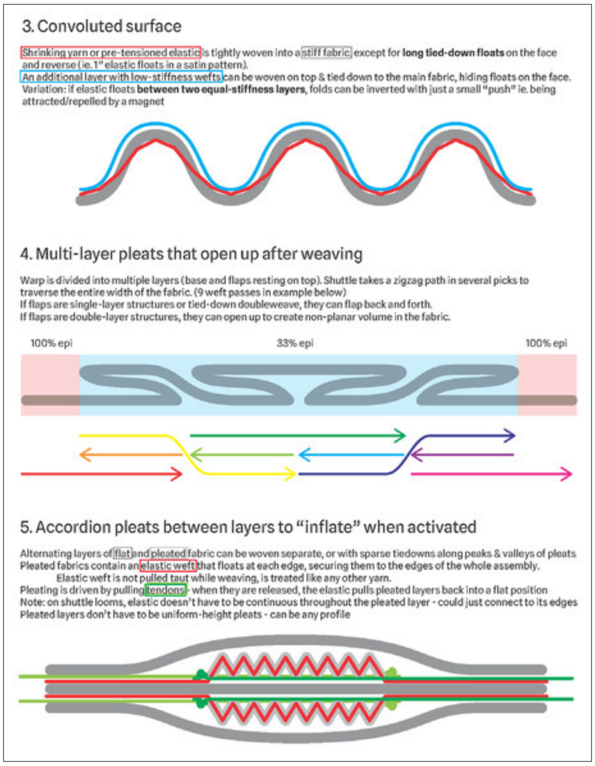


Sample 6 was a self-shaping design that failed to take shape after weaving, despite the hidden elastic floats in the middle layer. It uses interleaved floats of black and white wefts in offset satins to create its surface pattern.

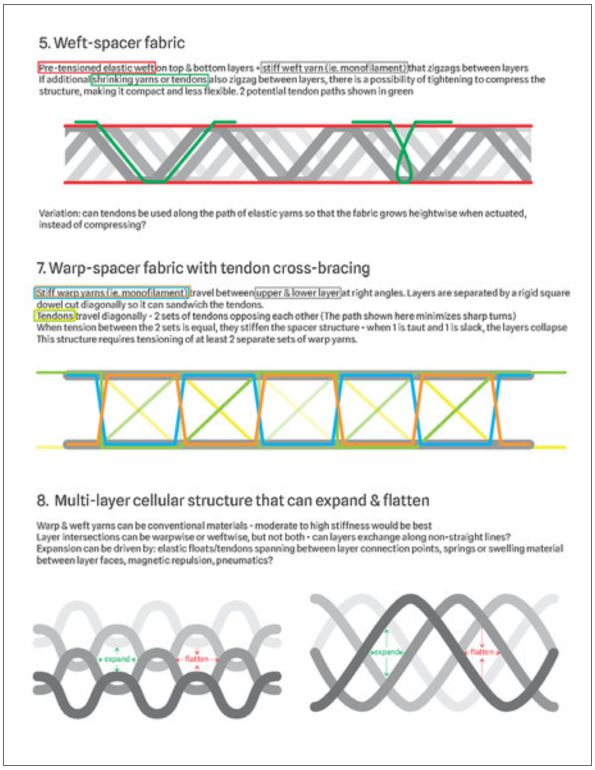
design bookkeeping

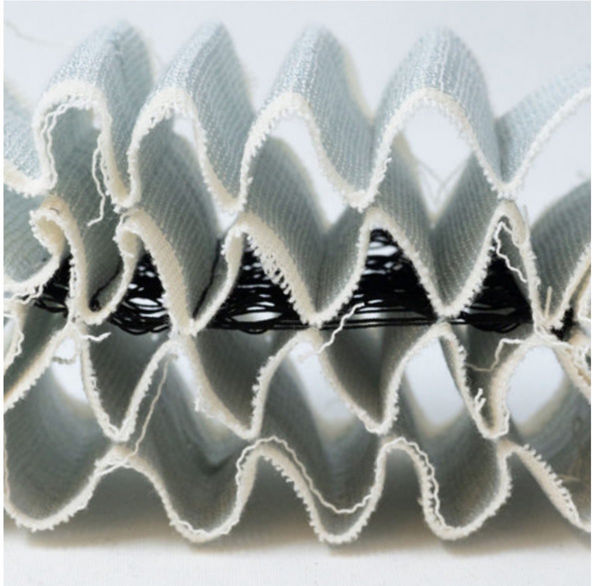
Designing and weaving complex multi-layer fabrics would be impractical, if not impossible, without some type of organizational system. Detailed sketches, diagrams, notes and revision histories are helpful when working with creative collaborators, but may be considered low-priority by solo practitioners. We were in agreement early on—shaped by past experiences revisiting and decoding our own intricate works of weaving and electronics— that documentation materials can function as a communication between the present and future self, mitigating the need to reverse-engineer our designs or re-understand why certain choices were made. Embedding the "why" of each design choice into documentation was particularly important for Elizabeth, as developing weave structures for multi-layer interaction is often a sort of logic puzzle involving compromise and process of elimination. Whether sketching all possibilities to demonstrate why the selected one is best, developing rudimentary proofs, or writing explicitly in her notes, "this is the only weft sequence that will work!", Elizabeth could take advantage of the current moment, deep in the weeds of weave structure, and preserve that clearheadedness for a future self who would want to pick up where she left off.





Diagrams of textile structures, shown as cross-sections of the width of the fabric. Some of these, like self-folding accordion pleats, were known and tested prior to starting the residency while others, like "inflating" pleats, were highly speculative.



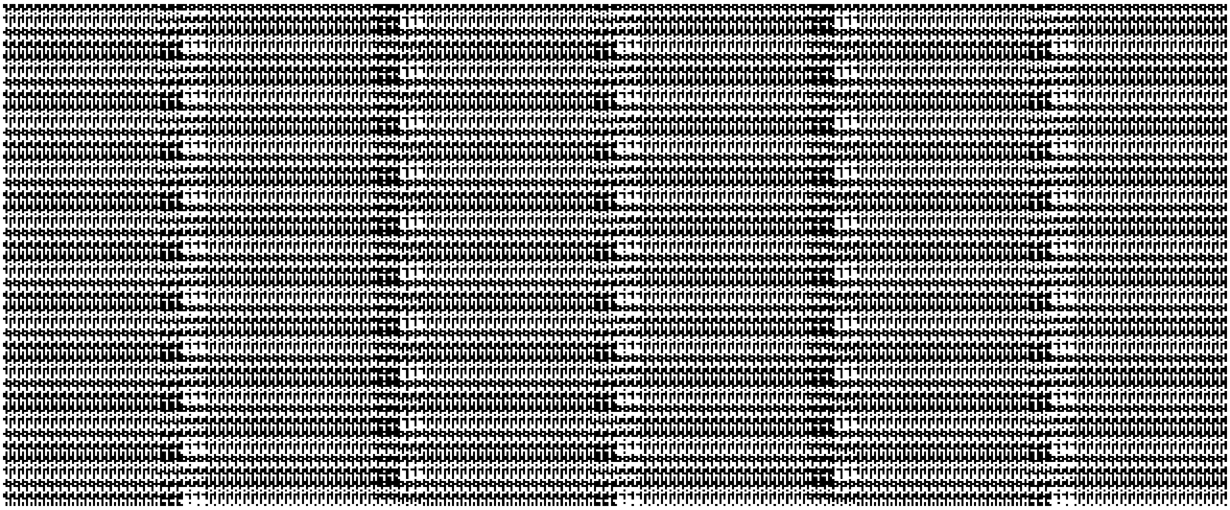


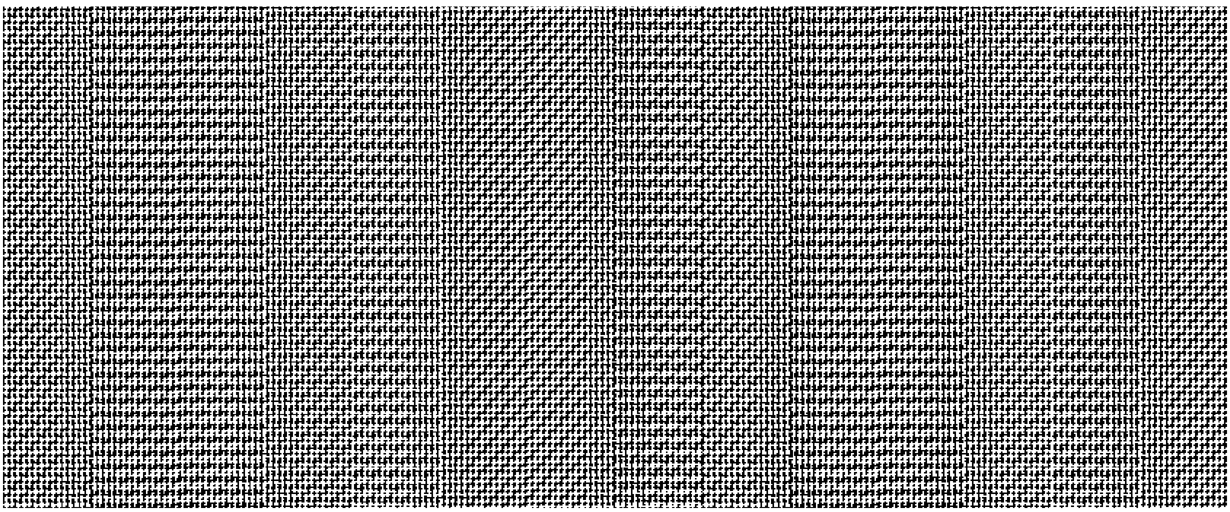
Two variations on 4-layer lattice structures inspired by 3D weaving “layer-to-layer” and “through-the-thickness” warp movements.

The term “design bookkeeping” encapsulates these strategies and is well-suited for weaving, a medium in which the standard system of notation, the weave draft, doesn’t fully convey design intent. The draft is a standalone, machine-readable format and accurately describes which warps will be lifted during each pick, but doesn’t specify which shuttle should be thrown, how to maneuver multiple shuttles at the edges of the loom for joined or separate multi-layer selvedges, or whether certain yarns (ie. elastic) should be inserted under tension or relaxed.

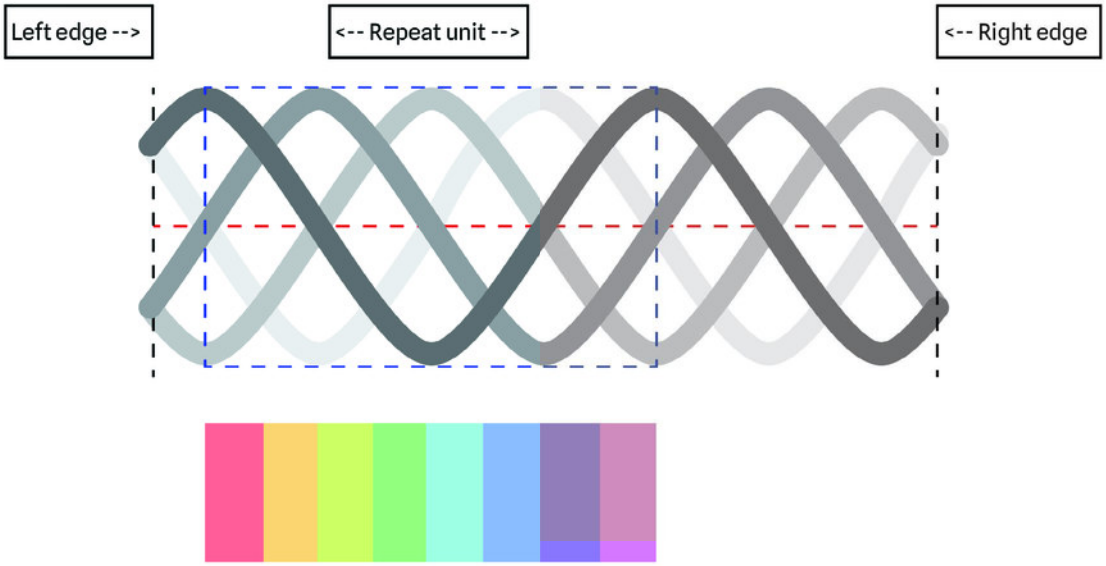
Aside from these fabrication-critical details, the draft also lacks context and human-readability. Trained Jacquard weavers can identify multi-layer drafts with some practice, but with different weave structures on each layer interleaved with uneven warp and weft ratios, it becomes difficult to disentangle the individual layer drafts or visually identify areas of difference such as layer exchanges.

In the past, Elizabeth has addressed this indecipherability by keeping vast folders and subfolders of weave structure .PNG files with consistent naming conventions, tracking which ones are the component parts of others. AdaCAD, the parametric weave design tool that the Unstable Design Lab develops, solves this by providing a complete map of how the weave was constructed from scratch, and Elizabeth found herself heavily annotating sections of drafts she created as a further note-to-future-self. The TC-2 only requires a .BMP file of a weave draft as input, but she often brought my laptop to the loom so I could follow along in "real time"—through color-coded versions of the draft in Photoshop or written notes on what happens in each section—ensuring that all of the information at the periphery of the draft could be incorporated into the weaving process as intended. We relied on weave drafts and their accompanying documentation to refine and fabricate samples, but we also found it helpful to step back and discuss woven structure and behavior from a high level.





Sections of weave drafts for sample 5 and sample 7b. It is clear from the vertical divisions in each draft that something distinct is happening in each demarcated section, but what?



layer order:	weft sequence in MWS:	warp sequence in MWS:
A,D,e,B,C	14523	1342
A,B,e,D,C	12543	1243
B,A,e,C,D	21453	2134
B,C,e,A,D	41253	3124
C,B,e,D,A	52143	4213
C,D,e,B,A	54123	4312
D,C,e,A,B	45213	3421
D,A,e,C,B	25413	2431

Yarn color key:

elastic weft - tensioned while weaving

A
B
C
D

Overall weft sequence: abcd e

Overall warp sequence: ABCD

Shuttle passes:

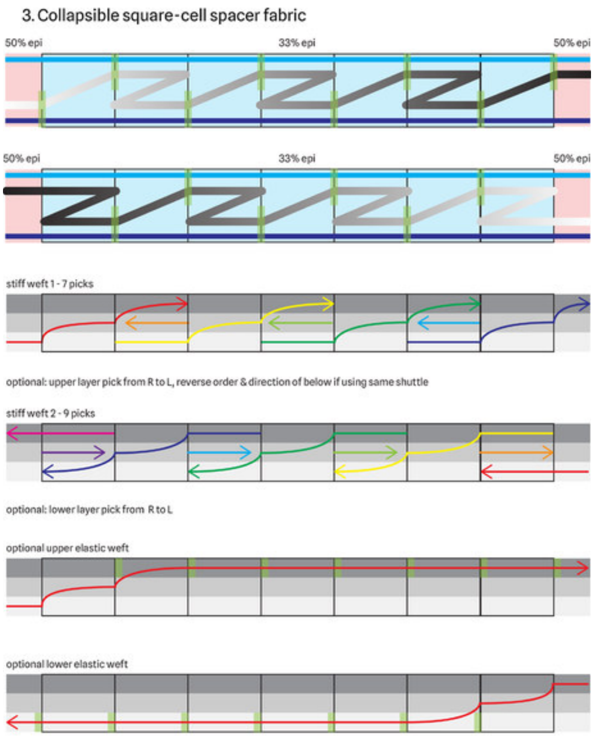
1. A> B< C> D<
2. e><

Extensive annotation is often part of the process when assembling complex layered structures. Sample 7b has 16 different combinations of warp yarn and weft yarn across its 4 layers, which can be counted by partitioning its cross-section diagram into slices wherever layers cross. The diagram can then be translated into a multicolor weave graphic, a standard step in Jacquard design that serves as a precursor to the weave draft. Each colored section is filled with a unique multi-layer weave structure. Creating multi-layer weave structures requires knowledge of which yarns are raised above or lowered below others: in this notation, a sequence like "Db, Aa, Cc, Bd" describes pairs of warp and weft groups stacked from top to bottom.

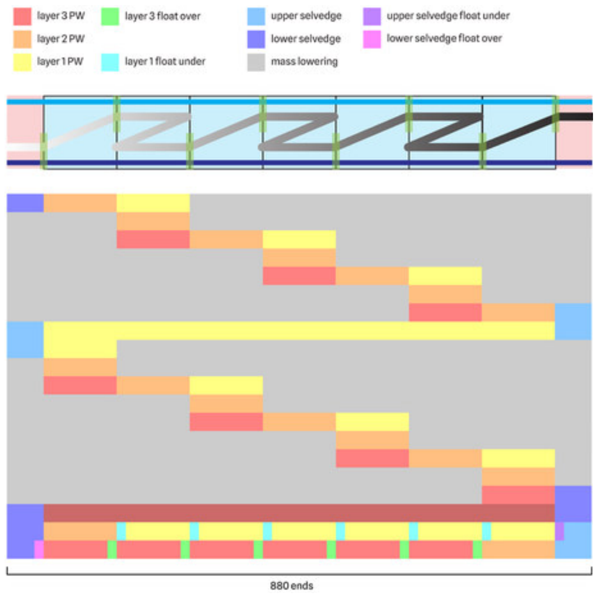
You can find a tutorial of how to recreate this structure using AdaCAD at:
https://docs.adacad.org/docs/howtouse/learn/lattice-tutorial

We sketched fabric layers as simple surfaces, lines and linkages, rendering cross-sections of woven structure as a way to illustrate what each weft is doing, and with which warp, at a given moment in time. This style of diagramming is shaped by two complementary ways of understanding weaving: first, as a fundamentally three-dimensional fabrication method, in which yarns are always crossing over and under each other and Z-axis positions are significant; and second, as a temporal process, as the stacking of wefts along the Y-axis gradually forms a complete fabric over time.

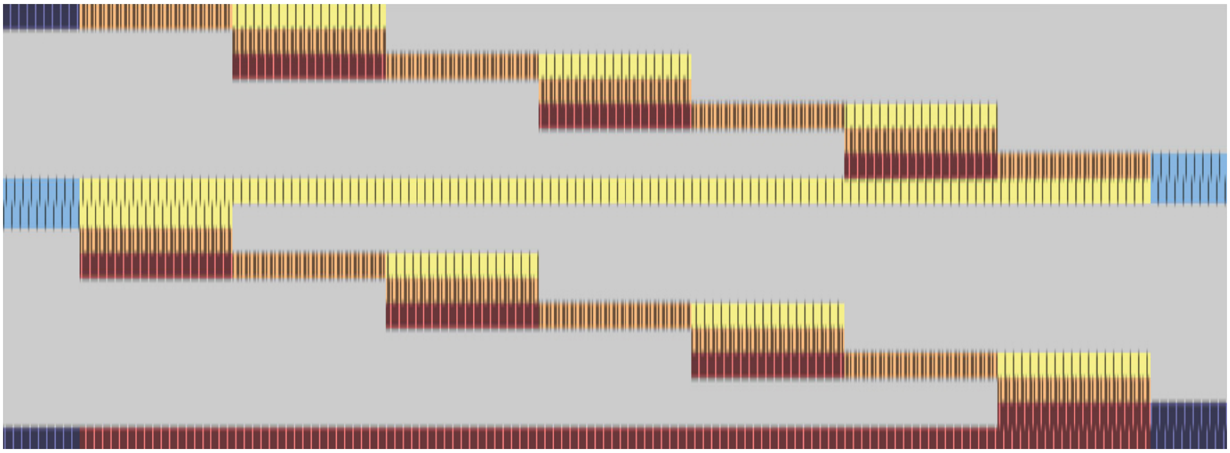
Wefts in multi-layer fabrics are always traveling, splitting up and joining, exchanging places or laying dormant in the background. Many of our fabrics, especially partial-weft designs, contain so many choreographed actions in a single cross-sectional slice that Elizabeth annotated them with color-coded arrows, describing how the journey of each shuttle is divided into successive picks, and in the process, optimizing that path into as few picks as possible. Diagramming served as a practical necessity and as a way of reasoning through complex problems, which in turn prompted new systems of notation to capture the movements of experimental weaving.

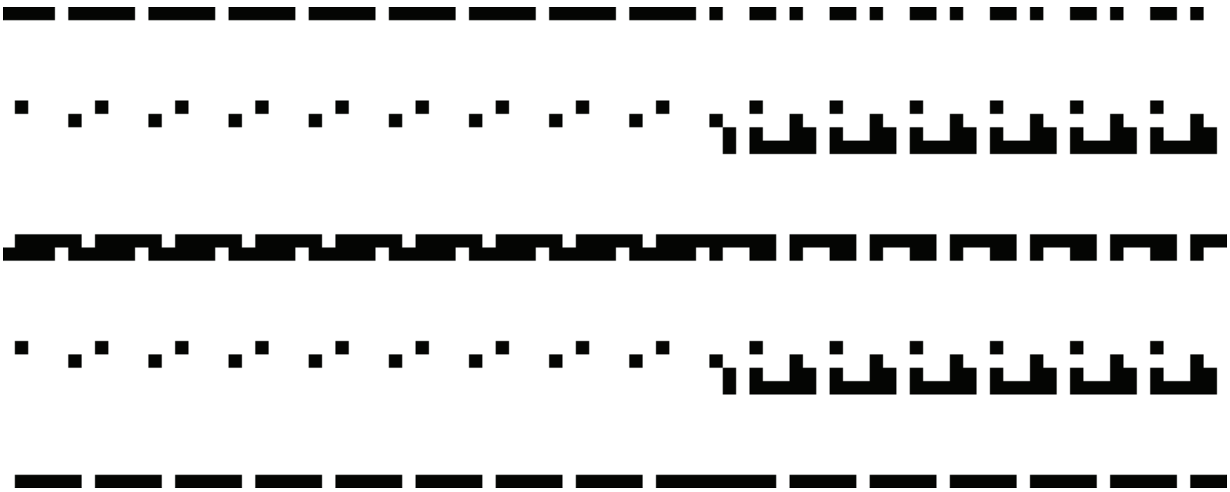


The movement of a weft yarn across the fabric is illustrated, first as a continous gradient line and then as a set of arrows traversing both the width and layer thickness of the fabric. In both modes, color changes indicate advancement along the length of the yarn or the passage of time as weaving takes place.



The multicolor arrow diagram is translated into a proto-weave graphic. Each time the arrow reverses direction, a new line is added to the weave graphic and only the area covered by the arrow is filled in. The diagonal switchback paths and negative space are characteristic of partial-weft designs.





From top: weave graphic with overlaid draft; a section of the weave draft; and a cross-section view of the finished fabric, all derived from the diagram on the facing page.

sensing

We experimented with resistive sensing fabrics, building upon previous work conducted at the Unstable Design Lab that used long floats of conductive yarn. I felt it was important to draw parallels between the sensor designs and principles that I was learning about for the first time (essentially, that more contact between conductive elements registers as more force) and known textile typologies like velvet, terrycloth and spacer fabrics. In woven pile fabrics, one set of yarns interlaces to form the base cloth while a supplemental set (typically warps, but in this case wefts) floats on top and is pushed forward to form loops that stand up from the surface. The plush and compressible nature of these fabrics, and the presence of many discrete loops, suggested an opportunity to transform a traditional structure by using conductive yarns as the supplemental material. Pressing two layers of this fabric together, with conductive loops facing each other should result in increasingly lower resistance as pressure is applied returning to a base level when the pressure subsides.

The weft loops in these fabrics were woven with a range of conductive material, narrowing in on those that had a softer, yarn-like handfeel and were able to bend into tight loops more easily. The base wefts were selected for their ability to shrink when heated or released from tension, although shrinkage was hindered in some samples by high density and low float length of conductive yarns. These yarns were inserted as inlays, traveling back and forth within a small area of the fabric, and the tie-down pattern of their floats (usually a satin weave) was interleaved with the weave structure of the base in varying ratios. Sample 2g was the most successful, with a ratio of 1 conductive pick for every 4 base picks. We conducted preliminary testing on these samples and found that they functioned well as force sensors, but didn't pursue rigorous testing to see if they addressed common problems like repeatability and drift. Miniaturizing these structures could also be a valuable step before implementation, since the conductive loops are at least a few millimeters tall; using thinner conductive yarns and finding the right weave structures and shrinking base yarns that make them deflect into loops at a sub-1mm scale would aid in the development of functional, low-profile woven sensors.

Sample 2f (top) and 2g (bottom). Sample 2f has a 1:1 ratio of conductive picks to base yarn picks, which proved to be too dense and rigid and prevented weft loops from forming when the fabric shrank horizontally.

Sample 2e (top) and 3a (bottom) use a crimped nylon yarn that shrinks up to 50% when steamed, causing the surrounding non-shrinking yarns to buckle and form compressible loops.

Samples 2a through 2d (top to bottom) use a thermoplastic weft yarn in increasingly-loose weave structures: plainweave, 3x1 broken twill, 8 satin, 16 satin. Little to no shrinkage occurred due to the stiff conductive wefts.

movement

If you spend enough time around weaving equipment, you'll end up learning about electronics without even realizing it. Elizabeth knew more or less what a solenoid was when she arrived at the residency from troubleshooting the 24 solenoids on a computer-controlled dobby loom: at its simplest, it consists of a coiled-wire electromagnet that attracts a metal plunger when powered on, providing linear motion. The TC-2 loom at the Unstable Design Lab (a hand-operated Jacquard loom) has a similar feature that controls the raising of each individual warp yarn, in this case 2,640 of them. It is a clever design whereby small elements magnetically determine which heddles are lifted and lowered. We were drawn to the idea of integrating electromagnets into fabric, in part because of this interesting parallel to the machine that the fabric would be woven on, but also because of prior work by Irene Posch and Ebru Kurbak that demonstrated the capabilities of electromagnetic actuating textiles.

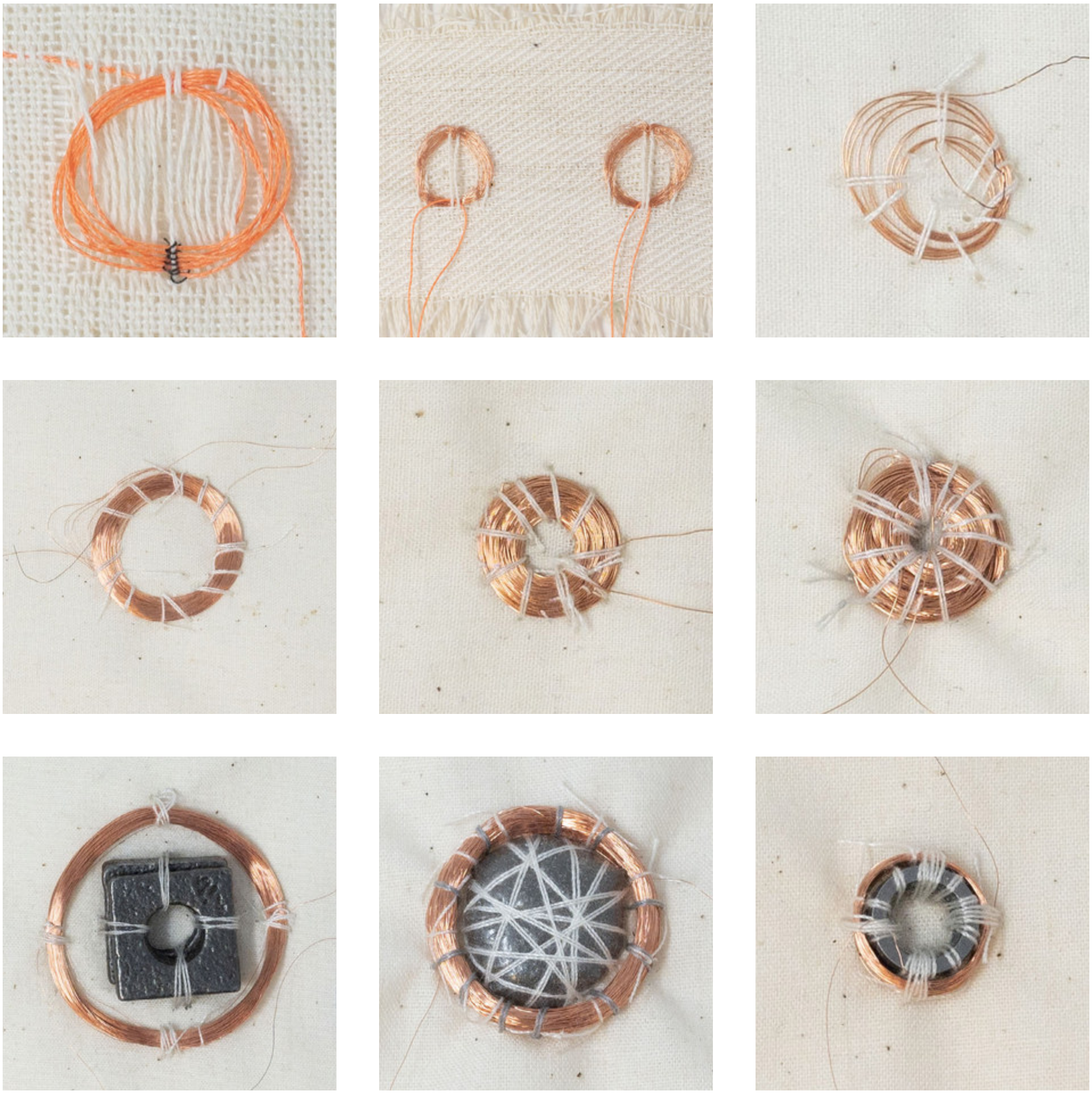
Detail of *The Embroidered Computer*: Textile relays connected through gold embroidery.

The Embroidered Computer, Posch and Kurbak's collaborative work, is a handcrafted and functional 8-bit computer with a network of relays embroidered in conductive gold thread. The relays switch between two possible states, sending information along to further relays by flipping a magnetic bead that rests on top of a gold wire coil. Changing the polarity of the coil (by way of switching which ends of the coil are attached to power and ground) causes the bead to rotate. The form factor of the flat coils in this piece, and their uncanny ability to make beads twitch and jump, motivated us to develop similar electromagnets that could lay flat between layers of fabric and cause them to expand and contract. Recent work by Doerger and Harnett (2018) also leveraged the abilities of flat electromagnets, using a more complex arrangement to create a continuous sliding motion rather than attracting and repelling[1]. We were also inspired by the challenge of integrating electromagnets into textiles in a way that felt formally rigorous and pure, following the rules of the medium: could they be constructed solely from the movements of a weft shuttle, or could the entire circuit be made from conductive yarns and threads? Could we bypass cutting, sewing, soldering or gluing and use only woven structure to build our actuators? Using copper magnet wire and a range of improvised coil-winding devices, we entered a stage of tinkering and testing in search of the optimal handcrafted coil design.

1-Bit Textile, a swatch created by Posch and Kurbak that occupies two distinct states (magnetic bead facing up or down) depending on the polarity provided to an electromangetic coil.

1. Doerger, Stanley R., and Cindy K. Harnett. 2018. "Force-Amplified Soft Electromagnetic Actuators." In *Actuators* 7, no. 4: 76. https://doi.org/10.3390/act7040076

coils

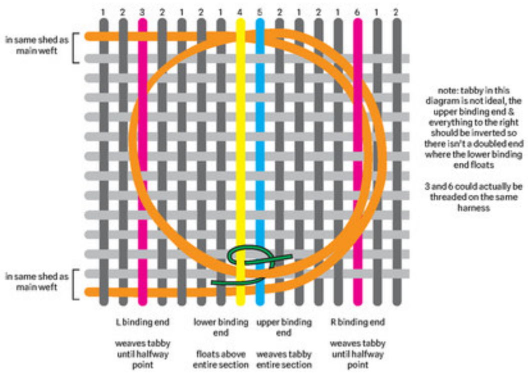


Simple helical or spiral coils create push-and-pull actuation; arrays of multiple coils can create side-to-side sliding actuation when powered in a specific sequence. Ferrous metal cores increase the strength of cylindrical electromagnets but had no effect on our flat versions. Handmade coils inevitably have overlaps where successive wire wraps cross each other, diminishing the strength of the magnetic field.

We chose to maximize the number of turns that would fit in a small low-profile coil by using thin magnet wire and a solid disk form factor rather than a hollow ring.

We experimented with forming coils on table and Jacquard looms, constrained by the mechanics of typical loom weaving that make any type of circle or spiral shape highly challenging to construct. Weaving is like Tetris: you can't go back and insert more material into fabric you've already woven because more recent wefts block the shed from opening in that section. A coiled wire, repeatedly traveling between the fell line (the most recent part of the cloth that's been woven) and a previously woven section, would be difficult to weave without breaking or bending some of the foundational rules. Adding supplementary wefts, whose motions are more like knotwork or embroidery than weaving, was one strategy to fix the coil to the cloth. Another approach (shown in variation 3) was to weave the coil within the cross-section of the fabric, rather than on its face, as a doubleweave tunnel. These precisely choreographed movements, and the wire coil's continuity, are only possible on shuttle looms.

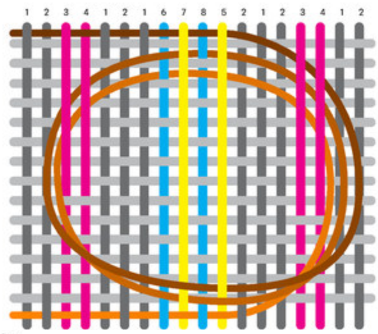
1. Simple coil held by single ends and binding weft



Weaving steps:

1. main weft in tabby - 135, 246
2. 1 pick copper weft in tabby
3. main weft in tabby mod1 until halfway point - 1345, 246
4. main weft in tabby mod2 until top of square- 13456, 2346
5. copper enters shed from far left & travels upward - 3456
6. copper enters shed from far right & travels downward - 4
7. binding weft goes over 4, under R side of copper weft from below, under 4 from L-R and through its own loop
8. repeat 5-7 many times, ending on 5
9. 1 pick copper weft in tabby

2. Coil woven into multiple binding ends

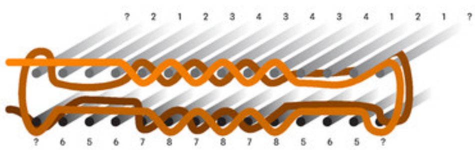


Weaving steps:

1. main weft in tabby - 1357, 2468
2. 1 pick copper weft in tabby - halfway across
3. main weft in tabby mod1 until halfway point - 13578, 24567
4. main weft in tabby mod2 until top of square - 134578, 234567
5. copper weaves 1st upper tabby shed - 34567
6. copper weaves 1st lower tabby shed - 5*
7. 1 pick main weft in tabby mod2 - 234567
8. copper weaves 2nd upper tabby shed - 34578
9. copper weaves 2nd lower tabby shed - 7*
10. 1 pick mainweft in tabby mod2 - 134578
11. repeat 5-10 many times (main weft frequency can be reduced)
12. 1 pick copper weft in tabby

Note: this method and the "simple" method could potentially embed the coil between layers of doubleweave - just need enough access to the space between layers to secure the bottom of the coil in place

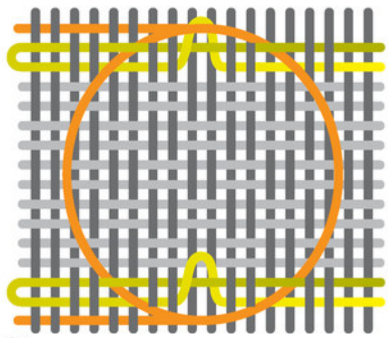
3. Coil woven on 2 layers that slip warpwise



Weaving steps:

1. add bar at back of loom that pulls upper-layer warps back by _" (height of coil)
2. re-tension at front and weave 1" tabby
3. main weft weaves 2 separate layers for 2" or more - 13, 123457, 24, 123468
4. copper weft enters on upper layer - ? 3
5. copper weft loops around and weaves on lower layer - 12347
6. copper on upper - ? 4
7. copper on lower - 12348
8. repeat 4-7 many times
9. weave _" (height of coil) of tabby with main weft on upper layer only
10. cut sacrificial ends (the ones at the edges of the coil that force it to be wider)
11. remove back tension bar and insert at front, pulling toward tie-on rod until upper and lower layer fell lines match up
12. continue weaving - layers can be separate or connected

4. Main wefts catch premade coil with a knot that can tighten



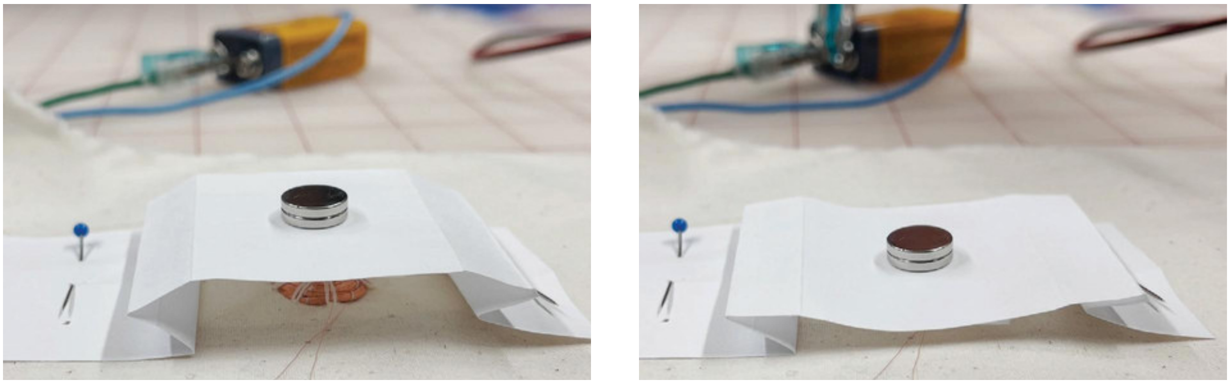
Weaving steps:

1. main weft weaves base structure (basketweave is useful - 2 wefts in a row have same shed, allowing knots to be easily tightened by pulling on the previous weft)
2. lower tail of coil weaves 1 pick of base structure, coil rests on top of all warps
3. binding weft weaves 1 pick with a long loop pulled up through the center of the coil
4. binding weft weaves 1 pick in same shed (plus some floats in the center?), passing over the coil and through the loop of the previous pick
   This pick can be split into left half & right half to make it easier to pass the shuttle
5. tighten loop by pulling on the binding weft
6. main weft weaves base structure for _" (height of coil)
7. repeat steps 3-5
8. upper tail of coil weaves 1 pick of base structure

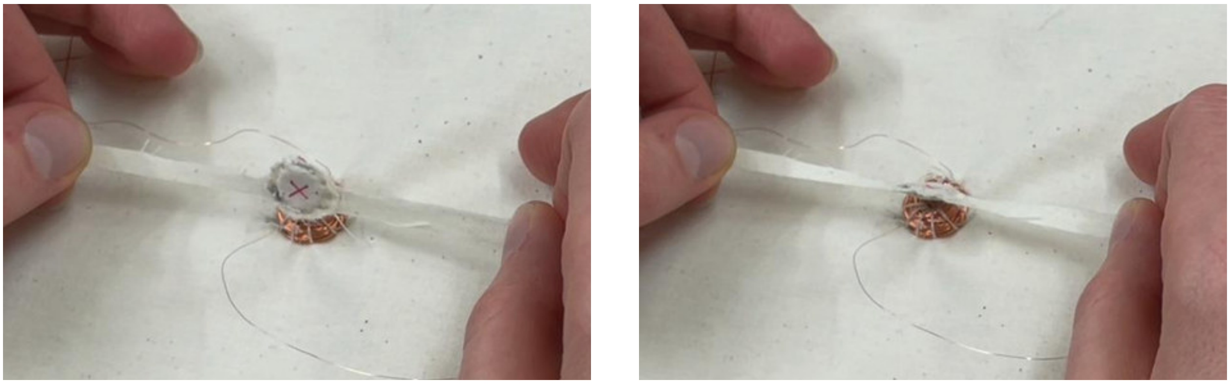
Note: binding wefts don't have to travel across the entire width of the fabric, they can be partial wefts
This also frees up the base structure to be anything - the binding weft will still be the same shed twice in a row but doesn't need to be camouflaged within the rest of the fabric

Prototype of a loom-controlled coil, with orange fishing line used as a stand-in for magnet wire. The darker weft yarn is a binding thread that keeps the bottom edge of the coil anchored to the base fabric. It must be tightened by hand because it is behind the fell line and cannot be beaten into place by the reed.

testing

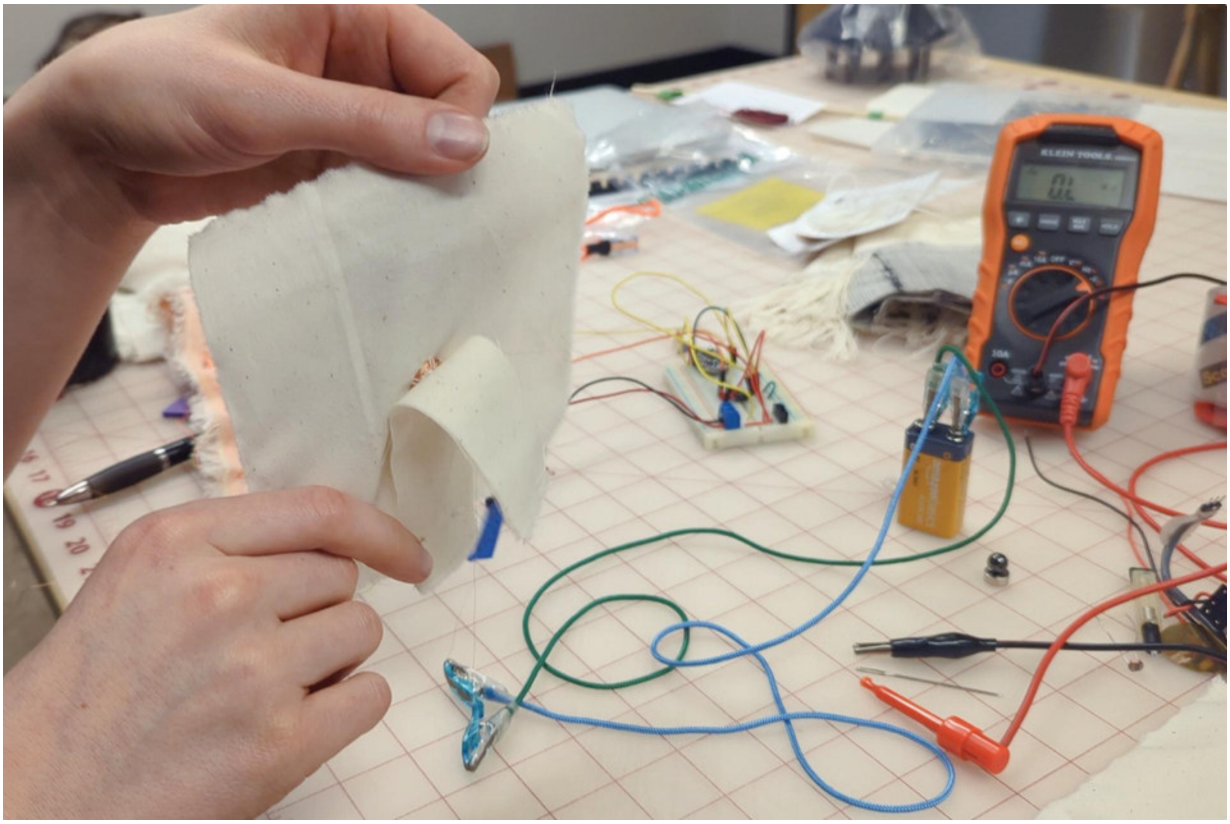


Testing up-and-down actuation with a single coil made from 30-AWG magnet wire with a magnet fixed to a pleated paper model. The stiffness of the paper keeps the magnet a fixed distance from the coil until it turns on.



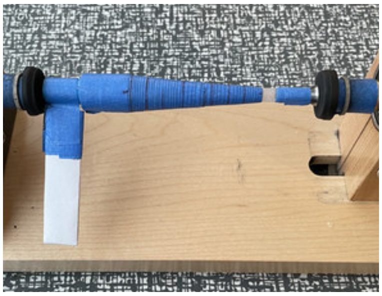
The same coil drives tilting actuation in a magnet that is magnetized across its diameter, rather than through its thickness (the typical direction of magnetization). This is similar to the flipping movement of the magnetic bead.

An assembly of two figure-eight coils (only the top one is visible). The two sides of the figure eight have opposite polarity. The magnet is drawn to a distinct point on the assembly for each combination of the two coils' polarities.

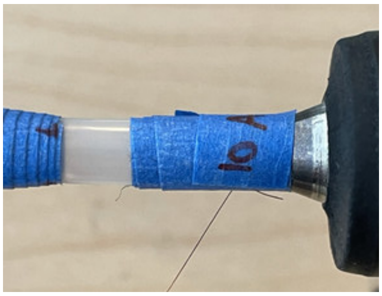


We envisioned early on that we wanted to make a wall-mounted or vertically-hanging textile with our electromagnets, so testing the strength of each coil on a vertical surface was essential.

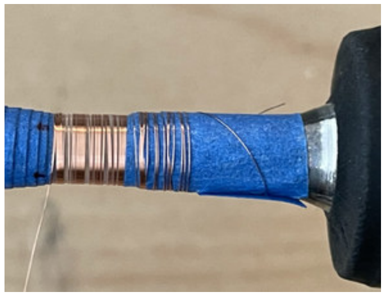
how to make a coil



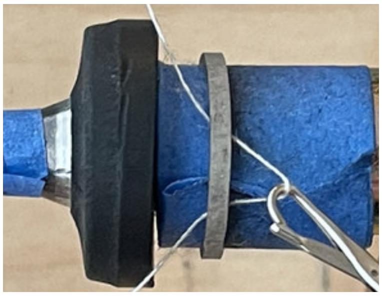
1. Mount your winding device* on a double-ended bobbin winder.



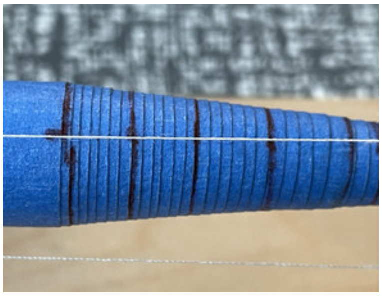
2. Tape magnet wire to the small end.



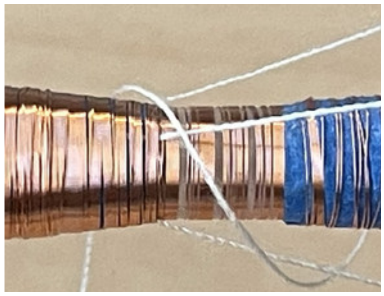
3. Wind at least 20 rotations. This will be the “tail” of the coil.



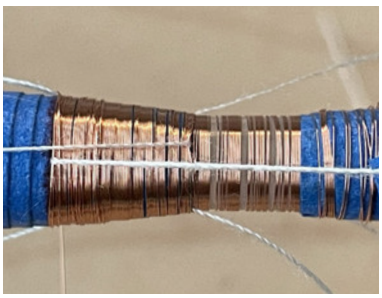
4. Secure the end of a 12” piece of thread to each end of the bobbin winder (rubber bands hold it well).



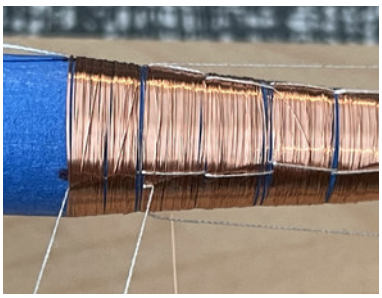
5. Repeat with 3 more pieces of thread and space them equally. These will be the counting threads.



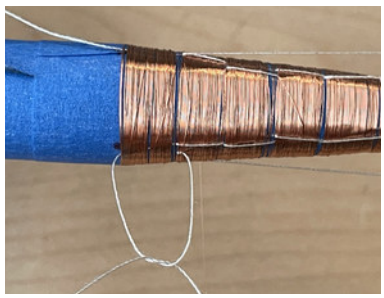
6. Wind 100 rotations, moving slowly from the start to the end of the first marked section. Wire wraps should be side by side, not overlapping.



7. Take the two ends of each counting thread and swap their positions, crossing over the wire wraps. Secure in place as in step 4.

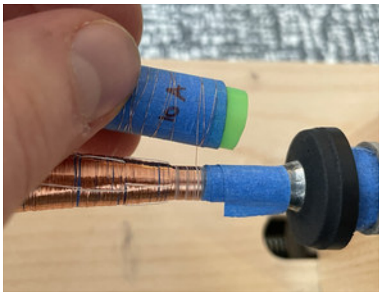


8. Repeat steps 6-7 until each section on the winding device has been filled.



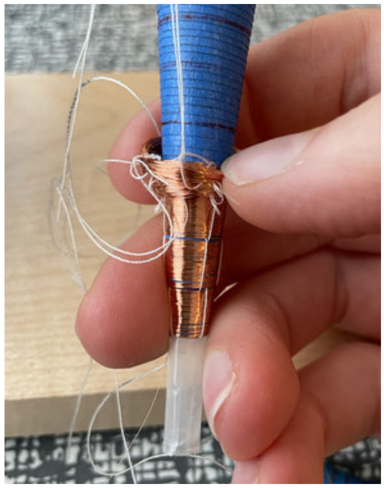
9. Take the two ends of each counting thread and tie them in a single knot.

*Our winding device is a boba straw affixed to a regular straw with tape. Be creative! Any tapered form will work.



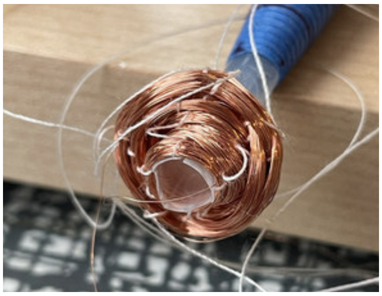
10. Wrap the tail of the coil around a bobbin.

11. Remove the winding device from the bobbin winder.

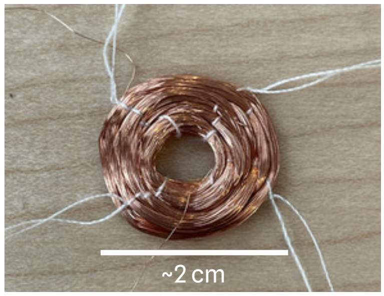


12. Gently push the coil towards the tapered end.

13. Pull both ends of each counting thread to tighten the slack running through the coil.



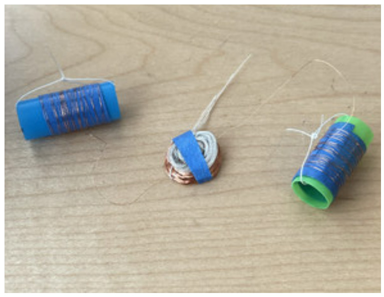
14. Push the coil to the very end of the winding device and re-tighten the counting threads.



15. Remove the coil and tie each pair of counting threads in a double knot.

16. Where the coil is still connected to the spool of magnet wire, unspool about 24", cut and wrap around a bobbin.

17. Twist all counting threads together and lower them onto the surface of the coil (they will naturally spiral) to keep them tidy and to mark the upper face of the coil.



18. Tape the counting threads in place. Note: labeling the start and end bobbins and the upper face of the coil is important when inserting and wiring the coil so it has the desired magnetic polarity when powered.

actuating folds

Testing the behavior of several coil designs got us excited about the strength and range of motion of a simple latch-style actuator that attracted and repellled a permanent magnet. We began constructing sewn mockups of fabrics with flaps that could open and close, knowing from previous samples that these flaps could be woven in a single piece using partial weft passes.

Certain positions of flaps cast shadows on the fabric when lit from above or bounced their neon color onto the surrounding fabric. We became intrigued by not only the animated movement of flaps moving back and forth, but also the concept of an “analog” color-changing fabric: rather than using thermochromic inks or LEDs, the fabric’s apparent color could shift due to the behavior of light.

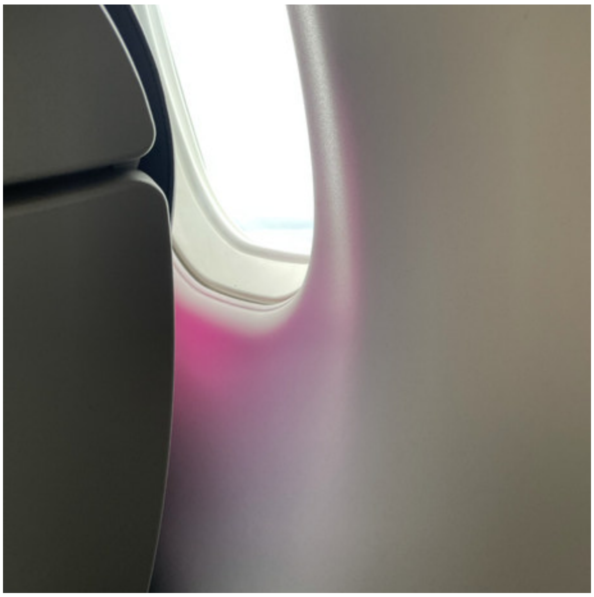
First sewn prototype using a combination of monochromatic shadows and reflected orange light from a flap’s neon interior.

Second sewn prototype, with neon orange ripstop lining the interior of every flap.

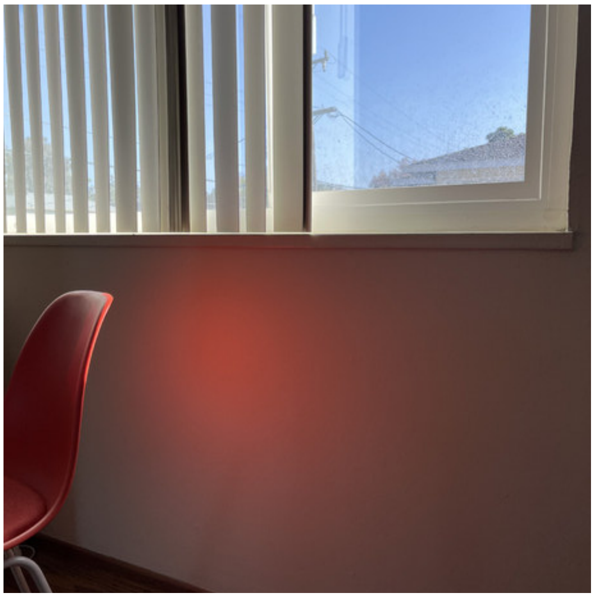
Reverse side of the second prototype. The base fabric is translucent and shifts in hue when neon strips are near.

color phenomena

Robert Rauschenberg, *Untitled (Early Egyptian), 1973*, sand on acrylic on cardboard with rebar and cement. Photo courtesy of the Portland Museum of Art.



Reflection from a plane passenger's pink jacket.



Sunlight bounces off a red plastic chair onto a wall. Photo courtesy of Jessy Lu.

Our design was inspired by the behavior of light scattering. When light hits the brightly-colored surface and is reflected, it changes the hue of nearby surfaces where it lands. This optical trick can make it seem like light is emitted, rather than reflected. Light is causing the color change—a lightbulb, neon tube or LCD screen—and the pigment concentration and intensely saturated color of the material it bounces off of create a colored effect. Examples of this phenomenon, from Rauschenberg sculptures to everyday objects, prompted us to wonder how this effect might be realized in woven form and how movement could heighten its chromatic and illusory properties.

Bike light in red backpack accidentally switched on.

Exit lights illuminating the floor in a museum hallway.

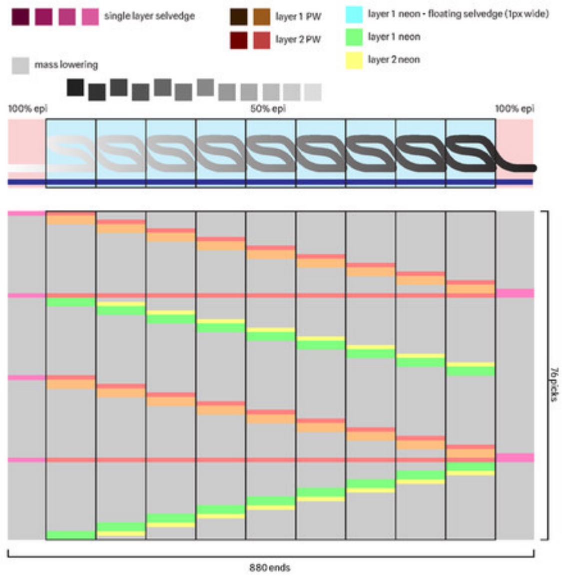
A building permit seen through backlit blinds.

Lights hidden under stair treads cast a warm glow.

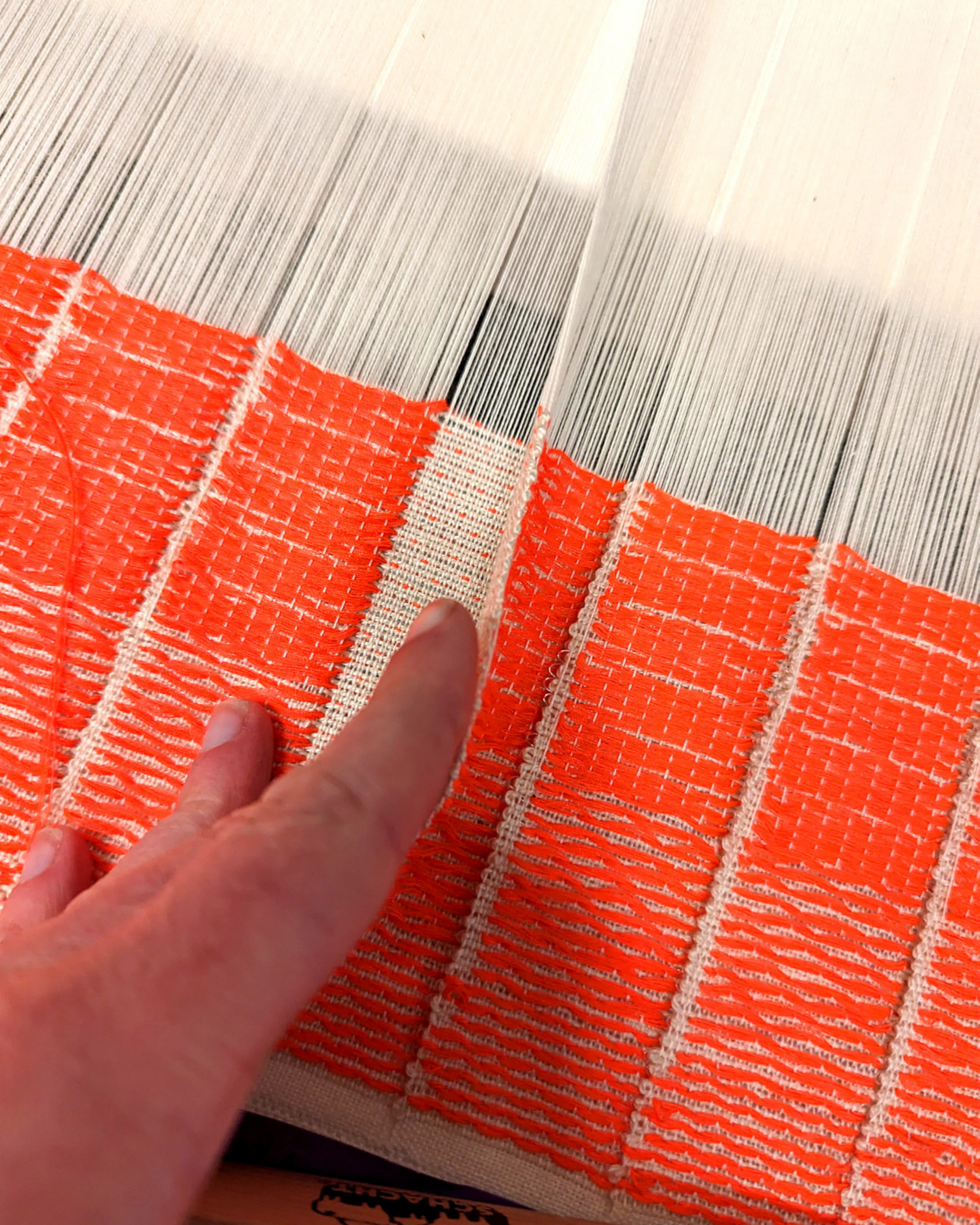
prototyping

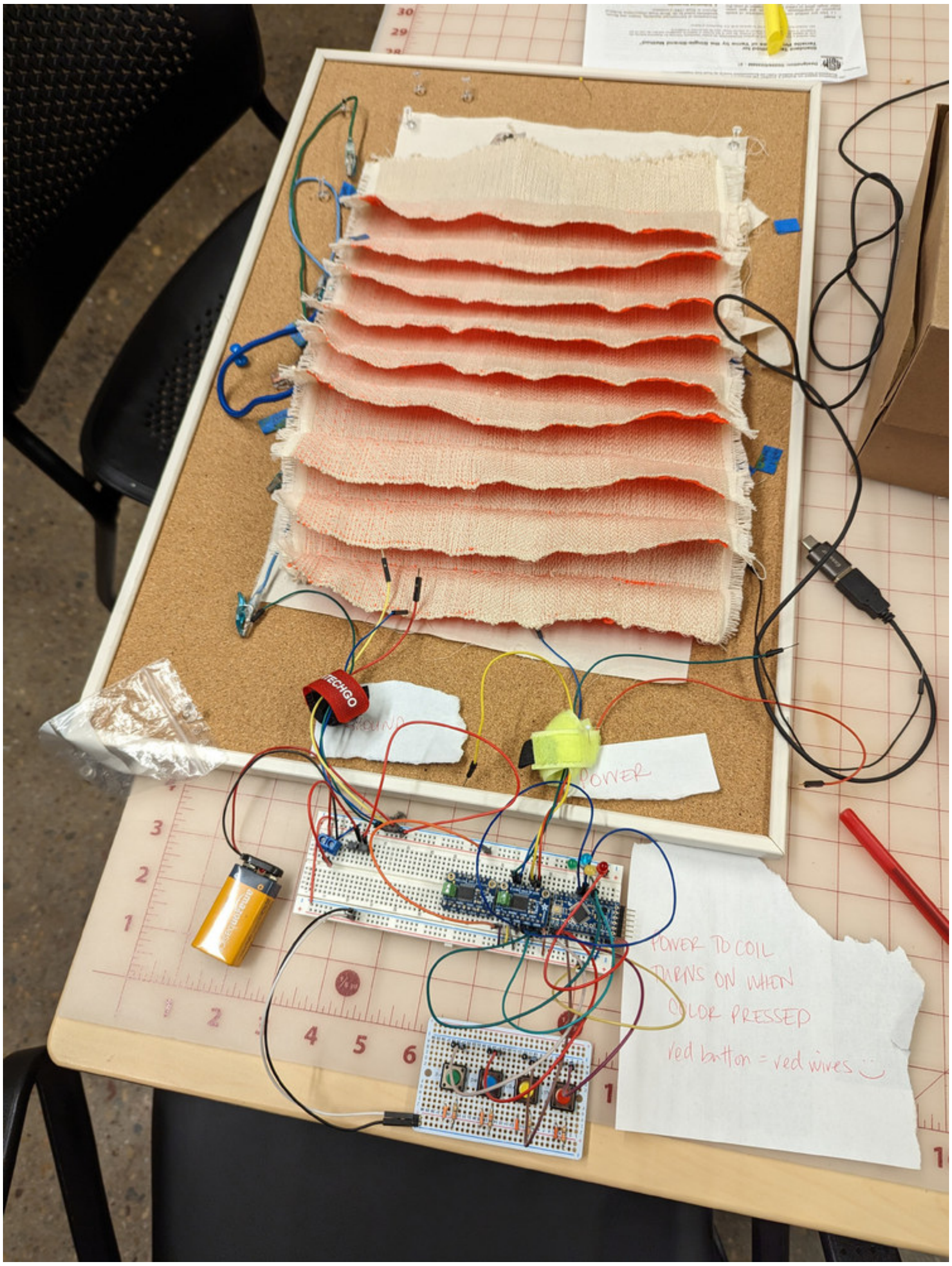
After collecting samples and inspiration, we envisioned a final piece that would play with electromagnetics and light scattering.

The first woven prototype towards this goal itself contains several prototypes of weave structures and files, refined and added in sections while the fabric was still on the loom. The primary goal of these iterations was to maximize the color intensity of the neon orange sections, which is not necessarily the same as maximizing the amount of neon yarn in the fabric. The first three sections have the same number of neon picks per inch, but in the first two the yarn is woven as floats in a satin formation tied down to a plainweave base, while in the third it is a sparse plainweave floating over a plainweave base with no warp yarns shared between the two. This allows the neon yarns to lie flat and straight, covering the base cloth, where tie-downs cause them to deflect into wavy lines and expose the white wefts underneath them. Occasional “warp exchanges” (sections



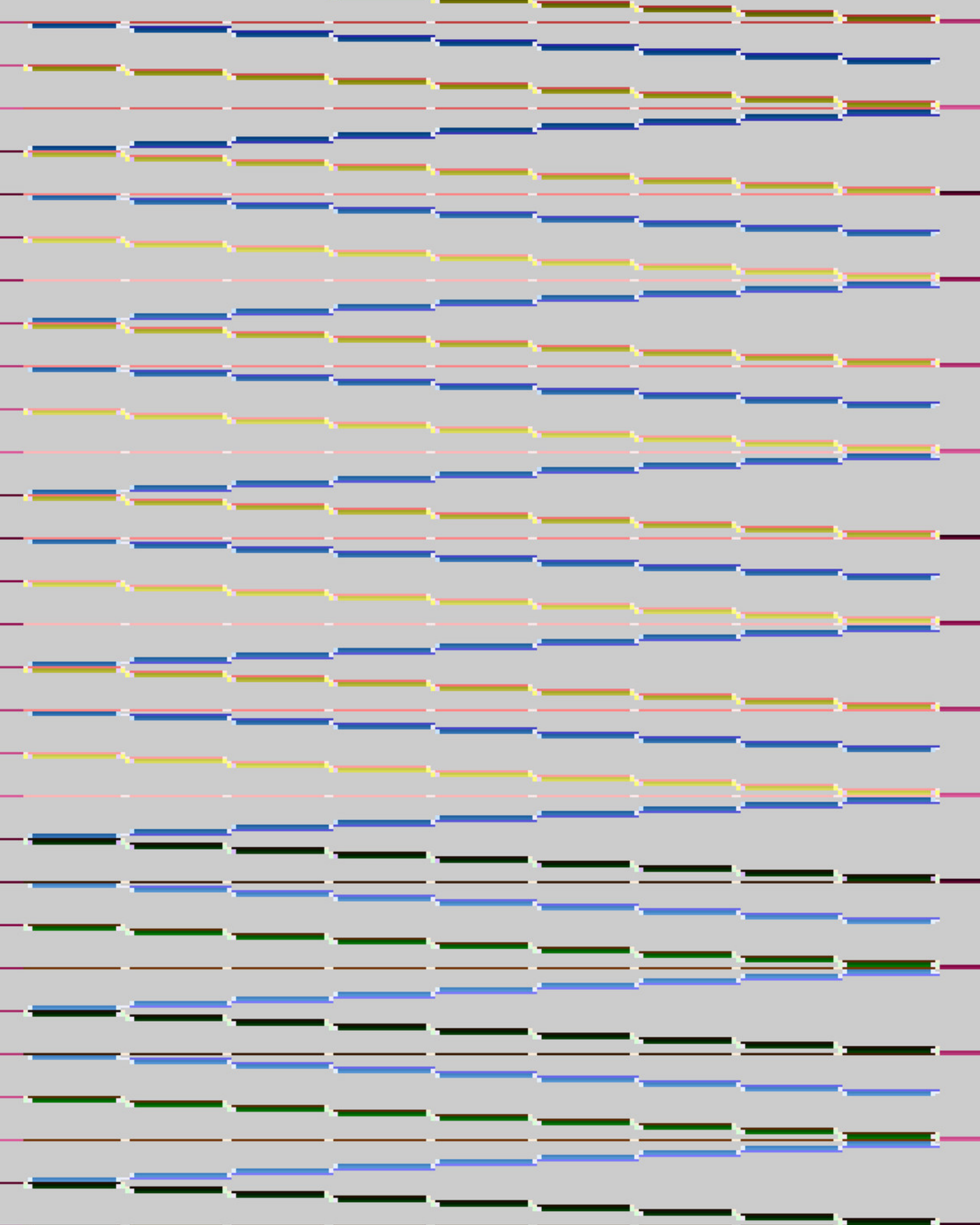
where the warps on the neon layer, ie. every 5th yarn, are brought back into the plainweave base and are replaced by a different set, ie. every 3rd yarn) keep the fabric stable and prevent warp tension discrepancies. Further sections in the prototype are sites of tiny tweaks and error corrections, like offsetting the location where the neon yarn travels from the face of the fabric to the reverse. In theory, this yarn shouldn’t be visible when the flap is closed, but yarns in woven structures get pushed around and sometimes seize opportunities: gaps in the weave structure at the hinge of the flap allow the neon to peek through. Shifting the hinge to the left by four warp ends isolated it from the traveling neon yarns, preventing this unwanted exposure. This was particularly important to refine, as the vision for the work was a plain white fabric transforming into a glowing orange display, flickering and fading, without immediately revealing how the light-scattering effect worked. The piece was designed so that at the viewer’s eye level, the glowing orange sections could be seen but the interior of the flap would never be seen directly. Fine-tuning the interaction of multiple weft systems and weave structures was necessary to maintain the ephemerality and sense of wonder at this work’s core.

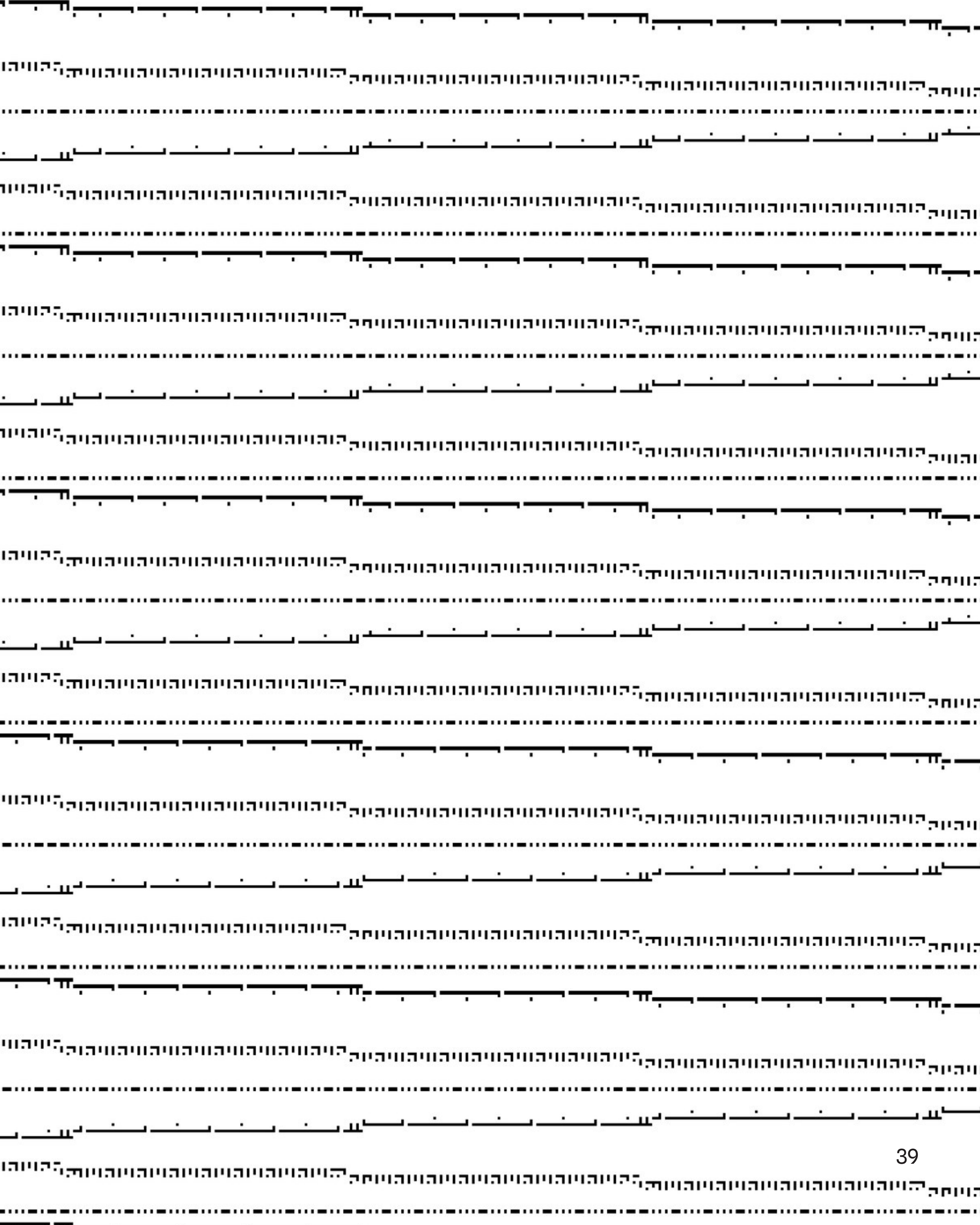




Adding actuators to the first woven prototype after removing it from the loom.

Following pages: sections of the weave graphic and weave draft for one of this fabric’s later iterations.

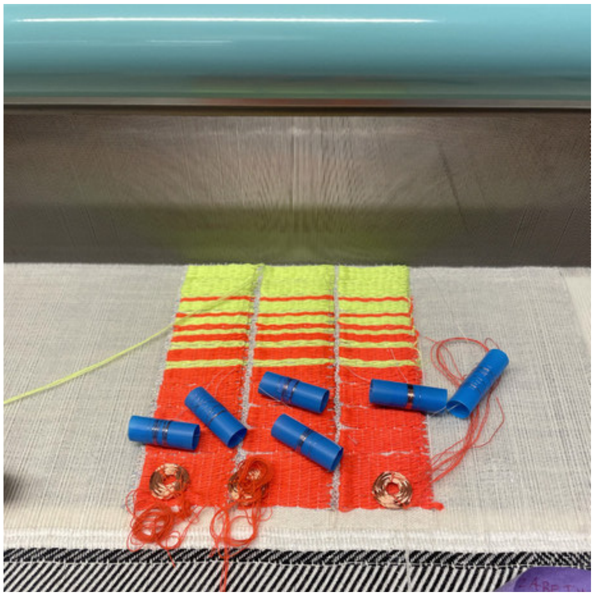


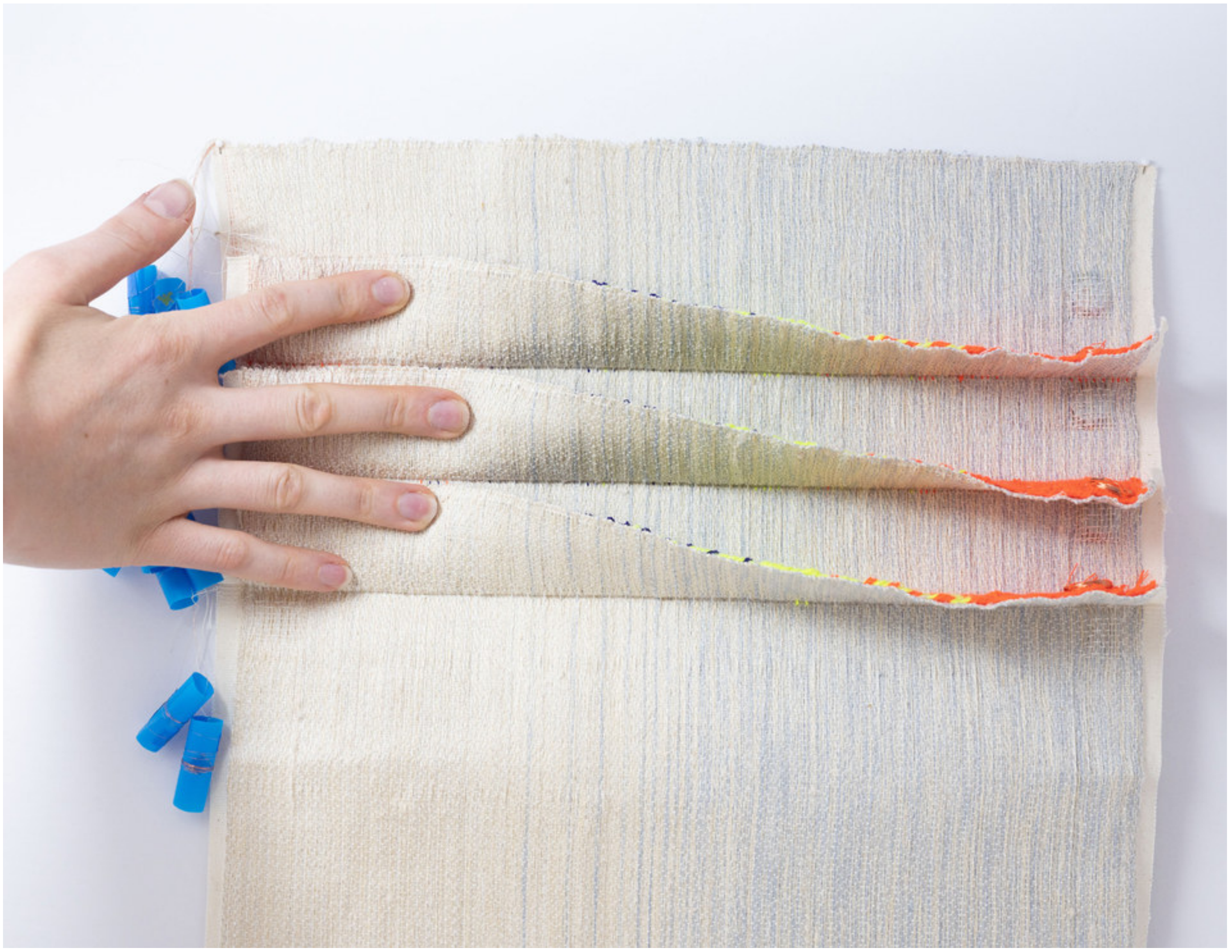


The next prototype tested mixing of multiple neon colors, which had to be done with a relatively coarse gradient stripe due to the constraints of shuttle passes in the existing file configuration. Still, the colors showed up as a diffuse blend due to the flaps' translucency and light-scattering abilities. This was also the first iteration in which magnets and coils were added on-loom, providing a very necessary dry run before Elizabeth wove the final piece.

It became clear when testing these embedded actuators that while they performed well in isolation, the "real-world" conditions of opening and closing a stiff fabric flap required more force than they were capable of. We wanted this piece to have a crisp, textured handfeel like linen or handmade paper, and for the flaps to hold their shape like the earliest sewn muslin samples. A combination of linen, paper, silk and metallic yarns met these requirements, but could only be used in the weft direction since changing the warp yarn would be a laborious task and not all yarns are suited for use as warps.

Because this partial-weft fabric is oriented sideways while on-loom, the stiff wefts travel along the vertical axis of the finished piece and stiffen the “hinge” where each flap meets the base, while the long unsupported length of the flap is relatively soft. Many woven fabrics, including this one, are inherently anisotropic, with distinct physical properties in the vertical and horizontal directions, so stiffness and bending behaviors are highly dependent on the “grain” or orientation of the material. We realized that the entire design would need to be rotated 90º, necessitating a move away from the partial-weft structure we developed and towards a completely new layer system in order to build a fabric that was conducive to actuation.





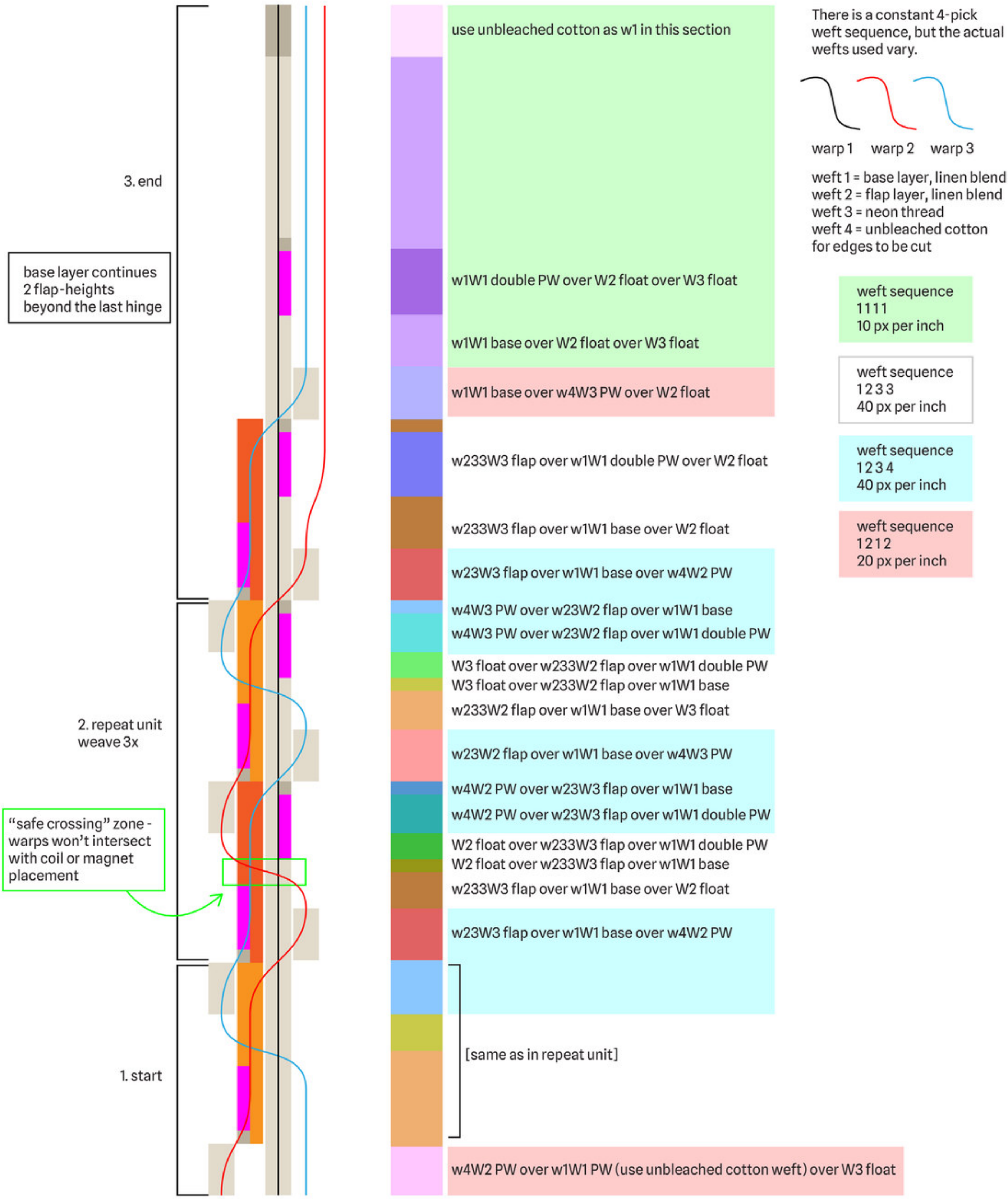
materials

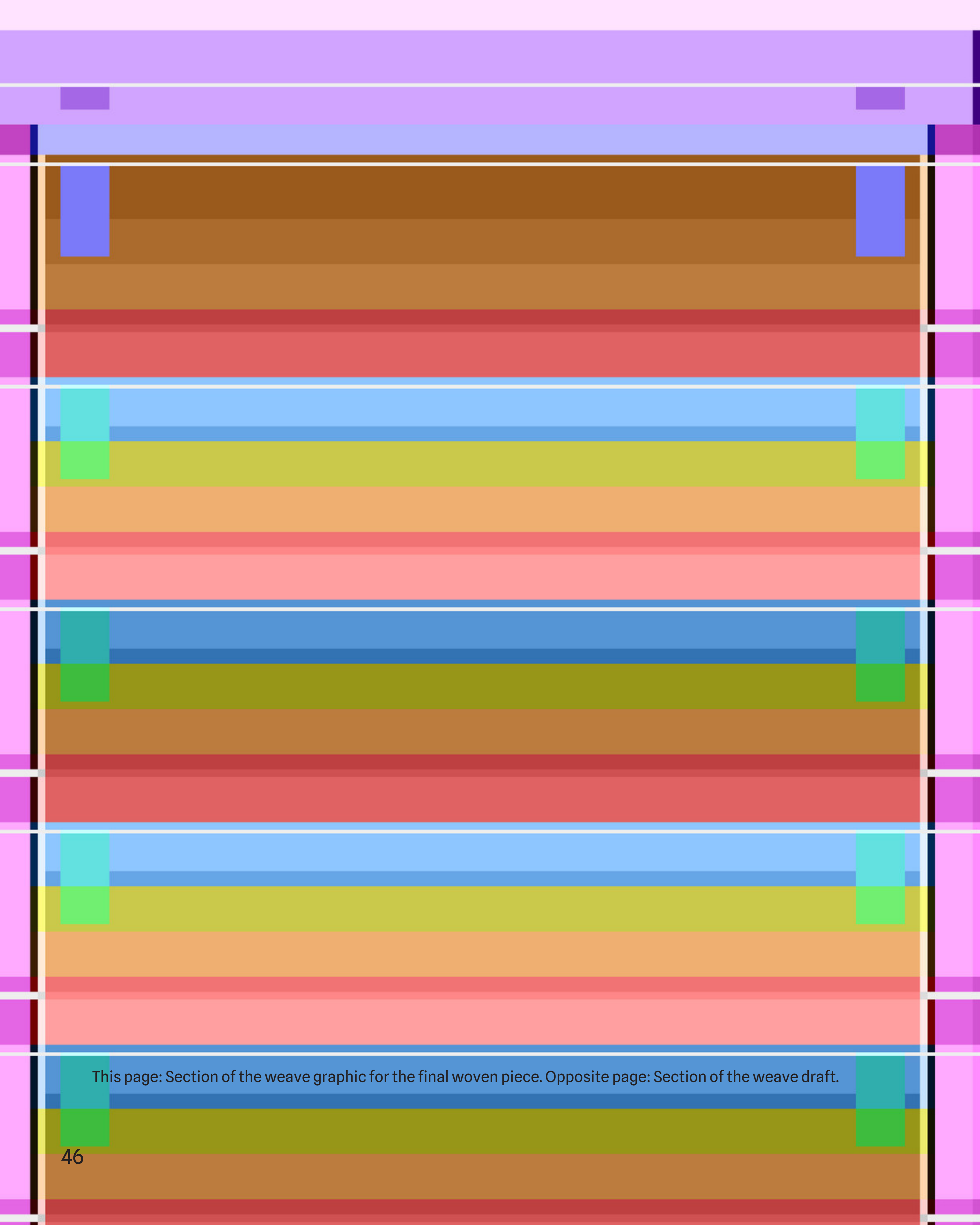
We initially used nylon monofilament combined with undyed cotton to lend stiffness to the fabric, but found it too rigid and a bit unwieldy to work with. Instead, we shifted toward a “kitchen-sink” weft with many yarns bundled together, eventually choosing a mix of bleached and unbleached linen, paper, and raw silk. Thin elastic yarn was briefly tested as a supplemental warp to help flap hinges snap closed, but we moved away from this idea when we rotated the design for the final iteration. Neon polyester sewing thread, strong neodymium magnets, and 40-AWG magnet wire (copper with an enamel coating to prevent coils from shorting) were selected to maximize the visual impact and actuation strength of the fabric.

making magnetic reverberations

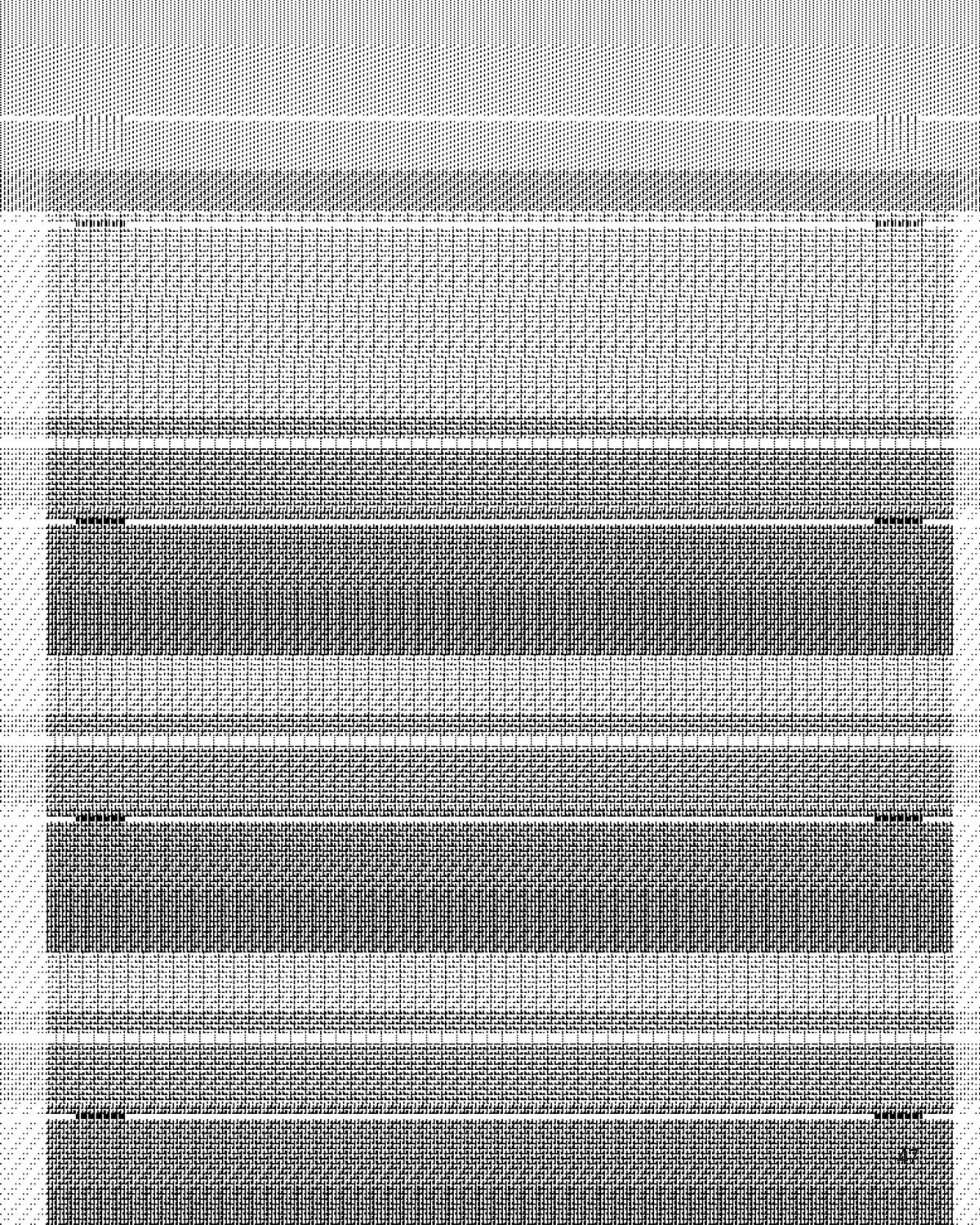
When we reoriented the grain of this fabric, we modified our style of diagramming structures and started to formalize a new suite of post-processing steps. Our previous prototypes required very little finishing work, as the partial-weft structure allowed each flap to be independently formed on-loom with a long selvedge edge. In the rotated version, the short edges of the flaps are located at the selvedges and the long edges are attached to a "sacrificial" layer that is cut after weaving to free the flap from the multi-layer structure. This was necessary because woven fabrics must have continuous warp yarns, in this case connecting one flap to the next, whereas the wefts can be discontinuous.

A quick pre-final prototype validated that the fabric's stiffness properties aligned with what was needed for smooth actuation and allowed us to safely test the cutting and separating steps. There was ongoing discussion about whether` modifying fabrics in this manner constituted rule-breaking, or strayed from our stated goals of developing complex structures through weaving alone. Ultimately, we proceeded with these methods and used a high level of precision (inspired by the craftsmanship of embroidery) when finishing edges, hand-stitching components to secure them in place and making electronic connections.


3. end
base layer continues
2 flap-heights
beyond the last hinge
2. repeat unit
weave 3x
“safe crossing” zone - warps won’t intersect with coil or magnet placement
1. start
use unbleached cotton as w1 in this section
w1W1 double PW over W2 float over W3 float
w1W1 base over W2 float over W3 float
w1W1 base over w4W3 PW over W2 float
w233W3 flap over w1W1 double PW over W2 float
w233W3 flap over w1W1 base over W2 float
w23W3 flap over w1W1 base over w4W2 PW
w4W3 PW over w23W2 flap over w1W1 base
w4W3 PW over w23W2 flap over w1W1 double PW
W3 float over w233W2 flap over w1W1 double PW
W3 float over w233W2 flap over w1W1 base
w233W2 flap over w1W1 base over W3 float
w23W2 flap over w1W1 base over w4W3 PW
w4W2 PW over w23W3 flap over w1W1 base
w4W2 PW over w23W3 flap over w1W1 double PW
W2 float over w233W3 flap over w1W1 double PW
W2 float over w233W3 flap over w1W1 base
w233W3 flap over w1W1 base over W2 float
w23W3 flap over w1W1 base over w4W2 PW
[same as in repeat unit]
w4W2 PW over w1W1 PW (use unbleached cotton weft) over W3 float
There is a constant 4-pick weft sequence, but the actual wefts used vary.
warp 1
warp 2
warp 3
weft 1 = base layer, linen blend
weft 2 = flap layer, linen blend
weft 3 = neon thread
weft 4 = unbleached cotton for edges to be cut
weft sequence 1111 10 px per inch
weft sequence 1233 40 px per inch
weft sequence 1234 40 px per inch
weft sequence 1212 20 px per inch

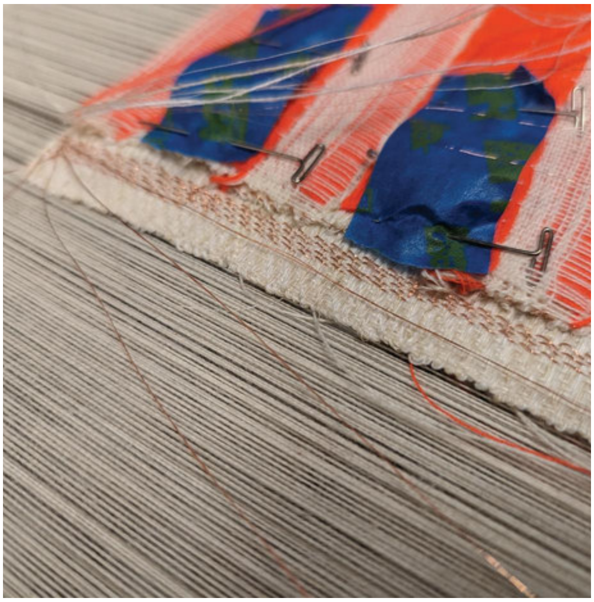


This page: Section of the weave graphic for the final woven piece. Opposite page: Section of the weave draft.

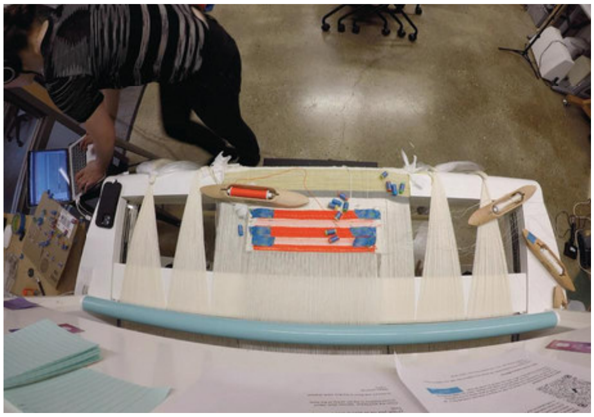


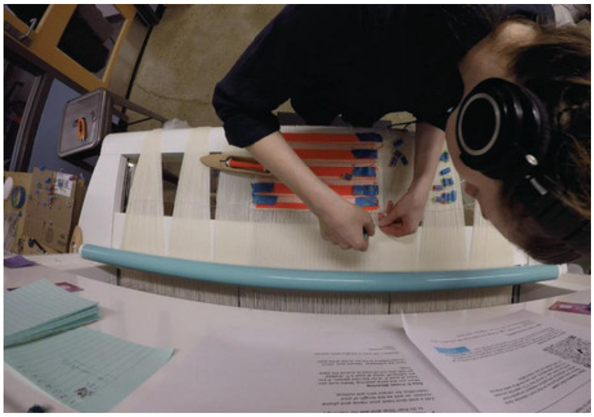
weaving

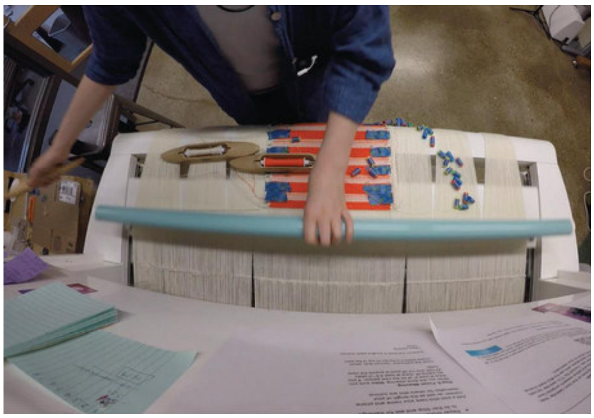
Preparing 16 800-turn coils, with labeled and color-coded bobbins to ensure they could be correctly identified when wiring the final piece.



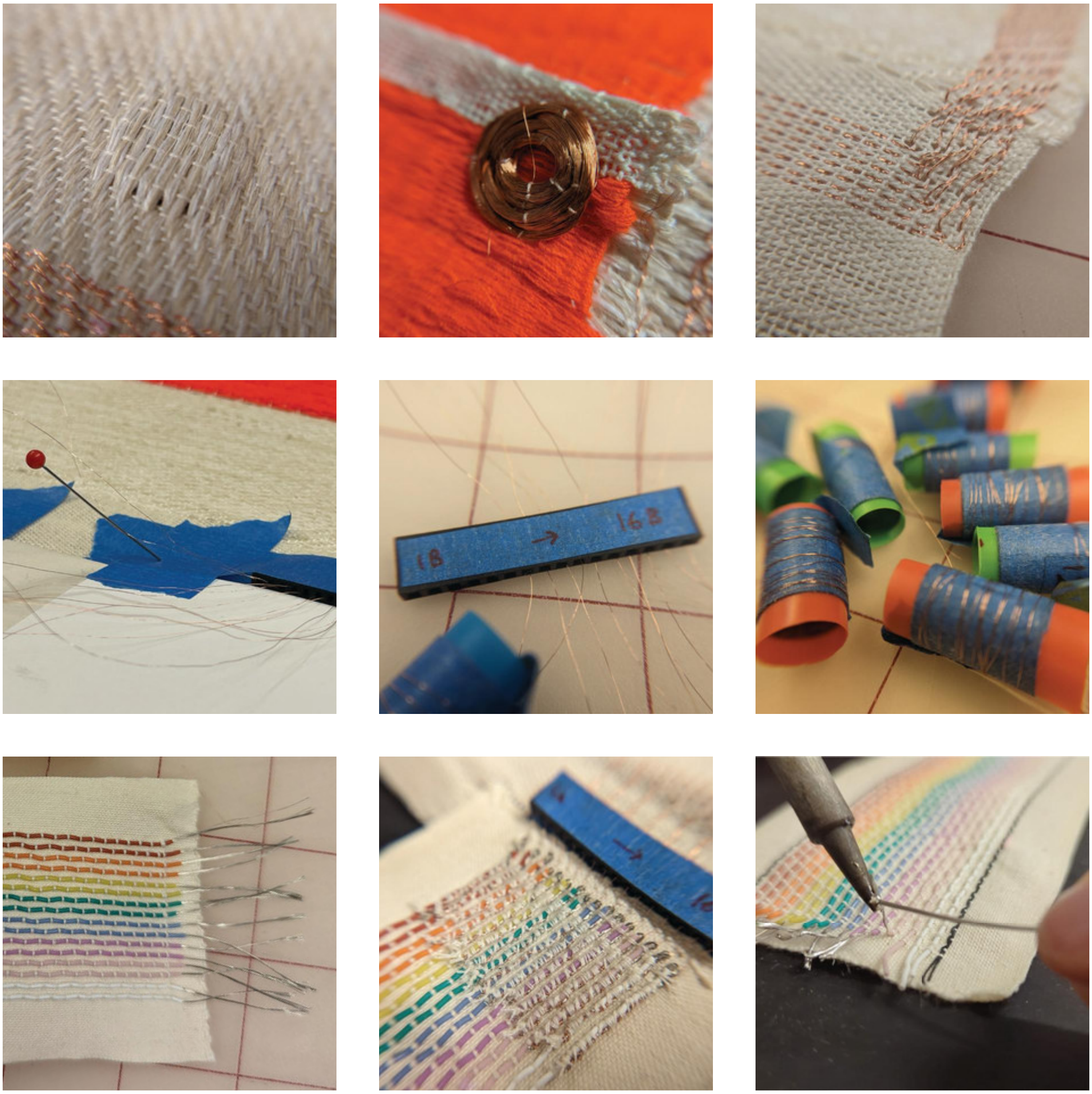
Routing the magnet wire was not explicitly defined in the weave draft. We used the existing twill structure as a guide for when to bind the wire to the fabric.



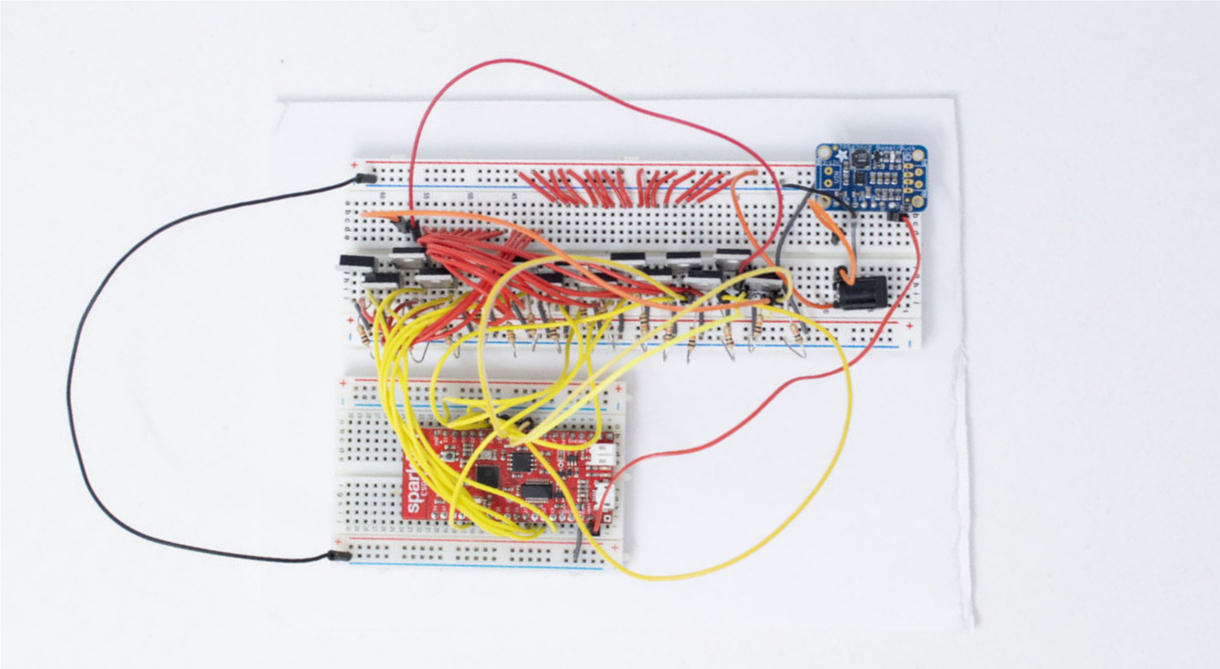




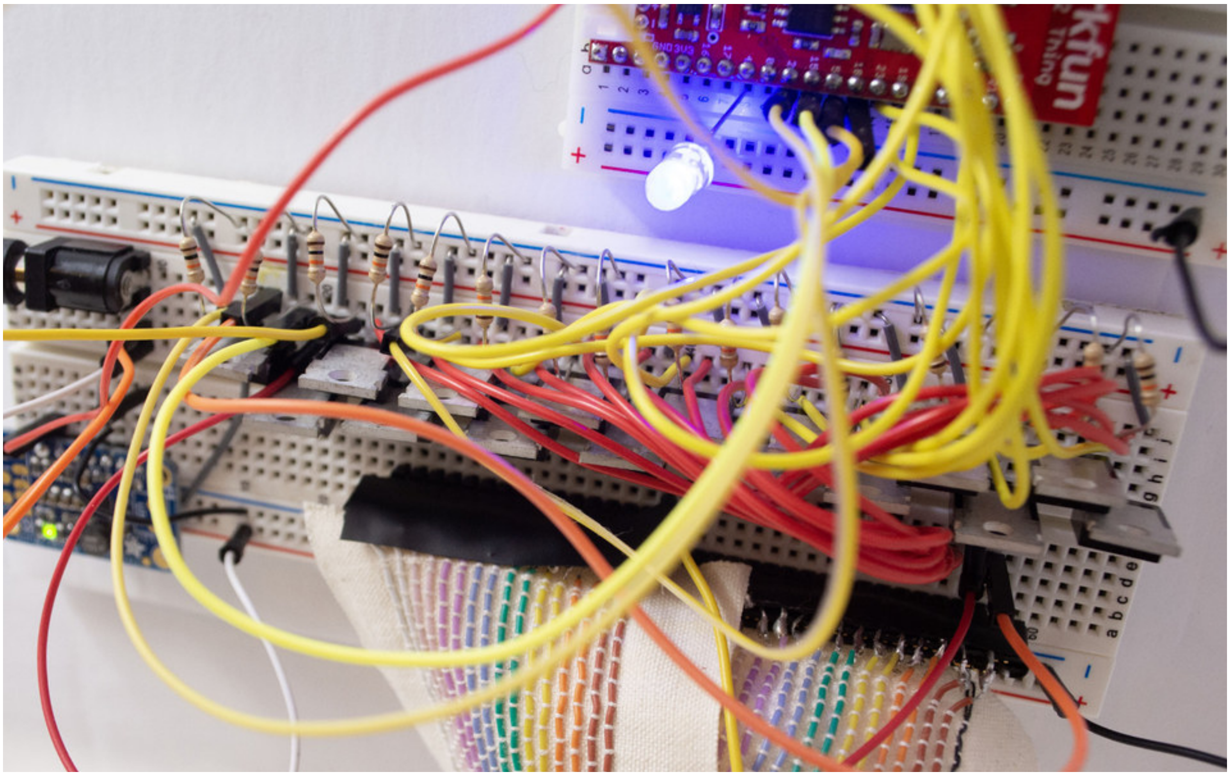
Three days of GoPro weaving footage: youtu.be/mfslgF5V1hU?si=x_oDOn-3UnosptL3



The detail work of connecting hair-thin magnet wires to electrical wires was aided by the use of boba straws to hold wire ends during weaving, and a hand-made fabric ribbon onto which connections could be sewn.

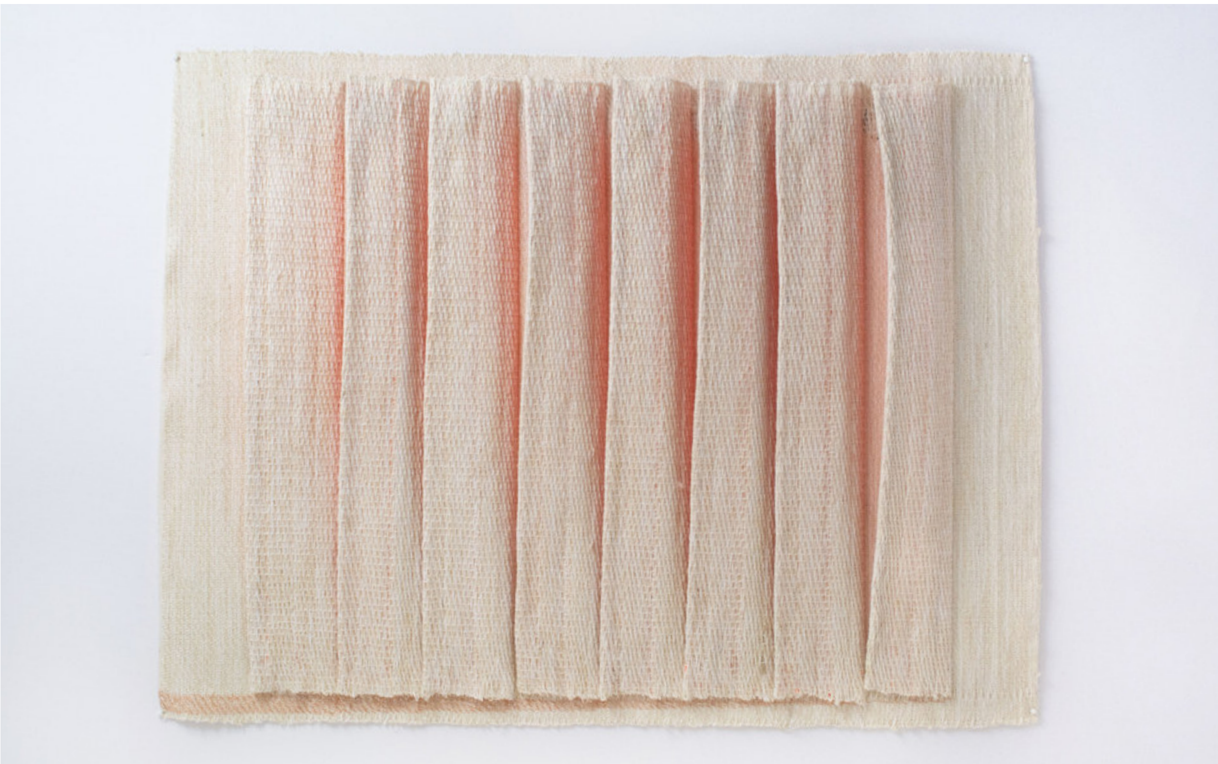


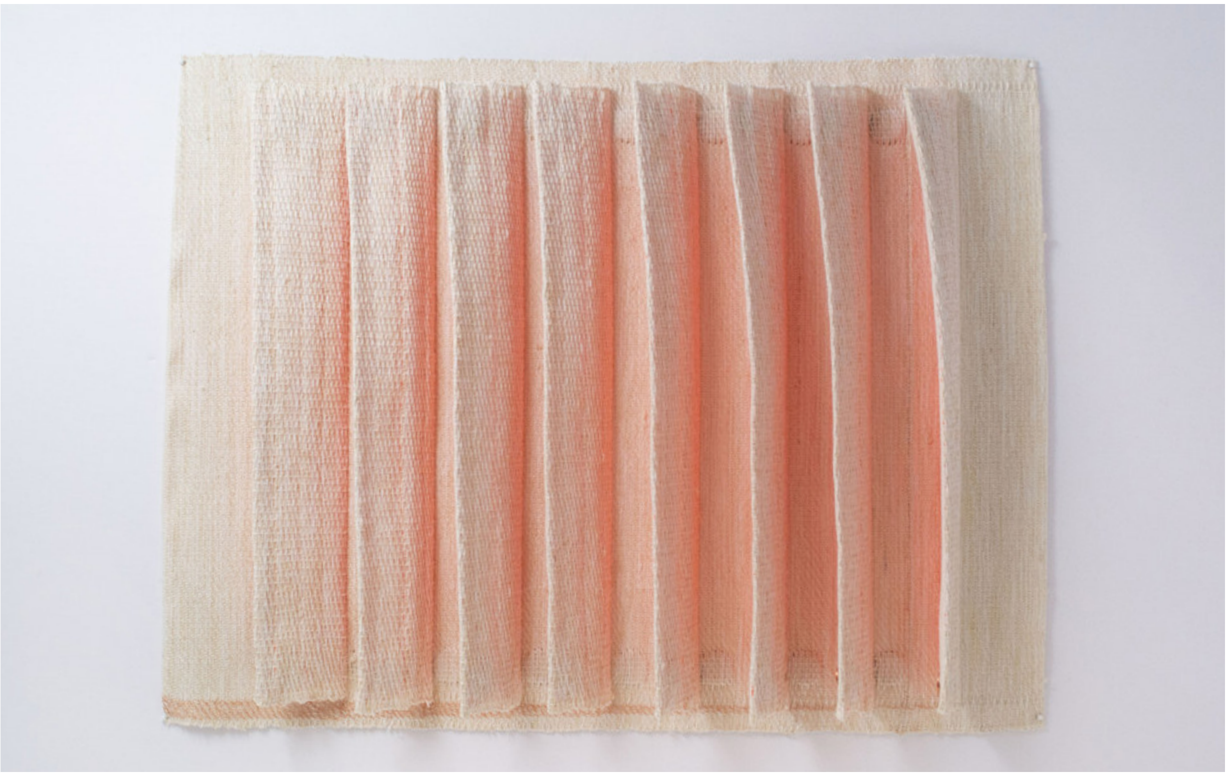
The guts consist of an ESP32 board, 9V 2A power supply, and 16 MOSFETs, one connected to each coil, that allow the coil to be programattically turned on and off. The ESP32 board lets us talk to the internet, and enables us to create a web-based interface for controlling the installation.



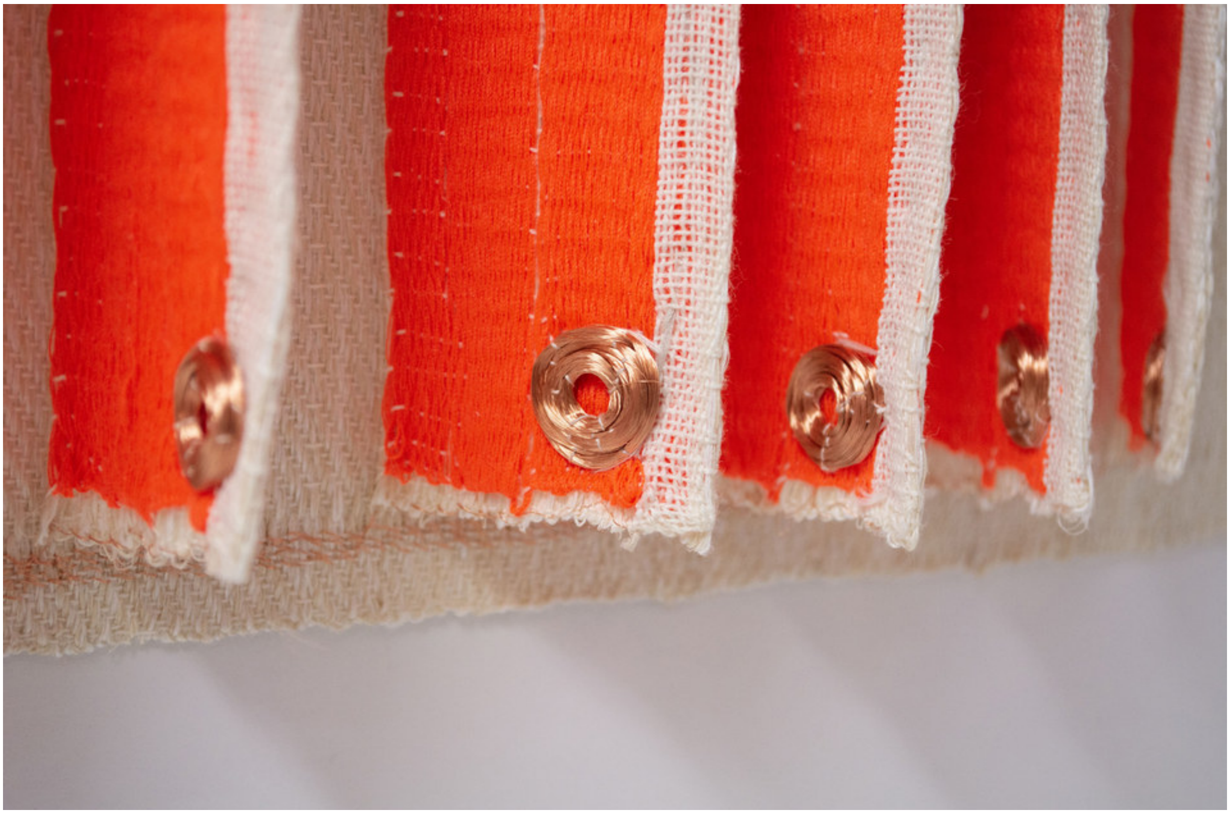
magnetic reverberations

The finished piece has 16 electromagnetic actuators that can be controlled individually. We built a web interface to allow real-time movement of the flaps based on a user's random tapping or carefully choreographed sequence.





Magnet wires weave into the cloth structure towards a single connection point on the back of the cloth.



Hand wound electromagnetic coils come magnetically alive with eletricity, attracting towards the strong magnets held within pockets in the base cloth. Part jewelery, part device, they make a soft tapping sound when they attact to the cloth but silently disconnect to fall back open with gravity.

Elizabeth Meiklejohn

Elizabeth Meiklejohn is a textile engineer, designer and researcher focused on complex structures and experimental techniques in weaving. Her work blends digital and hands-on methods to achieve dynamic forms and capabilities in fabrics, all while investigating material origins and lifecycles. She completed her MFA in Textiles at the Rhode Island School of Design, where she was a member of the Virtual Textiles Research Group.

elizabethmeiklejohn.com

Laura Devendorf

Laura Devendorf is an artist and technologist working predominately in human-computer interaction and design research. She designs and develops systems that embody alternative visions for human-machine relations within creative practice. Her recent work focuses on smart textiles—a project that interweaves the production of computational design tools with cultural reflections on gendered forms of labor and visions for how wearable technology could shape how we perceive lived environments.

artfordorks.com

Irene Posch

Irene Posch is a Professor of Design and Technology at the University of Arts Linz, Austria, where she directs the Crafting Futures Lab. Her research and practice explore the integration of technological development into the fields of art and craft, and vice versa, and social, cultural, technical and aesthetic implications thereof.

ireneposch.net

Unstable Design Lab

The work took place within and in collaboration with members of the Unstable Design Lab, including Steven Frost, Deanna Gelosi, Eldy Lazaro, Shanel Wu, Sasha De Koninck, Mikahila Friske, Lily Gabriel and Miles Lewis. We also gleaned inspiration and support from the broader ATLAS Institute faculty, particularly Michael Rivera. We approach design as a way to generate theory and things. Design is political and we develop working technologies to help people imagine alternative futures with alternative politics.

Members of the lab identify as technologists, artists, designers, and researchers. We share an approach that pairs design and making with critical thinking and reflection, combining and developing methods that blend art and engineering.

The Unstable Design Lab was established in 2017 and is housed within the ATLAS Institute at the University of Colorado at Boulder.

unstable.design

For videos and resources, please visit: unstable.design/2023-residency-in-review/


PLEASE DON'T MOVE!!

2023 Experimental Weaving Resdiency

organizers

Laura Devendorf
Director of the Unstable Design Lab
Assistant Professor, ATLAS Institute
& Dept. of Information Science

Steven Frost
Faculty Director of the
B2 Center for Media Arts & Performance

Allison Anderson
Assistant Professor, Smead Department of Aerospace
Engineering Sciences

additional support

National Science Foundation

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ATLAS
University of Colorado Boulder
COLLEGE OF ENGINEERING AND APPLIED SCIENCE

The Unstable Design Lab is housed within the ATLAS Institute at the University of Colorado, Boulder.

Title Typography
Zin Nagao, ZNVT14
foznt.com/

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Annet Couwenberg
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Scholar and Craft Researcher

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Georgia Tech

Jane Patrick
Creative Director
Schacht Spindle Company

Etta Sandry
Weaver and 2022 Experimental Weaver in Residence

Clement Zheng
Assistant Professor
National University of Singapore

about

The Experimental Weaving Resdiency aims to bridge craft and engineering in ways that offer mutual benefit to both engineers and craftspeople. It exists as a pillar within a broader project to bring visibility, credibility, and legibility to craft practice within technical communities. We do this because we believe these practices to be neccessary for the development of robust and sustainable future technologies.

2019: Sandra Wirtanen
In 2019, we began with support from the Center for Craft's materials-based research grant. The resident, Sandra Wirtanen, and collaborator, Katya Arquilla, focused on the development of techniques for weaving dry electrodes for physiological monitoring. During the residency term, Katya and Sandra worked closely to sample different methods for producing a shape-fitting garment with integrated electronics as well as different structural explorations of woven electrodes.

2022: Etta Sandry
In 2022, after taking a delay for COVID, we rebooted the residency with support from National Science Foundation Grant #1943109, and focused on ideation and play. We worked closely with selected resident Etta Sandry to develop instructional materials related to woven structure and its potential applications to engineering research.

published outcomes

Craftspeople as Technical Collaborators: Lessons Learned through an Experimental Weaving Residency. Laura Devendorf, Katya Arquilla, Sandra Wirtanen, Allison Anderson, and Steven Frost. 2020. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20).* Association for Computing Machinery, New York, NY, USA, 1–13.

Detection of the Complete ECG Waveform with Woven Textile Electrodes. Katya Arquilla, Laura Devendorf, Andrea K. Webb, and Allison P. Anderson. 2021. In *Biosensors* 11, no. 9: 331.

An Introduction to Weave Structure for HCI: A How-to and Reflection on Modes of Exchange. 2022. Laura Devendorf, Sasha de Koninck, and Etta Sandry. In *Designing Interactive Systems Conference (DIS '22).* Association for Computing Machinery, New York, NY, USA, 629–642. https://doi.org/10.1145/3532106.3534567

2023 Experimental Weaving Residency Catalog

Elizabeth Meiklejohn
Laura Devendorf
Irene Posch
with the Unstable Design Lab