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Chen, A, Tan, J and Henry, P orcid.org/0000-0003-4563-3242 (2021) E-Textile Design through the Lens of Affordance. Journal of Textile Design Research and Practice, 9 (2). pp. 164-183. ISSN 2051-1787

https://doi.org/10.1080/20511787.2021.1935110

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E-textile design through the lens of Affordance

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E-textile design through the lens of Affordance

E-textiles design integrates materials not usually native to textile design e.g. conductive yarns and optical fibres. E-textiles themselves are soft systems; a computational composite made up of fluid and rigid materials, each component essential to the functionality of the e-textile. The making process represents another complex system. The process of integrating electronics and textiles requires that the designer negotiates and unifies the properties of tools, the materials, and manual and machine enabled processes. E-textile designers leverage the affordances of unconventional materials to enable new functional and aesthetic potential while working within the constraints of different aspects of the e-textiles system, the tools, materials, and the requirements of electronics. This paper presents a discussion on affordance in e-textile design, drawing from literature detailing e-textile design processes and the author's practice. Affordance offers a new perspective in understanding the relationship between aspects of the e-textile design process. This paper focuses on the affordances of textile tools whilst also considering new affordances provided by e-textiles materials, and affordances and constraints in material manipulation. In the analysis of textiles tools, four key affordances that impact on e-textiles design were identified: design complexity, manual intervention, automation and tactile feedback. These exist to a greater or lesser degree, depending on the tool. Manual intervention, tactile feedback and design complexity are particularly beneficial for novel e-textile design, while automation can be problematic in e-textiles development since it can prevent the designer from enacting new techniques. Although the beneficial affordances are seldomly found together, there are examples of textiles tools that possess these affordances. Nevertheless, there remains a need for more tools that possess these affordances to allow for novel e-textiles development in the future.

Keywords: e-textiles, knitting, optical fibre, affordance, material development

Introduction

In its most basic form, e-textile design requires the synthesis of knowledge from electronic engineering and textile design, and as a result, it is a complicated process that does not follow the standard practices of either discipline. In addition to the design process being different from either electronic engineering or textiles design, due to the need to include the development of functional elements in conjunction with the textile or garment design (Tan 2015, McCann, Hurford, and Martin 2005), there is also a new set of materials that are typically not used in the textile design process, such as conductive yarns, small electronic components or optical fibres. While the materials are important in imbuing the fabric with its functionality, the tools used to manipulate them into a textile form are not frequently the focus of discussion. There are a plethora of tools used in e-textiles creation, from those classically associated with textile production such as weaving looms and sewing machines to new tools associated with other fields, like 3D printing (Goudswaard et al. 2020, Takahashi and Kim 2019). Tools can be used to manipulate the material in different ways, and as such, they have a significant bearing on the design of e-textiles. Textiles tools mediate the experience of the material by the designer, and in turn, can help or hinder the acquisition of embodied knowledge of the material (Philpott 2012).

This paper explores e-textiles design development through the lens of affordance. The paper firstly describes the concept of affordance and its relevance to e-textile design. To discuss this subject, the authors reviewed literature detailing e-textiles design processes, in addition to contributing findings derived from their practice, framing their analysis within the concept of affordance. This paper considers new affordances in e-textiles materials, affordances and constraints in material manipulation, and the affordances of tools. The paper concludes by acknowledging the role of the user, and how skills and experience can impact on the perception of design affordances.

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Affordance in design research

Affordance, introduced by Gibson (2015) (first published in 1979) from the field of ecological psychology has been used in design research to discuss the possibilities enabled through the interplay between the material, the user and the environment. Gibson describes the affordances of the environment as “what it offers the animal, what it provides or furnishes, either for good or ill” (Gibson 2015). While affordance is based on the physical properties of the environment or object, affordance is a relationship; it is relative to the animal. For instance, water may afford walking on for water bugs but not for larger animals.

The use of the term affordance in design research is often attributed to Donald Norman, in the book The Psychology of Everyday Things, first published in 1988, subsequently republished as The Design of Everyday Things (Norman, 2013). Norman’s usage of the term affordance retains the same overall meaning, “the relationship between a physical object and a person” (Norman, 2013), but it is applied to discourse on designed objects. However, with the adoption of the term by the design community, there has been some misinterpretation, leading to further clarification or expansion of affordance by Norman and other researchers.

Some of the key discussions in the literature are the differences between ‘real’ and ‘perceived’ affordances, information and affordance, and affordance and indicators of affordances. In Gibson’s original definition of affordance, affordances exist whether they are perceived or not. Norman (1999) and Gaver (1991) add the qualifiers ‘perceived’ or ‘perceivable’ affordances, in addition to Gibson’s ‘real’ affordance (Norman 1999). The perception of affordances is determined by the availability of information, and as a result, affordances can be perceived correctly, incorrectly, or be hidden to the individual (Petersen, Rasmussen, and Trettvik 2020, Gaver 1991). You and Chen (2007), Hartson (2003) and Norman (2013) discuss the difference between affordance and indicators in the design that facilitate the perception of affordances: the use of semantics (You and Chen 2007), 'sensory affordance' (Hartson 2003), which are aspects that support sensing (e.g. large text size), and signifiers, "any perceivable indicator that communicates appropriate behavior to a person" (Norman 2013). Petersen, Rasmussen, and Trettvik (2020) distinguishes between Norman's signifiers and information, as they see signifiers as cues or communication devices that require interpretation, while information is perceived directly. The application of the concept of affordance extends beyond the interaction between an individual and the object. Gaver (1996) applied affordance to social interactions. Gaver uses email systems as an example. The affordance of a high bandwidth email system compared to a dial-up internet email system affords different email cultures, with the first potentially using email in a similar way to telephone calls i.e. frequently and informally, while the second may treat it in a similar manner to a postal service.

Research exploring affordance in the design process provides interesting perspectives on how different elements interact to influence the development of novel and creative outcomes. Affordance has been used in a theory of creativity, used to categorises creative possibilities in relation to the interaction between sociocultural elements and the individual. The sociocultural model for an affordance theory of creativity by Glăveanu (2012), provides an explanation of why some creative possibilities may not be enacted. 'Unperceived' affordance are possibilities that the individual is simply not aware of, though can be enacted. 'Unexploited' affordances represent possibilities that the individual is aware of but chooses not to exploit for cultural reasons, while 'uninvented' affordances are affordances that are desired but are not yet possible. 'Uninvented' affordances are possible through transforming existing

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capabilities. Barati and Karana (2019) refer to the three types of affordances by Glăveanu (2012) in their paper on affordance as material potential. In their work, they use the concept of affordance as material potential to promote a material driven design process that unlocks new potential for materials. Barati and Karana (2019) cite examples of work that demonstrate spontaneous discovery, the invention of techniques and transgression of norms through material driven design; three techniques that can be used to realise the three unrealised affordances discussed by Glăveanu (2012).

Considering e-textile design with regards to affordance frames the discussion of e-textiles as a complex system of relationships between the materials, the tools and the designer. E-textiles designers are designing with affordances, as well as creating affordances through designing the capabilities of the fabric.

New affordances in e-textiles materials

E-textiles are soft systems in that the interactive and functional properties of e-textiles are not enabled solely by a single ‘smart’ material but a system of connected electronics. For instance, a conductive fabric sample can only work as a touch sensor when connected to a microcontroller that can detect a change in the material’s resistance or capacitance and then enact a response e.g. turning on or off a light. E-textiles materials have affordances that allow this system to function. For instance, conductive material allows for electrical circuits to be incorporated into the fabric, and various types of sensors to be created. Shape memory material can allow for actuation while light-emitting materials can be used to create illuminating fabrics. The wide library of materials means that they come in a range of physical forms. Using conductive material as an example, it is available in liquid form, as ink or coating (Karim et al. 2017, Wang et al. 2011), a yarn-like form i.e. conductive yarn, metal wire (Parzer et al. 2018, Atalay, Kennon, and Husain 2013, Perner-Wilson, Buechley, and Satomi 2011) and in textiles form (Strohmeier et al. 2018, Ngai et al. 2009). E-textiles can also incorporate small electronic components into the fabric structure, particularly for components that are difficult to replicate in textiles form, like solar cells or light-emitting diodes (LEDs) (Dongen et al. 2019, Dias and Ratnayake 2015).

Although e-textiles material can appear similar to their textiles counterparts, there can be differences that are not easily perceptible. For conventional textiles, material affordance can be explored through handling the material to examine its texture, elasticity and other material qualities. However, e-textile materials may require a tool to be used to change an affordance from hidden to perceptible. In the case of conductive material, conductivity is only perceptible when the material is connected to an electrical circuit or tested with a multi-meter. The ability to take advantage of available affordances is dependent on the perceptual information available to the designer. Polymeric optical fibre illustrates this. Its appearance is very similar to that of monofilaments used in textiles. Nevertheless, due to its composition, consisting of a core and layers of cladding (Tan 2015), the material affords end-to-end light transmission. As such, the material has been used for sensing, signal transmission and illumination. It also allows for selective illumination along the fibre through intentional damage to the fibre's cladding.

Affordances and constraints in material manipulation

Researchers have been successful in aligning the tools to the affordances for manipulation provided by the e-textiles material. This often occurs when the e-textiles material has very similar physical characteristics as the material typically used with that equipment. For instance, using conductive graphene ink in an inkjet printer (Karim et al.

2017), the technique of drip coating to produce resistive yarn (Parzer et al. 2018) or conductive thread in an embroidery machine (Gilliland et al. 2010). There can still be a need to make adjustments to suit the material and ensure that the e-textiles can be produced reliably. These actions are expected to take place within conventional textiles design, so aren't considered as a constraint specific to e-textiles design. Another approach is to modify the design of electronics to suit textiles processes. This is seen in the Lilypad Arduino (Buechley et al. 2008), a rigid microcontroller with holes to allow it to be stitched to fabric. Further this, ZSK Stickmaschinen GmbH (2020) created 'functional sequins', electronics premounted onto sequin rolls, allowing them to be automatically placed and machine embroidered.

Working with material affordances and constraints: polymeric optical fibre

Polymeric optical fibre (POF) has beneficial imperceptible affordances, with its light transmission properties, but also imperceptible constraints. POF's filament form leads to the logical assumption that it can work within the textile design process. However, this is not the case; it is more rigid and brittle when compared to textiles yarns and monofilaments, and it can struggle to withstand the strain that is applied to the material during the textiles production process. This impacts on the choice of tool and/or technique used to integrate this material. E-textiles designers often opt for weave or inlay, a technique in knitting in which a fibre is interwoven between knitted loops, rather than knitting the fibre into the loop structure. Weaving and inlay minimalise the strain on the fibre since it is not bent at an acute angle, therefore reducing the risk of breakages (Ge and Tan 2020, Oscarsson et al. 2009, El-Sherif 2005).

Despite the fibre having some constraints compared to conventional yarns, the author's work looked at working within the affordances and constraints of the material

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and developed a method for integrating it into a knitted structure. The rationale was to overcome the limitations present in woven and inlay POF fabrics. The project looked at taking advantage of the affordances of the knit structure. While weaving minimalises fibre damage, the process of weaving limits the fabric to being produced at fixed widths. In contrast, knitting has certain affordances inherent to the technique. Knitted fabrics can be knitted into shape. This is beneficial from several perspectives. From an environmental sustainability perspective, shaping the fabric during the knitting process rather than cutting the fabric to shape would produce less waste. From a garment design perspective, knitting to shape would mean that it wouldn't be necessary to 'frame' the POF fabric to create shaped illuminating panels, which results in excess fabric, potentially impacting on the appearance of the overall garment (Wong, Tan, and Luximon 2016). Knitting the fibre into the looped structure means that it would be more securely held when compared to the inlay technique, which allows the fibre to shift within the fabric.

Another constraint inherent to using POF for illumination is the connection to electronics. For POF, the fibres need to be connected to a light source for illumination. For POF in a fabric structure, there needs to be excess lengths of fibres from the fabric edge that can be bundled together and coupled with the light source. In weave structures, the excess lengths can be produced by removing the warp yarns to free the optical fibre for bundling (Tan 2015). Due to the structural differences between weave and knit, this process isn't directly transferrable to knitted fabric.

Through material exploration, it was possible to identify the affordances of the material with regards to its relationship with the knit structure. Firstly, POF could be formed into the loop structure, provided it is knitted at low speed and with minimal tension of the fibre. Secondly, the bend caused by the looped structure causes damage to the fibre's cladding, even if there is not a clear breakage, leading to light leakage at the loops. Finally, the denser the distribution of loops, the shorter the travel distance of the light from its source. To work with the optical fibre in a knitted structure, a knit structure had to be developed that leveraged these affordances. The fabric, seen in Figure 1, was designed to minimalise the number of loops the optical fibre is formed into. Light loss at the knitted loops was used as the form of deliberate damage to the cladding, which meant that an additional process, for example, laser engraving, did not have to be done to allow for fabric illumination. The details of the knit structure are documented separately (Chen et al. 2019).

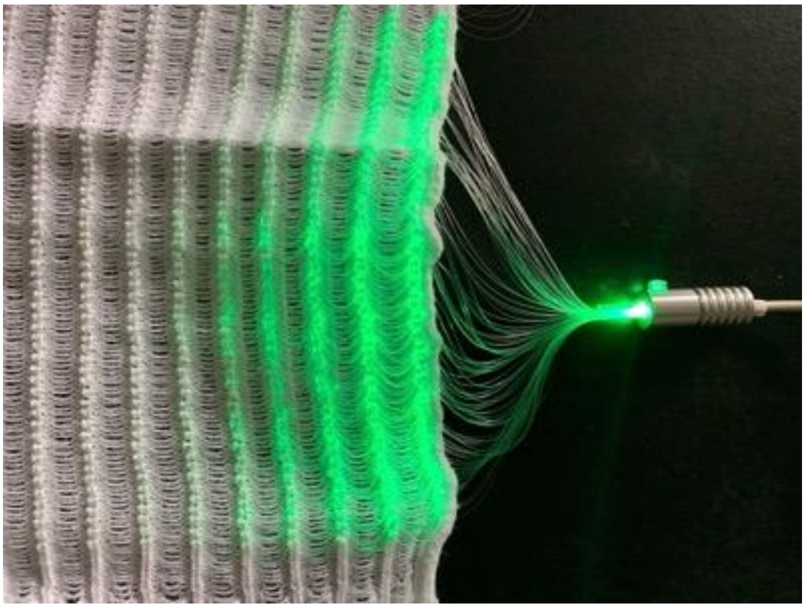

Figure 1. Knitted optical fibre fabric attached to a light source

The affordance of textiles tools

While Barati and Karana (2019) touch upon the relationship between tools and material, stating how the invention of techniques, new tools and repurposing existing tools can create novel material affordances, there is the capacity to further explore the interplay between the affordance of tools and materials in e-textile design. Textiles

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manufacturing equipment is developed in accordance with its expected use, likely with conventional textiles materials in mind. As such, the developments around the textiles production system has been built upon the recognised affordances of tools, the designer/maker and the materials. However, the physical properties of e-textiles materials can differ significantly from those of common textiles materials. Yarns made from fibres twisted together are soft and malleable, while materials associated with electronics, such as metal wires or printed circuit boards, are often the antithesis of this. E-textile materials also require that the material is integrated into the fabric structure in a certain way to provide the desired function, as they have to take into account the requirements of the electronics and the way the function is enacted. As such, there is a potential gap in the affordances of textiles manufacturing equipment in relation to e-textiles practice. Through an analysis of the literature and reflection on the author's practice, four key affordances of textiles tools were identified: tactile feedback, manual intervention, design complexity and automation.

Tactile Feedback

The value of the hands-on approach has been acknowledged in textile design. Hands-on material exploration allows the designer to build tacit and embodied knowledge of the material and craft process, that can inform later design (Philpott 2012). Viewing this from the perspective of affordance, hands-on material exploration allows the hidden affordances to be perceived by the designer. In the initial work on developing a knit structure for illuminating optical fibre, a hand-operated knitting machine was used (Figure 2).

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Figure 2. Wealmart knitting machine

While hand-operated machinery adds distance between the designer and the material when compared to hand knitting, hand-operated machines still afford a degree of tactile feedback and this feedback is continuously provided to the designer during the making process. In machine knitting, perceived difficulty in pulling the carriage across the needle bed informs the designer that there is an incompatibility between the yarn and the machine; the yarn tension is potentially too high, or the yarn is too thick for the machine. This immediate feedback can be lost in a computer-operated knitting machine, as it is difficult to observe the interaction between the yarn and the machine within the machine enclosure. When manipulating e-textiles materials with more challenging physical properties, such as optical fibres, continuous tactile feedback is important for identifying the cause of an issue and allows the designer to adjust accordingly.

Manual Intervention

In addition to providing tactile feedback, the hand-operated machines provide the affordance of manual intervention. Intervening in established practice allows for new techniques to be developed. Looking at the opposite end of the spectrum to industrial manufacturing, at handcrafted e-textiles (Perner-Wilson, Buechley, and Satomi 2011), it is possible to see the variety of forms and functions that are enabled by using handcraft techniques like crochet and tufting. Handcrafted e-textiles offers a high degree of control and it is not inhibited by automated machine actions. Creative manual intervention is required as there are aspects of conventional textiles construction that are not well aligned with the needs of electronics. For example, neither knit nor weave are suited to producing the vertical paths of electronic circuitry (Friske, Wu, and Devendorf 2019, Gowrishankar, Bredies, and Ylirisku 2017). Manual intervention can be used to overcome these shortcomings. Devendorf and Lauro (2019) use manual warp insertion to selectively place conductive yarn paths in the vertical direction.

This affordance can come into play in the form of modifications to the machine, and not solely as manipulation of the material. In the production of the floating optical fibre sections for bundling in the knitted POF work, the hand-operated machine technique was able to overcome a limitation in the number of needles floated across since the yarn feeder can be lowered to bring it closer to the needle. However, this is not possible for the computer-controlled machine, resulting in an inability to recreate this part of the structure on the computer-operated machines. Wu and Devendorf (2020) encountered limitations with industrial looms that prevented them from using a shaped weaving technique. As a result, they developed their proof-of-concept sample on a hand-operated loom (rigid heddle loom) modified with additional beams.

In the context of using hand operated machines, the hand/body and the tool/machine are a system linked through affordances. The designer is heavily embedded in the production of the fabric, they are the motor and controller of the system, and the tool is an extension of their body. In contrast, when using a computer operated machine, there is a separation between the designer and the tool. The tool itself

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is its own system of sensors, motors, and controllers. When considering a piece of equipment's affordances, it may be easy to focus on the intentionally designed affordances, such as the ability to perform a certain technique. Interestingly, tactile feedback and manual intervention, ever-present in the hand operated machines, are more a consequence of requiring manual operation rather than being a designed affordance. They are affordances that can go unperceived until the designer realises that they are not present.

Design Complexity

An affordance of more advanced textiles machinery is that they can allow for greater design complexity, with the design of the machine supporting the production of complex structures. In the case of knitted optical fibre, it was found that limitations inherent to the Wealmart knitting machine prevented particular elements of the design from being realised. Limitations in the number of yarn feeders and the inability to restrict their movement meant that the samples produced using the Wealmart did not have a closed selvedge along both edges (Figure 3). To produce a more refined version of the fabric, a hand-operated machine which allowed for more control had to be used, in this case, a Dubied hand-operated machine. Figure 4 illustrates the differences in the two knitting machines and how this impacts on the POF knit structures that could be produced. Using this machine meant that a closed fabric selvedge could be created along both sides, along with long floats of optical fibre that are later bundled and connected to the optical fibre (Figure 5).

Figure 3. Wealmart knitted POF sample

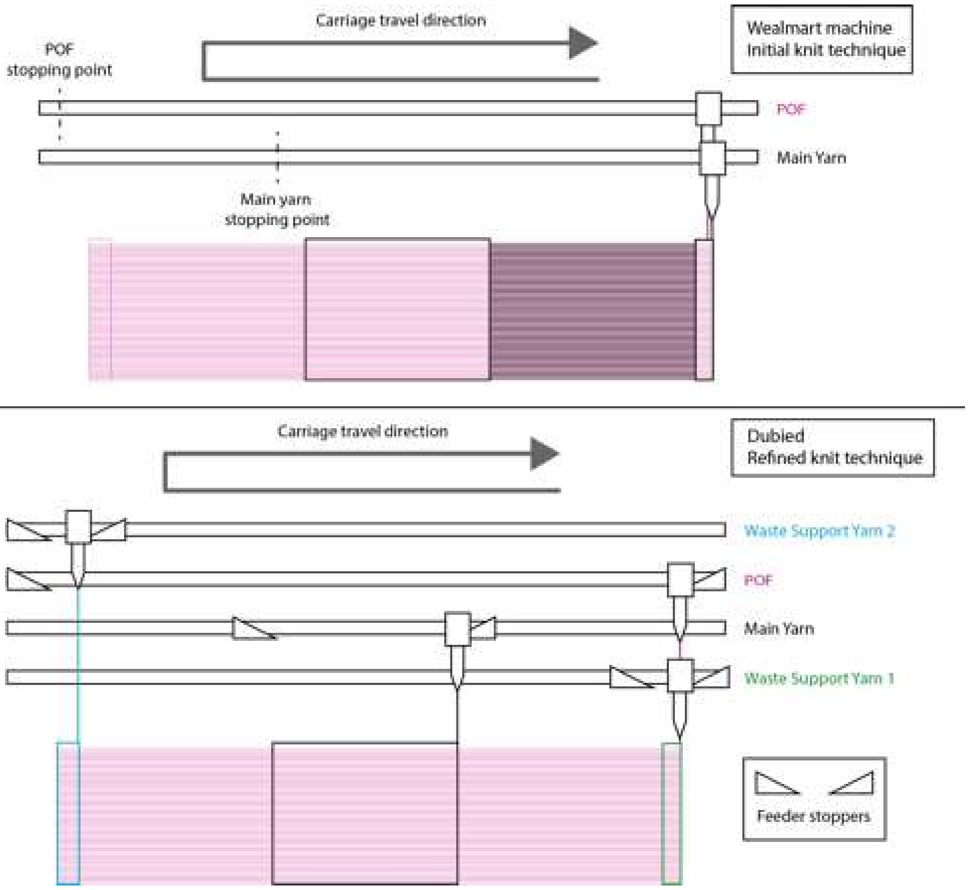

Figure 4. Wealmart Knitting machine setup (Top), Dubied Knitting machine setup diagram (Bottom)

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Figure 5. Dubied knitted POF sample

It is not necessarily impossible to produce certain textiles structures on machines with less functionality. For example, it is possible to produce intarsia knitting, as used by Li et al. (2010) to create knitted circuitry, through hand knitting and not only with a computer-operated machine. Similarly, the double weave structure used by Poupyrev et al. (2016) to isolate conductive yarn for later connection to electronics can be produced on a hand-operated loom (Devendorf and Lauro 2019) as well as a jacquard loom. In these situations, the skill of the maker is brought to the forefront as they must manage the production of the complex structures. However, as designs become more complicated, it can be impractical for the maker to manage all the elements of the design and human error is more likely to come into play. It is possible to see the benefits of offloading complicated structures to the technology in e-textile design. The CAPI cushion by Tan et al. (2019) uses a jacquard loom to produce a fabric that combines double weave structure, woven motifs, optical fibre, spandex and the selective placement of conductive yarns. This enabled the creation of an e-textiles design with textile-based touch-sensitive buttons and illumination, that are also produced in the same process.

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Automation

Automation is linked to design complexity, in that the machine's automated processes can allow for design complexity, such as with the jacquard weave controls. Automation is of particular importance in works that aim to be scalable (Olwal et al. 2018, Poupyrev et al. 2016, Oscarsson et al. 2009). They allow for complex textiles constructions to be reproduced more reliably and easily. Computer operated machinery can mitigate some of the constraints of requiring a skilled maker to produce the e-textile. By utilising the capabilities of the hardware and the high degree of control a computer provides, it is also possible to streamline the production process. Albaugh, Hudson, and Yao (2019) demonstrate the ability to integrate a tendon in knitted fabric to create an actuating soft object in the same process as knitting the object itself. This is through the use of inlay and 'tangling', a vertical inlay technique, in combination with shaping on a computer-controlled knitting machine.

Industrial textiles manufacturing equipment automate the production process and are often optimised for speed and throughput. As a result, they can indirectly prevent the development of new textiles production methods. For instance, industrial looms feed the weft yarn from edge to edge and cut the weft yarns, making them unsuited to the goal of designing for e-textiles disassembly (Wu and Devendorf 2020).

Interrelationship between affordances

Upon analysis, the affordances identified can be paired, manual intervention with tactile feedback and design complexity with automation. As mentioned, automation helps enable design complexity by offloading some of the maker's actions to the machine. Manual intervention and tactile feedback relate to hands-on human control. In requiring the maker to be physically involved in the production, the maker learns about the affordances of the material and the tool and can derive new designs and production techniques that correspond with these perceived affordances.

Comparing textiles tools and machines within the context of technological capability, handcraft can be placed at the lower end of the scale, while computerised machines are placed at the opposite end. Hand-operated machines can be placed at the centre of the scale. The machine affordances can also be considered on a scale (Figure 6). One perspective on affordance and tools is that with increasing technological capability, there is an expansion on the affordances of tools. This is true to an extent. The more feature-rich Dubied hand flat machine could produce the knit structure that the Wealmart machine could not. Another perspective is that there are affordances that are lost in the move from hand-operated to computer operated tools. In the development of the knitted optical fibre fabric, the difference in the design of the tracks of the computer-controlled machine introduced an unanticipated issue in the knitting process that was not present in the hand-operated machines. For the computer-operated knitting machine, the cam tracks that control the movement of the knitting machine needles are shorter and steeper, as they are designed for quicker knit speeds. However, this feature caused the optical fibre to be subjected to a significant amount of force, no matter the knit speed, resulting in breakages

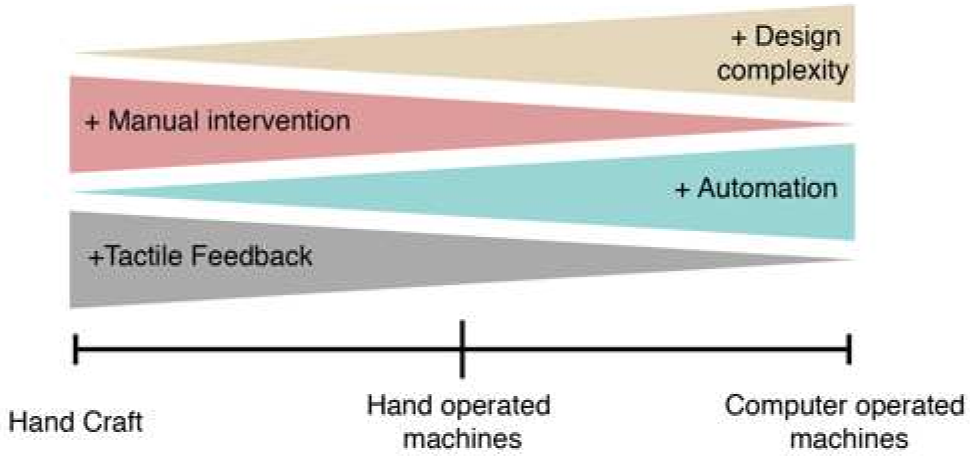

Figure 6. Affordances in textile tools

This scale of affordance and technological capability can be applied to all textiles production and it is not specific to e-textiles. However, the requirements of e-textiles design mean that with this compromise in affordances, e-textiles design may not be as easily scalable as conventional textile designs. It is challenging to move beyond small-scale production for e-textiles that use new or uncommon techniques and materials since industrial equipment is not designed with this in mind. The limits of the textile production ecosystem are highlighted by the existence of e-textiles solutions like the Functional Sequin Device, used to place LED sequins onto the fabric (ZSK Stickmaschinen GmbH 2020). Yet it is not always practical to develop specialised equipment for what can be regarded as niche use cases. Machine features not specifically for e-textiles can be used in e-textiles production. Examples include the loop pressor used to inlay yarn into knit fabrics, or the Yarn Unwinding Option, a machine used to actively feed yarn into the knitting machine (Shima Seiki 2020, 2016). However, these are not standard in machines, and therefore less readily available. For computer-operated machines, additional features are required to perform actions that the maker could do manually on the hand-operated machine. As such, e-textile design and production benefits from a balance between the four affordances rather than leaning

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heavily towards one end of the scale, as the human maker is more versatile compared to the set features of automated machinery.

Tools with affordances for novel e-textiles production

The necessity of tools with affordances for e-textile design has been acknowledged in research. Posch (2017) highlights that at present e-textiles uses a mix of tools traditionally belonging to textiles or electronics, and as a result, they may not fully support the e-textile design process. Posch and Fitzpatrick (2018) address one aspect of the e-textile design process by creating an e-textiles testing tool for checking electrical conductivity and providing power to the e-textiles. Friske, Wu, and Devendorf (2019) address the e-textile weave drafting process by creating AdaCAD, a software which allows yarn paths to be visualised to check electrical connections, and supports less conventional textiles techniques, such as supplemental warp connections. This section focuses on the physical production of the e-textiles. There is a tendency for the affordances of manual intervention and tactile feedback to decrease as design complexity and automation increase. Yet, this does not mean that these cannot exist in the same equipment. Tools which can provide a degree of each affordance can aid the production of novel complex e-textiles, with the technology assisting the designer but not preventing them from exploring new design possibilities.

A tool that provides this balance of affordances is the TC2 loom (Tronrud Engineering 2019), a hand-operated jacquard loom. It has been used by Friske, Wu, and Devendorf (2019) and Hardy et al. (2019) in their e-textile development. Production is not fully automated, and the weaver must throw the shuttle through the warps. This allows the designer to both gain tactile feedback and manually manipulate the material while benefiting from the jacquard element of the loom which enables the complex

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Journal of Textile Design Research and Practice, 29 November 2021
http://www.tandfonline.com/10.1080/20511787.2021.1935110

patterns to be produced. However, there does not appear to be an exact equivalent for knitted e-textiles; a knit machine that provides computer control while being hand operated. One potential candidate can be seen in the maker space, an electric domestic knitting machine with AYAB (2020), an Arduino based modification that connects the machine to the computer, allowing complicated images to be knitted. Without the modification, the needle control is limited to creating narrow repeating patterns, while the AYAB modification allows each needle to be individually controlled similar to the jacquard loom. The domestic knitting machine is hand operated, providing tactile feedback and allowing the knitter to manipulate the knit structure directly e.g. hooking up or transferring loops by hand. It has been used in the research project Knitflatable Architecture (Baranovskaya et al. 2016). Nevertheless, given the Do-It-Yourself nature of the modification and its use of vintage hardware, this may not be an accessible option when compared to the commercially available TC2 loom.

The role of the maker

The skills and the experiences of the designer/maker plays a significant role in the realisation of an e-textile design. Experiences gained by the designer add to their repertoire, serving as a reference for future designs (Schön 1983). Taking this and the concept of unperceived affordances by Glăveanu (2012) into account, it is reasonable to suggest that past experiences impacts on the perception of affordances and therefore what is enacted by the designer. However, the impact of the designer’s skill and experiences is difficult to quantify. Affordances in machines, embodied in the features of the machine and their technical specifications, can be quantified more easily compared to the designer’s skills and experiences. Designers may be highly specialised or multidisciplinary in their approach, and this may impact on their approach to design.

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In reviewing literature describing design processes for e-textiles, mentions of limitations impacting on the reported work are infrequent. Of the literature reviewed, Oscarsson et al. (2009) were the only ones to make explicit mention of the machine's limitations and the impact on their work. For the other works, it was possible to infer what the limitations of the equipment were based on the solutions devised by the designer. Comments on the limitations of the designer's skills are rare. This may be as a consequence of the tendency for academic literature to be written in the third person, or a reluctance to admit personal limitations. Positives are mentioned, for instance, "As an experienced knitter and weaver who learned these fiber crafts alongside traditional engineering and science subjects, Wu was uniquely positioned for this exploration" (Wu and Devendorf 2020, 3). However, for the e-textile research that has been discussed, it is difficult to deduce the impact of the designer's skills and experience since it isn't explicitly mentioned.

With this in mind, the authors draw from their own experience in e-textiles design, and how limitations in skills and experience impacted on perceived affordances, and how new knowledge impacted on the subsequently enacted affordances. Following the development of the initial knitted optical fibre structure, the work was transferred to computer-operated knitting machines, with the aim of making production less labour intensive. However, the transfer from a hand-operated machine to a computer-operated machine brought unexpected issues. It was found that even when knitting at a slow speed, the optical fibres tend to break (Figure 7), which initially led to the conclusion that the cause of the breakages was related to the interaction between the optical fibre and the computer-operated machine, and that it was not possible to knit this design on the computerised knitting machine. This work was taking place concurrently with the refinement of the knitted optical fibre fabric on the Dubied knitting machines, which dealt with a separate issue of optical fibres breaking when used to knit the waste sections. The solution was to knit the fibre in these sections with an additional supporting yarn. This led to the idea of testing the concept of a ‘support’ yarn in the computerised knitting work, ultimately resolving the majority of the issues with fibre breakages in the main fabric (Figure 8).

Figure 7. Knitted POF sample without support yarn.

Figure 8. POF knit sample with white support yarn. Breakages marked with blue yarn

Conclusion

This paper applied the concept of affordance to the discourse on e-textile design. A review of literature on e-textile design and reflection on the authors' practice was used to illustrate the interplay between e-textile material, tools and the designer from the perspective of affordance. The affordances were identified in textiles production equipment: design complexity, manual intervention, automation and tactile feedback, can be found in varying degrees depending on the technological capability of the machine. This work presented these affordances on a layered spectrum (Figure 6) that depicts the complexity of the design of e-textiles in practice. A key point raised in the discussion is that technological capability can help but also hinder e-textile design as it can restrict the designer's direct involvement and their ability to gain tacit knowledge. While e-textile designs which feature manual manipulation techniques may be less scalable, since it cannot be produced within the current capabilities of automated textiles production equipment, it is beneficial for e-textiles design research as it does not restrict the creativity of the designer. Although some of these affordances appear to be in opposition to each other, existing textiles tools have shown that is possible for the affordances of design complexity and manual intervention to be present in the same machine.

While this is not present across a wide range of textile tools, it is hoped that by identifying this gap in the affordances available in textiles tools for e-textile production, it will encourage further development and consideration about the e-textile design process. One direction is the development of textiles production equipment that is in the middle of the scale of technological advancement and affordances, allowing for better human-machinery collaboration. In a broader sense, the paper draws attention to the continued importance of human makers in an industry that tends to progress towards automation.

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