Hybrid Crochet: Exploring Integrating Digitally-Fabricated and Electronic Materials with Crochet

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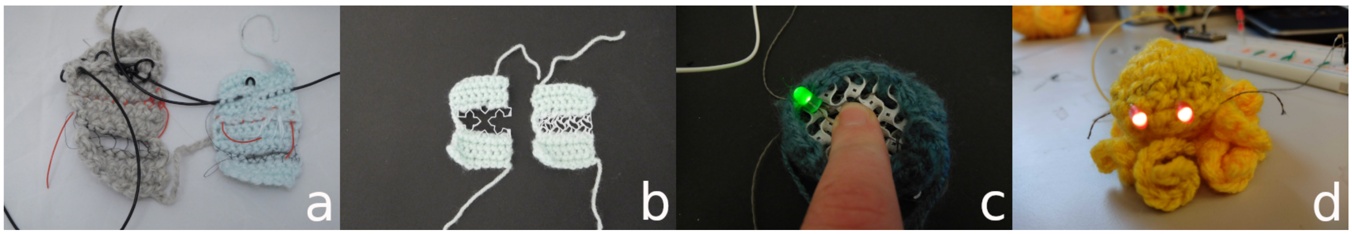

Figure 1: Examples of crochet fabrication and interaction with 3D printing and electronics. Stitches made of thread, cable, and cTPU (a), using printed infill patterns (b), a pressable crochet button (c), and a crochet octopus with integrated LED eyes (d)

ABSTRACT

Human-computer interaction research with yarn-based crafts has concentrated on those that can be done by machine, like knitting and weaving. Crochet, on the other hand, has received little attention in HCI, because it cannot be automated. We explore integrating both electronics and digitally-fabricated materials—like 3D prints—into handcrafted crochet objects. We use 3D printed structures to guide crochet stitches by constraining stitch sizes and placement, and infill patterns to change the works' form, stiffness, and appearance. We also explore printed ring structures that bridge soft crochet and hard electronics, and whether different conductors can be crocheted. We demonstrate combining these primitives to build crocheted input devices like buttons and an interactive octopus. Our techniques can help crafters design and create interactive crochet objects.

KEYWORDS

crochet; yarn; hybrid craft; soft interfaces; smart textiles; 3D printing

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1 INTRODUCTION

Crochet is a traditional handcraft that uses yarn to create diverse objects, from decor and clothes to toys. Unlike knitting and weaving, it must be done by hand [12, 18]. This means there is relatively little work integrating computation with crochet: in particular, it focuses on changing the yarn's appearance through thermochromic pigments [9, 17]. Other handcrafts like hand weaving, embroidery, and ostrich egg jewelry-making have been integrated with both 3D printing [8, 15] and electronics [5, 7] to expand the crafts' design possibilities; we take inspiration from these works to explore the integration of crochet with such computational materials.

In brief, crochet is a craft where loops are pulled through other loops to form a crochet stitch. Several stitches in several rows form a crochet work. Crochet works can be 2-dimensional fabrics, or 3-dimensional objects. Many crochet designs include additional decorative materials that are pushed through the stitches after they are completed, for example, to function as eyes for characters. Some patterns also call for crocheters to embroider on the crochet fabric once it is completed, using the existing crochet stitches as guides.

We strive to open the design space for crocheters to make interactive crochet pieces. Today's crochet is rarely interactive[1], and non-crocheted parts (e.g., the eyes and embroidery mentioned above) are purely decorative. We explore using crochet works as input or output devices by integrating electronics. Additionally, we test how 3D-printed objects can be used to guide creation and change pieces' visual and tactile characteristics.

To integrate electronics into crochet pieces, we test both how to include different conductive materials and how to connect traditional hard electronics to soft crochet works. We explore different integration methods that are possible with thin cables, cTPU, conductive thread, and flexible LEDs, including creating traditional crochet stitches, crocheting around them, and wrapping them around

[1] A tree with LED and a star made from yarn and fairy lights are exceptions that integrate electronics visited 2023-12-04.

existing stitches. Many of the materials tested were too stiff to use for all these methods. We found that conductive thread behaved the most similarly to yarn, thus making it the easiest to integrate into traditional stitches. It is also suitably conductive to connect low-voltage electronics to a power source. To connect such flexible, soft conductors to rigid electronics, we developed 3D printable ring-like structures that hold the electronics and can be crocheted through. These structures also prevent shorting.

We test two methods to connect yarn and 3D printed objects. The first, which we call "intentional design," explicitly creates a structure with a series of individual holes, one for each intended stitch (similar to the looms created in *EscapeLoom* [8]). The second uses 3D-printed infill patterns from a commercial slicer, and enables more flexible designs, as crocheters can more freely choose where and how to place stitches along the structure. In both cases, crocheters can use normal stitches, assuming there is space for a crochet hook and yarn. We explore all infill patterns available on Cura, in densities from 5–20%: while most accommodated the needle and held together well, not all are equally suitable.

Our techniques can be combined in various ways to create hybrid crochet pieces. We present input and output devices, haptic feedback for buttons and sliders, and crocheted circuitry to light an octopus's eyes. For multi-part works, we also demonstrate substituting 3D printed support structures for parts that would normally be crocheted.

In summary, we contribute methods for:

- making interactive crochet works by integrating conductive material and electronic components directly with crochet stitches
- changing flexibility, stretchability, and appearance of crochet works by including 3D printed structures
- guiding the shape of crochet works by restricting stitch placement with 3D prints

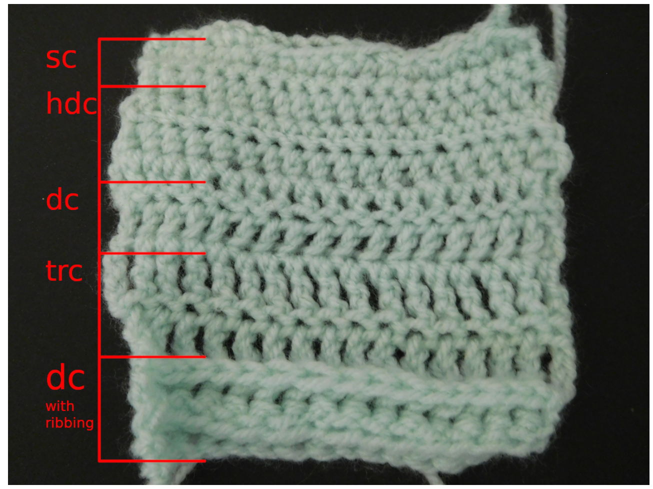

Figure 2: Different crochet stitches, single crochet (sc), half double crochet (hdc), double crochet (dc), triple crochet (trc) and double crochet with ribbing (dc with ribbing). Note the different sizes of different stitches due to a different number of loops in each stitch.

2 RELATED WORK

Computing, digital fabrication and electronics can change and enhance crochet and other hand– or machine-crafted objects like knitted, woven or stitched pieces. We build on works that explore adding interactivity to other handcrafted objects (crochet is not automatable [18]), and those that make techniques accessible to crafters and designers.

Researchers have explored several methods to integrate electronics into textiles. Conductive yarn, with a higher resistance than conductive thread, can be used as a sensor itself, as in *KnitUI* [16]. Thermochromic pigments can communicate information by changing colour when they are heated, and have been used on conductive thread that is then crocheted [9] or applied on fabric over heating elements as in *Spookies* [4]. *MetamoCrochet* deactivates pigments on the yarn with a heatable hook [17]. Others lower the knowledge threshold for integrating electronic components. The *LilyPad* Arduino is designed for integrating electronics with textiles [5] by directly embroidering or stitching them onto fabric. *Quilt snaps* allows children to design electronically-enhanced quilts and learn about coding [6], and *littleBits* allows designers to integrate small, modular electronic parts into objects [3]. Deepshikha and Yammiyavar [7] uses LEDs in traditional local stitching practices to augment social communication. These works enable crafting experts to combine electronics with various textile techniques, but none explore crochet.

Combining soft crafts with rigid digital fabrication can leverage both materials' properties. Rivera et al. [20] integrate thin fabrics with holes (e.g., polyester) into 3D prints and print on top of fuzzy fabrics like felt, while Vahid et al. [21] create shape-changing fabric samples for fashion designers. Jacobs and Zoran [15] combine digital design with traditional hand-jewellery-making from the Kalahari. All of these use digital fabrication to enhance crafts; we take inspiration from them and extend to crochet.

3 WHAT IS CROCHET?

Crochet is a handcraft in which crafters use yarn to create objects like clothes, toys, and home decor. To create a crochet piece, a crochet hook pulls loops of yarn through both other loops of yarn and previously-completed stitches to create new stitches. The more loops are used, the longer the stitch is. Figure 2 shows stitches that differ in the number of loops (1–3); "ribbing" is produced by different stitch placement [1, 11]. We mostly use single crochet stitches (Figure 3).

When crafting, crocheters can have different amounts of freedom. On the one end of the spectrum, crochet patterns instruct how to crochet a certain work. This includes information about which materials to use, when to change the yarn color, and when and how to add non-crochet components like stuffing and eyes. On the other end of the spectrum, some people do free crochet and use no pattern at all [2]. When following a pattern, a crafter leaves most of the control to the pattern, while they have more control in free crochet. In both cases, different materials with different functionalities can become part of the crochet.

Figure 3: The steps for a single crochet stitch. Active stitch on the hook (a), hook is pushed through the upper part of a previous stitch (b), yarn is pulled through the previous stitch and creates a new loop on the hook (c), yarn is pulled through the two loops on the hook to finish the stitch (d), there is now a new active loop on the hook (e).

4 DESIGN BASICS

In this section, we describe basic methods to combine electronic or fabricated objects with crochet.

4.1 Crocheting with Different Materials

Crochet often uses yarns of different thicknesses and materials. Common materials include wool (sheep, alpaca, etc.), cotton, polyester, acrylic or blends. To introduce conductive pathways, we must integrate a conductor.

Crochetable materials fit certain criteria. The more yarn-like a material, the easier it is to integrate: the best materials are long, string-like and very flexible. We explore cTPU, thin cables, conductive thread, and flexible LEDs (nOOds [14], an electrical component). These materials can be integrated in several ways: (a) used in a crochet stitch alongside or as a replacement for yarn in a whole or partial stitch, (b) laid on a crochet row while the next row is crocheted around it, or (c) wrapped around the stitches (Figure 4). The first and last methods make the conductor more visible than the second.

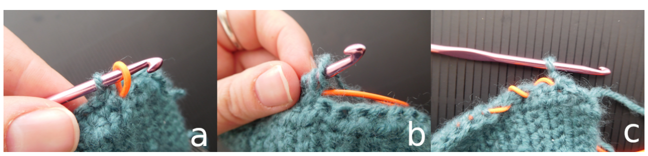

Figure 4: Different techniques to integrate a flexible LED. Using material instead of/combined with yarn in a crochet stitch (a), laying material on the previous crochet row and crocheting around it (b), wrapping material around crochet stitches (c).

Thin cables, cTPU and flexible LEDs all face difficulties with integration. While they have a similar thickness to the yarn, they are not as flexible. A full stitch is larger than one with yarn as it cannot be pulled as tight; this consumes more linear material and does not blend in with the surrounding stitches. This is especially problematic for flexible LEDs, which have limited length. Cable is very stiff, both TPU and flexible LEDs are stiff and have a tendency to return to their previous form (Figure 5a).

We had the most success with conductive thread. Its flexibility means it can be easily used to create partial or full crochet stitches. If used instead of yarn, it gives a lacy appearance (Figure 5a), but it has little influence on the behaviour or appearance of the work when used alongside yarn. We expect conductive yarn would have similar desirable properties, but it is not commercially-available to consumers in thicknesses that approach those of crochet yarn. Conductive yarn that is similar in appearance to general yarn is explored in other projects [19].

4.2 Guiding and Controlling Stitches

While crocheting, a crafter often crochets into stitches from the previous row, which somewhat constrains the form of each row. We explore replacing a previous row with a different material. In this case, the yarn needs a hole or something to wrap around: we use 3D prints, either with open structures (Figure 5b) or closed loops that explicitly constrain stitch locations (Figure 5c). We also use 3D printed infill patterns (Figure 6).

A 3D design that contains explicit places for the stitches allows for more digital control of stitch placement at the cost of pre-planning. At every hole or ridge, a stitch can be placed, as long as holes are large enough for a needle to pass through. The printed substrate's material characteristics can also influence the character of the work: PLA is completely stiff while TPU is more flexible (Figure 5c).

By removing the bottom, top, and walls of a 3D object, we can print its shape in only infill patterns, thus giving less-explicit guidance for stitch placement. We tested all infill patterns available on Cura, printed in PLA, and found three important characteristics that make a pattern suitable to be used with crochet: the stability, density and connectedness of the pattern (Figure 7). The best patterns were Gyroid, Cross and 3D Cross because they are flexible and even stretchable in the case of the Cross (Figure 7a). Patterns like Zig Zag break easily, while Quarter Cubic creases when bent (Figure 7b). At high densities, some infill patterns no longer fit a crochet hook (Figure 7b). Connectedness varies based on pattern and overall object shape: in our test the Cross pattern yielded disconnected parts, while Gyroid remained connected for the same outer shape (Figure 7c). To create a printed part that is stable, fits a needle and yarn, and is connected completely one must consider infill pattern, density and the overall shape of the object. Crafters may also weigh the explicitness of the pattern, its haptic texture, and visual features when choosing a pattern.

4.3 Connecting Electronics to Crochet

The biggest challenge when integrating circuits is connecting soft crochet to hard electronics. Conductive thread can be easily integrated within the crochet piece, but still needs connections to component legs or wires.

Figure 5: Materials as part of or to replace crochet: Integrating material into crochet, top to bottom: cTPU (black, thick), insulated cable (red), thread (black thin) (a). 3D-printed parts can replace a row of crochet stitches, even without closed holes (b). Stiff PLA or flexible TPU can guide the work in different ways (c).

Figure 6: Crochet and crochet with infill patterns Cross and Gyroid behave differently, a) lying flat, b) stretched and c) bent.

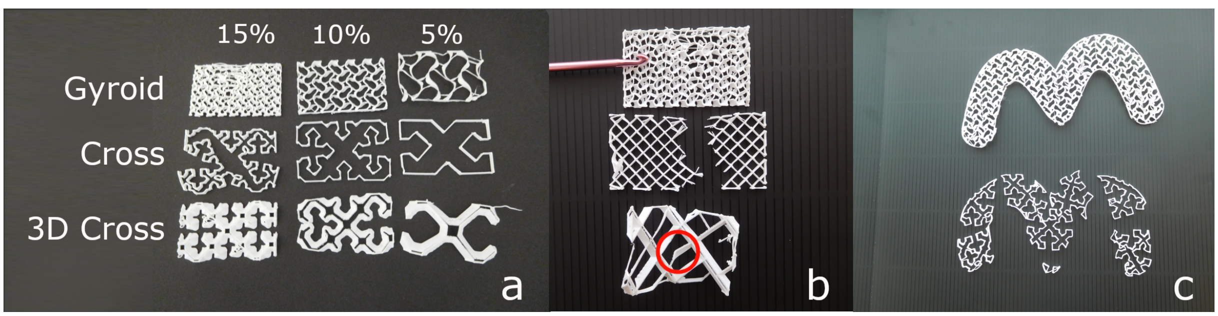

Figure 7: Infill patterns and their problems. Best infill patterns (a), infill patterns that are too small or breakable, or crease when used (b), printed infill patterns may be disconnected (c).

One way to connect the two is simply wrapping the legs of a component, like an LED, in conductive thread after crocheting. While this gives freedom and does not require pre-planning the exact component location while crocheting, it does not give a stable connection. We developed 3D-printable rings that are sized to fit a crochet hook at its widest part, and which have holes on the sides to fit standard-sized 0.8 mm component legs (see Figure 8a), which help to stabilize both the location and connection of the component.

To use the ring, the crocheter inserts one leg of an electronic component through the small hole. They then pull conductive thread through the ring without yarn (Figure 8b.b and b.c). Any loop of a crochet stitch can be replaced by the thread, or a thread loop can be added without changing the stitch's appearance. To ensure that circuits do not short, at least one row of purely yarn-based stitches is put between rows with conductive thread.

5 APPLICATIONS

5.1 Input Components

We built two input devices, a button and a slider, using PLA and electronics in our crochet designs. Our button (Figure 9 left) uses objects 3D printed in PLA as the bottom and top. These are physically connected and separated by a springy crochet tube, with the source and sink on opposite sides. The circuit with the LED is closed when the button is pushed down and the conductive thread on the PLA plates connects. The slider (Figure 9 right) features a flex sensor that has been integrated into the crochet by crocheting around it in every row. The sensor can be bent and temporarily fixed in a particular configuration with crochet stitches.

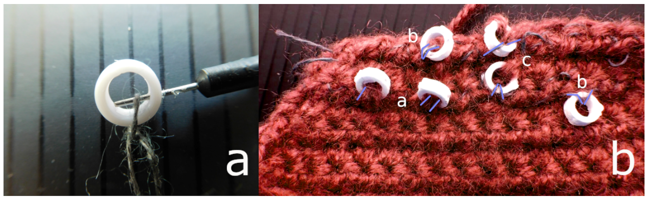

Figure 8: Printed ring connectors hold together hard electronic parts and conductive thread (left). Rings can connect to the crochet in different ways, with differing reliability (right): crocheting with both yarn and conductive thread through the ring (a), crocheting with only the tread through the ring (b), crocheting with only the conductive thread and then only the yarn in another stitch through the ring (c). Conductive thread is marked in violet.

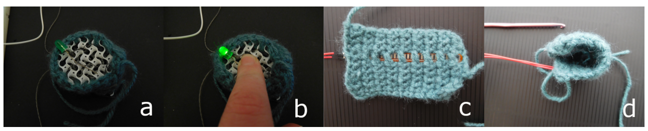

Figure 9: A button (left) and a slider (right), realised in crochet. The button uses 3D printed components alongside electronics, while the slider was realised by crocheting around a flex sensor.

5.2 Modified Crochet Patterns

5.2.1 Octopi. To highlight playful opportunities for integrating electronics in crochet, we crafted two Octopi of different sizes, based on and inspired by a crochet pattern[2]. This pattern includes the use of "safety eyes" (which are pushed through the crochet fabric after it is completed) for the eyes of the octopus: we replace them with LEDs. Two rows were crocheted with both yarn and conductive thread with a row of only yarn in between. In the case of the smaller octopus, the LEDs were inserted after the work was finished, which allowed for free placement of the lights (Figure 10a). The bigger octopus in figure 10b used our printed rings (see Figure 8), requiring planning the LEDs' placement while crocheting. We also integrated a flexible LED as eyebrows by wrapping it around the crochet stitches during the crochet process (as in Figure 4c), connected to the same circuit as the eyes.

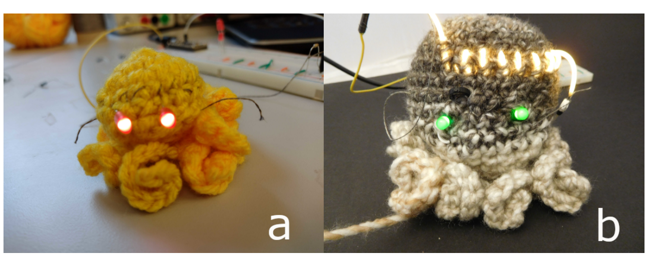

Figure 10: Two Octopi with LED eyes: a small one (left), and a large one with an additional flexible LED eyebrow (right).

[2]Baby Octopus tutorial in English visited 2023-12-04

5.2.2 Flowers. We modified an existing crochet pattern for a flower [3] by replacing a central, crocheted circle with a 3D printed version made of the cross infill. In both versions, petals are created by crocheting into loops, either crocheted or 3D printed (Figure 11 left). The cross pattern had four edges/loops—which we used as a restriction to create 4 petals instead of the original 5—and which adds artistic flair. Our two-tiered flower[4] is also separated into the base—normally crocheted but which we again 3D printed—and the petals (Figure 11 right). We also added lights to this design. The printed base is electrically connected to ground, and LEDs in the the leaves are connected in parallel on each tier. Leaves' edges connect to a positive pole so each tier can be controlled separately (Figure 11 right).

6 DISCUSSION AND LIMITATIONS

We envision a rich future of integration between the handicraft and digital worlds through crochet. Digital guidance, as in our 3D printed structures, could be used in concert with crochet pattern generation tools like *Knitty* [13] or *AmiGo* [10] to help novices generate and follow patterns precisely. A more advanced crocheter could 3D print parts which are normally tedious to crochet or which have undesirable material characteristics when crocheted, like our flower centres, while still having expressive capability for the unspecified parts. Experienced pattern designers could include instructions for integrating electronics into their patterns; it is not uncommon to include different materials in crochet patterns, and we believe that the structures we developed will expand this space further while still allowing free-hand crochet. We also see artistic possibilities in interactive crochet, for example, adding new levels to works like the crochet coral reef project [22]. In the future, we would like to do workshops with crochet artists to elicit more ideas, and to integrate other types of digital fabrication techniques with crochet, for example laser cutting.

Even with printed ring structures, we occasionally struggled to isolate our crocheted circuits appropriately, as the thin conductive thread was more difficult to manage than thick yarn. This was especially a challenge in the two-tiered flower, where having multiple segments in the work meant that there were more loose thread ends to manage. Stitching the rings too loosely created circuit problems where conductive thread lost contact with the components: as it is a human process, this is more challenging to control. Further evolution of the rings' design or experimentation with other stitch types might help. There were also many trade-offs to manage between print strength, print weight, and crochetability in our exploration of using infill; materials like TPU could make printed parts more durable and lighter weight. Using a conductive filament could combine the ideas from both our electronic and the 3D printing explorations.

7 CONCLUSION

In this paper, we present ways to integrate crochet with 3D-printed objects and electronics. We explored intentionally designing 3D objects with designated locations and numbers of stitches, and the less-defined empty spaces in infill patterns. Both designs allow

[3]Big Flower tutorial in German visited 2023-12-04
[4]Crochet Flower tutorial in German visited 2023-12-04

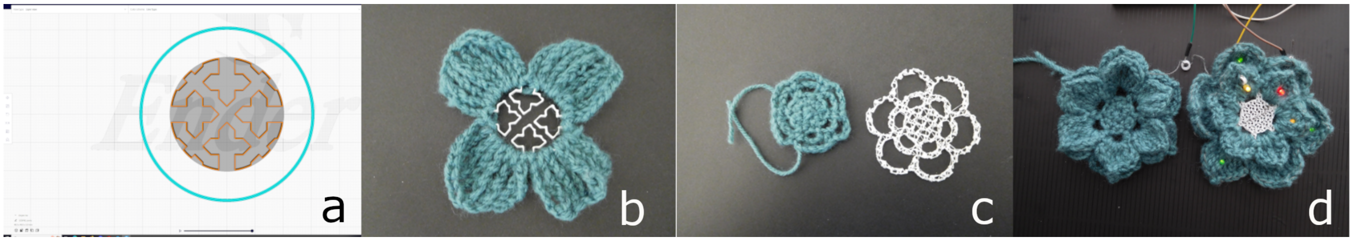

Figure 11: Flowers with 3D printed base and crochet petals: four petal flower (left), two tiered flower with LEDs (right).

common crochet stitches. For electronics, we explored crochet with many conductors and found conductive thread was simplest and easiest to integrate. We also developed printable, crochetable structures to link traditional electronic components to crocheted circuits. With these techniques, there are opportunities for both guiding the crafter in their work and giving them tools to integrate with their freehand creative work.

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