Disappearing Stitch: Exploring e-textiles design for disassembly

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Abstract. E-textiles combine electronics and textiles, making it difficult to recycle due to the inherent difficulties already associated with its constituent parts, and the tight integration of electronic components and textiles. In order to enable circularity in e-textiles, components need to be easily removed from the textiles. This paper addresses the disassembly of textiles integrated e-textiles, by exploring stitching techniques to create e-textiles that can be readily disassembled. This paper presents the inquiry into designing e-textiles for disassembly. The disappearing stitch project demonstrates how the e-textile design can be designed to leverage existing textile technologies for circular practice and how design can be used to optimise material recovery, allowing the conductive threads and electronic components to be re-used.

Keywords: e-textiles, embroidery, sustainability, disassembly

1 Introduction

Sustainability is a concern within e-textiles (electronic textiles), as it is in many areas of everyday life. The fashion and textiles industry has a significant negative environmental impact, which is being tackled by industry and research organisations (Mistra Future Fashion, 2019; WRAP, 2019). The integration of electronics into textiles compounds these problems, adding issues associated with electronics, such as the consumption of scarce resources e.g., metals, and contributing to increased waste through progressive technological obsolesce. E-textiles can be more difficult to recycle due to the tight integration of electronics and textiles (Hardy et al., 2020; Köhler, 2013). Applying a Design for Environment approach to e-textile design is one means of addressing these issues. It is a multi-faceted approach that aims to address environmental issues caused by the production and/or disposal of a product, by tackling different aspects of design, such as Design for Product Recovery, Design for Product Disassembly, and Design for

Recyclability (Fiksel, 2009). This design ethos has been seen in product design (Framework, 2022), as well as within research (Forst, 2020; Rahman & Gong, 2016).

The disappearing stitch project explores the use of removable stitch techniques to produce a circular textiles-integrated e-textiles; e-textiles that are designed for disassembly. This work explored chain stitch, a sewing stitch that consists of intralooping threads, typically used in decorative embroidery, to enable disassembly and reuse of materials.

2 Literature Review

2.1 Disassembly in fashion and textiles

Fashion and textiles are typically not designed for recycling and remanufacturing, therefore creating a circular economy in which waste can be reused in production is a challenge; a challenge that can be effectively tackled if the issue is considered in the product development process (Vignali et al., 2019). Clothing is largely non-modular in construction. It needs to be hardwearing, therefore attachment techniques i.e., stitching, are designed to be permanent. As such, the process of disassembling and recycling existing garments is time-consuming and inefficient (Pal et al., 2021). This contrasts with the situation for electronics. Electronics legislation, such as WEEE (waste electrical and electronic equipment) (UK Gov, 2021), provides motivation for designing electronics that can be disassembled and recycled since they must comply with standards. Modular garment design for sustainability has been explored (Rahman & Gong, 2016). While the modularity of the garment could increase product lifespan, the modular pieces would suffer from the same issues of disassembly as conventional garments. It potentially adds a further burden to the recycling process due to increased fastenings in modular pieces. As such, although modularity can contribute to the Designing for Environment ethos, design for disassembly still would need to be considered.

Designing for disassembly in fashion and textiles can be tackled from different angles. From a materials perspective, dissolvable threads offer a solution that can integrate easily into existing production practices. These threads weaken under microwave radiation (Durham et al., 2014) or high heat (Resortecs, 2022), simplifying the disassembly process. However, the requirement for industrial microwave units could prove to be a financial barrier to adoption. From the perspective of e-textiles, high heat and radiation may not be a suitable disassembly method for textiles with electronics integrated into them.

Design for disassembly can be approached through innovative design. Designer Lee Mattocks (2022) uses an interlocking technique to join the pieces of their leather bags without stitching or fastenings. Forst (2020) also used the principle of interlocking to tackle the challenge of recycling textile blends (mixed material textiles). The techniques combine textiles semi-permanently to achieve different material properties. While techniques based on interlocking materials are promising, they require hand assembly and specific material properties such as a certain level of rigidity.

2.2 Designing for disassembly in e-textiles

Exploration into sustainable practice in e-textile design has been investigated from a system design approach, as well as product design. Closed Loop Smart Athleisure Fashion (Veske et al., 2019) is a collection of garments that monitor heart rate and respiration that approach sustainability through the design of the system. The garments are part of a lease and recycle system, with de-lamination as the means of disassembling the electronics from the fabric.

It is worth highlighting disassembly in the context of e-textiles prototyping. Delamination as a means of disassembling e-textiles is utilised in the Rapid Iron-on User interface (Klamka et al., 2020), a system for easily prototyping e-textiles through iron-on components. The system consists of a specially designed rolling iron and components in tape form to allow the maker to draw on the conductive circuitry. While the iron-on system works well for the disassembly of the circuitry, the rigid electronics may still need to be attached through stitch or through snap buttons, which are difficult to remove from fabric.

The affordances of textiles techniques have been leveraged in e-textiles prototyping. Punch needling, a method in which yarn is pushed through the fabric with a punch needle has been used by Jones et al. (Jones et al., 2021) as a means of creating easily removable e-textiles circuitry. Mistakes in the circuitry can be easily rectified since the yarn can be easily pulled out. However, there are situations in which the textiles technique does not lend itself to sustainable practice, and it is necessary to overcome its limitations. Wu and Devendorf (2020) developed a technique that allows woven e-textiles to be readily disassembled. In woven fabrics, namely fabrics woven on shuttle-less looms, weft threads (horizontal threads) are cut at the edges of the fabric, which means that it is difficult to recover a usable quantity of material. This limitation was overcome using continuous weft and doubled supplemental continuous warp (vertical threads), although the production is limited to a hand-operated loom.

Common in the existing research on e-textiles disassembly is the use of what can be considered more manual textiles craft techniques. The affordances of manual craft techniques have proven valuable in e-textiles development (Chen et al., 2021), as they allow for direct intervention with the material which is especially necessary when developing textiles outside the realms of conventional textile design.

3 Exploring removable stitch

Stitching is prominent in e-textiles research. Hand embroidery is often used in e-textiles for STEM teaching to create textiles circuitry and attach electronic components (Peppler, 2013), while machine stitching allows for complex designs to be produced easily and reliably (Hamdan et al., 2018; Jo & Kao, 2021; Lenninger et al., 2013; Nabil et al., 2021; Rocha et al., 2022) through digital embroidery machines. Machine stitch and its role in the end-of-life of the e-textile product is an under-explored subject.

3.1 Chainstitch

Chainstitch (Fig. 1 (Left)) is a technique that can be produced by hand and by machine, under the formal name BS 3870-1:1991, ISO 4915:1991 stitch 101 (British Standards Institute, 1991). It consists of intralooping thread; a loop of thread is held in place by the succeeding loop (British Standards Institute, 1991). It can be created using a sewing needle or using a fine hooked needle, with this type of embroidery called tambour embroidery. An advantage of tambour chainstitch embroidery is that it can be quicker to produce compared to forming chainstitch using a sewing needle since it uses a continuous length of thread, and the hooked needle doesn't have to pass completely through the fabric.

While the first sewing machines used chainstitch, chainstitch machines became less popular after 1900 and today chainstitch machines are primarily used for embroidery (Risley, 1973). Lockstitch, a stitch formed by 2 interlinking threads superseded chainstitch, since it has the advantage of being strong and difficult to unravel. In contrast, a simple chainstitch unravels very easily if the end of the stitch is not secured. It is this feature that this project takes advantage of. This project explored hand-produced chainstitch through tambour embroidery and machine chainstitch using a Cornely embroidery machine; a machine design dating back to 1865 (Risley, 1973).

Fig. 1. Chainstitch (Left), Moss stitch (Middle), Lockstitch (Right)

3.2 Other stitch options

Before chainstitch became the focus of this project, other stitches were examined in relation to their ease of removal. It was not only the ease of removal but if the thread can be removed intact, since the aim of this project is to design for revalorization, i.e. recovery of materials for reuse (Fiksel, 2009, p. 70). A criterion was that the stitches could be produced on a machine as well as by hand, in the interest of scalable production. Punch needling and lockstitch were examined in addition to chainstitch, through a hands-on approach. Stitch samples were produced and disassembled, and the process was recorded and examined.

Punch needling can be produced by hand using a punch needle, a hollow needle with an eye. The same stitch can be produced on the Cornely embroidery machine; a Moss stitch (Risley, 1973) (Fig. 1

(Middle)). Punch needling is an easily unravel-able stitch, but it is much less secure compared to chainstitch since it is essentially an unsecured chainstitch. Punch needling/Moss stitch would be impractical for an e-textiles garment. As there is no intralooping in punch needling, pulling a single loop anywhere along the stitch with enough force can unravel the stitches.

Lockstitch samples were stitched using a Bernina domestic sewing machine. Although lockstitch is difficult to unravel, it is not impossible to remove. Using the longest stitch setting, in this case no.5, made removal significantly easier. It is possible to pull one of the threads out, though the tension typically used to create a strong stitch makes this difficult. Forcefully pulling the thread can snap it. The removability is further hampered when the stitch follows tight bends and corners, as the fabric then ruches rather than allowing the thread to be removed (Fig. 1 (Right)).

Chainstitch strikes a balance between the removability of punch needling and the security of the lockstitch. It can be unravelled with ease even when stitched into shapes with tight bends and corners, while only being unravel-able if the final stitch is not secured. The stitch can be secured by threading the end of the thread through the last loop.

3.3 Resistance and thread usage comparison

It was necessary to check whether for any disadvantages to using chainstitch from an electronics perspective. The resistance of the stitch and thread usage was examined for chainstitch and lockstitch. The conductive thread used was HC12 from Madeira. The thread weight is 235x2 dtex, with an advertised < 100 ohm per metre (Madeira, 2019). For this test, the lockstitch was stitched using a Bernina domestic sewing machine, with the conductive thread fed through the lower bobbin and a polyester thread used for the top thread. Stitch length 5 was used in these samples. For the chainstitch, the conductive thread was not used with another thread. It was not possible to vary the stitch length for the Cornely machine. For each condition, three 30cm stitch samples were produced and a mean average was calculated. The thread usage was calculated by unravelling stitched sample after the resistance was measured. For the lockstitch, the thread usage measurement is for the conductive thread only. The results are shown in Table 1.

Table 1. Resistance and thread use for chain stitch & lockstitch for HC12 (30cm of stitching)

	Chainstitch		**Lockstitch**	
Sample	**Ohm**	**Thread usage**	**Ohm**	**Thread usage**
A	10.7	124	20.8	31.5
B	13.2	137.7	19.4	31
C	10.8	140.3	18.6	32
Average (Mean)	11.57	134	19.6	31.5

The results were in line with expectations, with the chainstitch having a lower resistance over a 30cm length of stitching, compared to the lockstitch. However, the resistance of the lockstitch can be decreased by using a conductive thread for the top thread. The thread usage for chainstitch is higher compared to lockstitch, using approximately 4 times more conductive thread. However, this isn't a negative point as the lower resistance is due to the higher thread use. The thread supplier recommends using more thread to lower the electrical resistance (Madeira, 2019).

4 Design inquiry: chainstitch for e-textiles

After determining that chainstitch was the most appropriate option for a removable stitch, the production process for circular e-textiles had to be developed. The assembly process for circular e-textiles was refined through a series of sensitising activities which involved creating and disassembling several e-textiles samples using chainstitch to identify areas of opportunity and concern. The repeated processes of construction and deconstruction allowed for the construction process to be refined and the effects of multiple cycles of material reuse to be observed. Three key elements of the circular e-textiles construction process had to be considered: attaching rigid electronics, designing for disassembly, and designing for maximum material recovery.

4.1 Attaching rigid electronics

E-textiles often incorporate rigid electronics into the fabric however it is difficult to use the Cornely machine to stitch electronic components since it cannot accommodate the components underneath the machine foot. Some solutions were considered, such as mounting the electronics to a fabric with conductive fabric tabs, in a similar manner to

Buechley's construction kit for electronic textiles (Buechley, 2006) prior to machine stitching. However, this would add additional steps to construction and extra bulk to the e-textile product. Therefore, combining hand-stitched chainstitch with machine chainstitch is a more appropriate option. The Cornely machine is used to quickly stitch the bulk of the circuitry. The ends of the machine stitch can be temporarily secured using a safety pin (**Fig. 2** (Left)), with excess conductive thread left to continue the stitch. At a later stage, the chainstitch can be continued through tambour embroidery (**Fig. 2** (Right)), allowing the components to be stitched to the circuit.

Fig. 2. Left: Transferring chainstitch to tambour hook. Right: Chainstitching the component

However, there are some circuit designs in which using the chainstitch to attach the components is less convenient, such as the parallel circuit in **Fig. 3** (Left). Since the distance between the positive and negative stitching lines is the width of the LED, it is easier to use standard stitching to join the LED to the circuit and the fabric. This stitching can be removed relatively easily using a stitch unpicker.

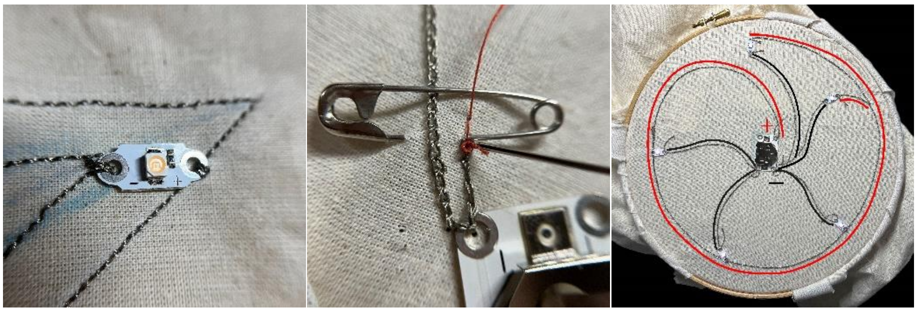

Fig. 3. LED stitched onto the circuitry (Left), Contrasting stitching (Middle), Parallel e-textiles circuit (Right)

4.2 Designing for disassembly

During the sensitising activities, the deconstruction process took place a few weeks after the samples were created to allow the author to forget the construction process and separate ‘the assembler’ from the ‘disassembler’. The main issue found in the disassembly process was the difficulty in finding the end of the chainstitch to start the unravelling process. To address this issue, a contrasting stitch is to indicate the end of a chainstitch. The tail of the chainstitch is pulled through the loop to prevent the stitch from unravelling, while an additional stitch is used to both secure the loop and as a marker (Fig. 4 (Middle). The marker can be removed with a stitch unpicker, and the tail of the chainstitch pulled out of the loop.

4.3 Designing for maximum material recovery

To ensure that the recovered conductive thread from an old e-textiles piece can be reused effectively, the stitching of the circuit needs to be designed to minimise the number of short conductive stitching sections. Short lengths of conductive stitching are less useful for later reuse. In the context of simple illuminating e-textiles, using a parallel circuit design helps to this end, as there can be a long positive and negative main line from which the circuitry can branch out towards the components, as seen in Fig. 4 (Left). It is difficult to avoid wastage entirely. While small segments of conductive thread are less useful for machine stitching, they may still be reused for tambour embroidery. However, the conductive thread becomes more frayed with repeated handling, making it more difficult to work with.

5 Proof of concept: Embellished Jacket

The disassemble-able e-textiles design principles developed through the design enquiry were applied to the embellishment of a denim jacket. The jacket (Fig. 5) was embellished twice, with the previous chainstitch e-textiles circuit disassembled, and a new circuit stitched in the same position. Electronic components, such as the battery holder and LEDS, and conductive thread were reused from the first design.

Fig. 5. Embellished Jacket, undergoing 2 design cycles

6 Conclusion

This paper has demonstrated how an existing textile technique can be used to address the emerging problem of e-textiles sustainability. What is considered a negative of chainstitch is leveraged to support e-textiles as part of a circular economy. The hands-on approach to design inquiry was important in developing an understanding of the affordances of chainstitch and how to integrate it into e-textile design for disassembly. This project has highlighted the value of employing handcraft to address design problems associated with the current limits of technology. There is potential to further explore chainstitch in e-textile design, particularly the aesthetic possibilities of tambour embroidery. As a technique that is typically used with beading and embellishments, it has the potential to create highly decorative circular e-textiles pieces.

Existing technology has been used successfully in this project though it is hoped that new technology can be developed that can encourage the adoption of the techniques outlined in this paper. For instance, combining chainstitch with digital embroidery technology could aid in its adoption in larger-scale e-textiles production. This project focused on one aspect of circularity in e-textiles, disassembly. The e-textiles assembly and disassembly processes demonstrated in this paper would need to be designed into a closed-loop e-textiles system to ensure that e-textiles products are recycled.

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