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CIRCULAR TRANSITIONS

23–24 November 2016

Where Does Wearable Technology Fit in the Circular Economy?

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Abstract

Wearable electronics has emerged from a niche industry to one expected to rise to US\$70 billion by 2025 (Harrop, 2015). While starting to recognise environmental concerns they have yet to become an industry driver. In this paper, we explore options to better position wearable technology in the Circular Economy.

Introduction

Environmental concerns have become a core focus in today's fashion and textile industry. Sustainability underlies all aspects of the industry from sourcing raw materials through design, manufacturing, consumer use and end-of-life disposal. Wearable electronics has emerged from a niche industry to one with an estimated market value of US\$20 billion in 2015 and expected to rise to US\$70 billion by 2025 (Harrop, 2015). Although still a relatively immature industry, it is starting to recognise environmental concerns but thus far it has not become an industry driver. In this paper, we first look at the current state of sustainability within wearable technology. In the second section we identify key drivers and issues then propose ways in which wearable technology can more fully embrace the Circular Economy. In the concluding section we look at future technologies and their likely environmental impact.

As wearable technology has now started to mature all aspects of sustainability need to be addressed. We will look at lessons that can be taken and applied from the textile and fashion industry such as the sourcing, use, reuse and disposal of material. We will also examine issues unique to wearable technology for example the need for a power supply and the problem of technological obsolescence within the garment. From a design perspective we examine the ways in which wearable technology is applied within fashion and how this could more closely relate to the activity of garment use. From this position we then question whether it is possible

CIRCULAR TRANSITIONS

23–24 November 2016

for wearable technology to contribute to garment longevity by examining issues and concepts related to fashionability, durability, and repair. In the concluding portion of the paper we consider the introduction of future technologies and disruptive manufacturing processes that have the potential to provide challenges that demand design and manufacturing solutions that are both sustainable and innovative.

Wearable technology

Wearable Technology refers to the incorporation of technology into clothing to provide for a dynamic clothing system that senses and responds to stimulus. It is also referred to as Smart Clothing, Interactive Clothing, Intelligent Clothing and Wearable Computers. The discipline emerges from the fields of Military, Medical, Space, Sportswear (O'Mahony, 2002) and Computers. Early iterations can be traced back to the 1960's, however, it was in the 1990's that developments began in earnest with partnerships forged between industry and academia notably in America with universities such as Massachusetts Institute of Technology (MIT), Georgia Tech and Carnegie Mellon University. The early iterations were driven by a desire to create wearable computers (Suh, et al 2010). The prototypes that emerged through the 1990s can most accurately be described as 'portable' rather than 'wearable'. There were many reasons for this. Energy was key as many waited to see whether the much-anticipated lithium battery would materialise and be affordable, bringing with it a smaller, lighter and more efficient power source. Wearable Technology has excited technologists and fashion designers alike causing it to be seen both as the "future of fashion" and the "future of computing" (Dunne, 2010). It is only relatively recently that technology has become 'cool' and the computer industry has begun to reach out to fashion acknowledging its value to their products.

The end of the Cold War saw a reduction in military spending on research and development and as a result there was a shift towards consumer applications for wearable technology. While the soldier had little choice about what they wore, the consumer clearly expected any garments and devices to be fully functional, reliable, lightweight, comfortable, and stylish. Early adopters include Hussein Chalayan with spectacular clothes that appeared on the catwalk as early as 2002. While fashion embraced the concept and aesthetic of wearable technology, cost and development meant that it is sportswear that has taken the lead on commercialisation and getting products into the shops. In particular, biometric clothing that monitors the wearer's vital signs during activity is being produced by

CIRCULAR TRANSITIONS

23–24 November 2016

brands such as adidas, OMSignal and Hexoskin with products that are being well received by Early Adopters. The challenges they and others entering the market face include increasing user engagement, greater aesthetic and comfort, ease of use and customisation. Environmental issues are starting to emerge, as the industry is realising that they are part of the apparel industry and the concerns there need to be addressed by wearable technology also.

Clothing and the circular economy

Clothing products are developed for a wide range of markets, and they have to meet the specific requirements, needs, and values of an identified consumer. It is because of this variety that garment characteristics differ in their aesthetic qualities, fabrications and construction methods, most of which will have been determined to suit a predetermined price point, purpose, and function. High street fashion garments, for example, are typically developed for their aesthetic appeal and are constructed from inexpensive materials that keep the items affordable and (easily) replaceable. Meanwhile many workwear and uniform garments typically place a greater value on functionality and durability during use, connected to performance during wearing and maintenance requirements.

Post-purchase, during the use phase, a garment goes through a series of activities including wearing, washing, storing, repairing (adaption and alteration), and disposal (Bras-Klapwijk and Knot 2001). Each person will have an individual pattern of use that may be different to the practice employed by others. Consequently, this means that whilst the characteristics of a garment may be the same the practices adopted by two people may be starkly different (Gwilt, 2015). Laundering may be poorly or carefully executed, for example, or a garment may be discarded early or it may be repaired or altered and kept for longer. Significantly when and where a garment is discarded will depend on the philosophical viewpoint of the wearer. In a study conducted by WRAP (2012) more than half the adults interviewed believed that discarded garments had no value and so placed items in a waste bin.

These points show that there is a direct relationship between design and production of garments, the practices applied during use and the generation of textile waste. Working towards a circular economy in the clothing industry can, then, pose a variety of challenges. While it is apparent there is a need for specific and specialized solutions that take into account the individual

CIRCULAR TRANSITIONS

23–24 November 2016

characteristics of a garment type, there is also a necessity to be aware of the individual practices adopted by wearers during use. The question is whether the picture will be further complicated if garments are embedded with wearable technology.

Reflecting on the strengths and weaknesses of wearable technology in the circular economy

Wearable Technology is in a unique position aligned both to the clothing and technology industries. Dunne describes the current model of developing smart clothing as “...a grafting of two existing approaches (an electronic device grafted onto a garment), when what is necessary is a redevelopment of both.” (2010, p56). From an environmental point of view this allows it to transcend some of the issues that the fashion and sportswear industries in particular are currently struggling with such as fast fashion. That said, it also creates another set of problems. There are three areas in particular that have to be addressed: energy in production and use; technology integration; design aesthetics and garment care.

Energy

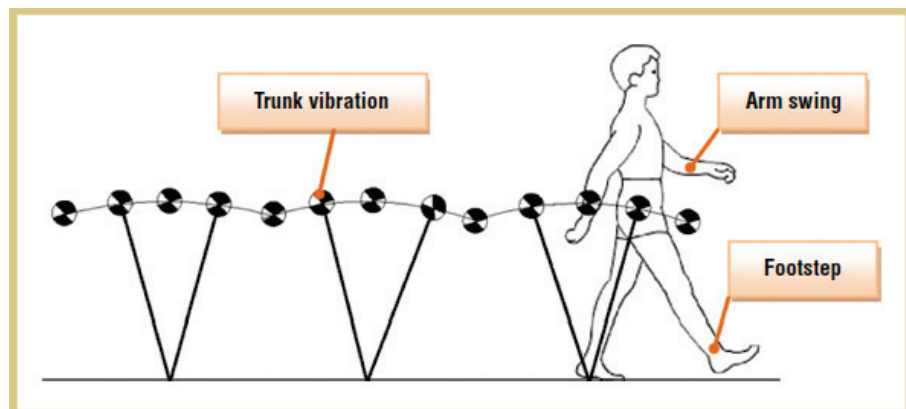


Figure 1: Human movement while walking showing the hip and trunk motion up and down measuring 4-7cm as the body is propelled forward from one leg to another. Illustration: Xie and Cie

Energy is an issue in material selection, garment production, distribution, and use as with all garments. However, Wearable Technology brings with it additional challenges of the energy needed to provide power to the devices incorporated into the garment. While Steve Mann was transporting his energy supply in a Pentium II housed in his backpack, one of his fellow researchers at MIT Thad Starner, was investigating the potential of the

CIRCULAR TRANSITIONS

23–24 November 2016

wearer to supply their own energy needs through movement (Starner, 1996). Starner points to two issues here. The first is that of energy that he defines as being "the capacity to do work", and the second is that of power being "the time rate of doing work". As his research looks at the potential of breath, body heat and movement (leg and footfall in particular) to provide energy, ultimately he concluded that it was not feasible beyond certain military applications because of the consumer demand for fast Central Processing Unit (CPU) speeds and high broadband. More recent research in the field looks at foot and human trunk motion to provide power identifying the need for further development in reducing weight and bulk in such devices before they become acceptable to the consumer (Xie and Cie, 2014). An energy approach that is receiving greater commercial success is the use of Photovoltaic (PV) Cells. More commonly used in architecture to harness the sun's rays and convert it to electricity, the technology has developed sufficiently that it can be scaled down and produced in a flexible form that can be incorporated into garments.



Figure 2: Garments designed to maximise the positioning of the PV cells, Yuxi Wang Digital Futures Graduate collection, OCAD University. Photo: Yuxi Wang.

Technology

The integration of technology into clothing in Wearable Technology has technical, comfort and aesthetic criteria that need to be addressed. Hussein Chalayan's Ballerina dress (S/S, 2002) used forty-five meters of shape memory alloy and was powered off-stage at Sadler's Wells by a car battery. While acceptable for a catwalk show this is not something that could be sold commercially in that form.

New developments in yarns, conductive inks and fabric technologies are making it easier to design more discrete garments. There remain challenges of how to protect the technologies against wear, laundry and human

CIRCULAR TRANSITIONS

23–24 November 2016

perspiration while ensuring that they are correctly positioned to be effective at all times while in use. The ideal material in terms of recycling is a monomaterial that ensures a material can be broken down at the same temperature and process (O'Mahony, 2011). In wearable technology materials are by necessity hybrids, usually comprised of a textile and non-textile component presenting the challenge where "the existing Design for Recycling (DfR) principles for textiles or electronics do not match with the properties of the combined products." (Kohler, 2013).

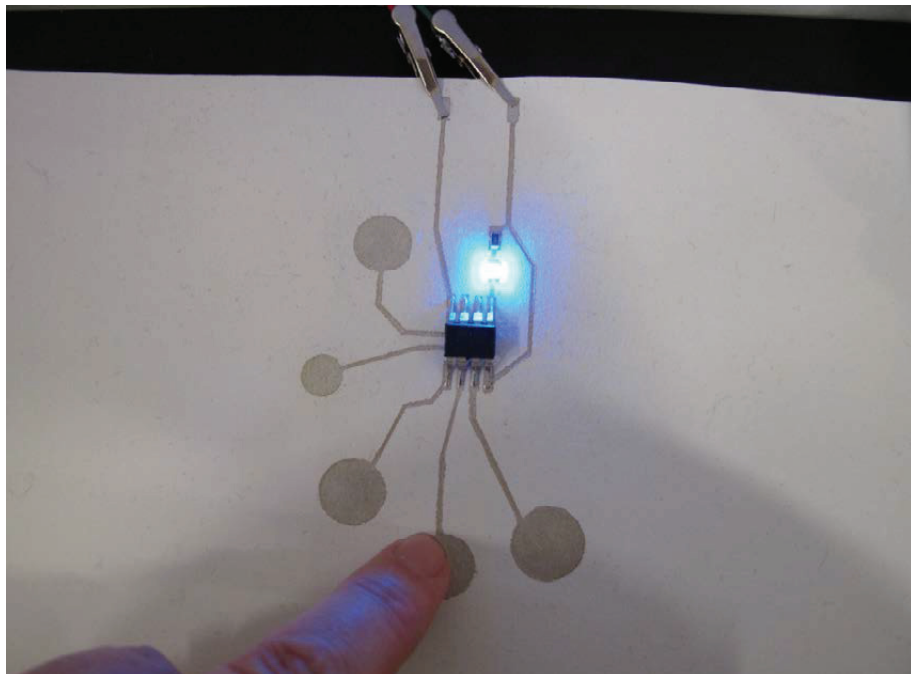


Figure 3: Advances in textile and coating technologies that are making it possible for designers to incorporate conductivity and sensors more discretely into garments.
Photo: Marie O'Mahony

Design

In a commercial context wearable technology has become an increasingly important attribute in the development of performance sports and outdoor wear clothing. Garments designed for these sectors usually place an importance on functionality, and the aesthetic look of the garment will be developed in a way so they can be worn for a number of seasons or years. In the fashion industry there is a great emphasis on producing garments with a built-in obsolescence. As Welters (2008) argues, the availability of inexpensive, poor quality clothing has created a demand for 'instant fashion', products that are designed to stimulate the cost-conscious fashion consumer's desire for consumption. For the fashion industry the promotion

CIRCULAR TRANSITIONS

23–24 November 2016

of the disposal of one garment in pursuit of another is a model of production / consumption that provides economic benefits. However, this emphasis of a 'designed obsolescence' in fashion items may be highly problematic in the context of wearable technology. Since the fashion garment typically has a different lifecycle to that of technology components, Seymour suggests that, "...making a workable integration between the two is a challenging proposition" (2009, p25). Garments may still be discarded after one season although they incorporate technology developed to last for many years.

Amongst the existing literature a common perception is that the future for wearable technology "...lies in applications such as medical, workwear and other technical applications rather than fashion." (Berglin 2013, p24) Whether this is a correct assessment or not these items of clothing, just like fashion garments, will still require some care and maintenance during use, which may include laundering. Typically care labeling is provided in clothing at the point of purchase to assist users at home (Cox, et al 2013). However, whether there are benefits in providing labeling is contentious. Many people, it seems, do not execute the advice given on care labeling even though it is known that the life of a garment may be extended if care instructions are followed (van der Merwe, et al 2014). Routinely people will draw on existing knowledge that is either self-taught or passed on by family members (Shove 2003). Whilst the disparate practices in themselves may not be poor for conventional garment types, for those with embedded electronics laundering practices may be complex or problematic especially if the circuit boards and components are not encased in a detachable compartment (Dunne 2010). Further, as garments age specific areas may break down requiring repair, however in general people are not routinely involved in the practice of repairing worn or damaged clothing (Fisher et al., 2008; Gwilt, 2015). While this in general is problematic in a circular economy, if users lack basic repair skills then any attempt to replace or reattach rigid electronic components maybe difficult especially if, as Dunne (2010) notes, stitching through wires can damage the electronic circuitry.

Where next for wearable technology?

The enthusiasm for Wearable Technology is reflected in the fact that one in ten Americans own such a device (Lee, et al 2016). Unfortunately, the same research shows that one third of these consumers stopped using their product within six months. The illustration (Figure 4) highlights the importance of social impact, meaningful design purpose and public interest as key tenets. This is starting to take shape at a research level from the

CIRCULAR TRANSITIONS

23–24 November 2016

medical and wellness sector. In his PhD, Martijn ten Bhomer raises the important question of how Wearable Technologies can offer services that are more meaningful to people's lives (ten Bhomer, 2016). In his garment titled 'Vigour' for instance, the intention is to explore the potential for healthcare applications to become a means of communication between Alzheimer patients and their therapists encouraging greater interaction. The knitted, long-sleeved shirt uses a combination of stretch sensors and conductive yarn to gather patient data over the course of the day, which is communicated to the care-giver and the patient through sound or vibration. However, there are other ways in which Wearable Technology can positively contribute to life whilst being mindful of a need to work within the Circular Economy.

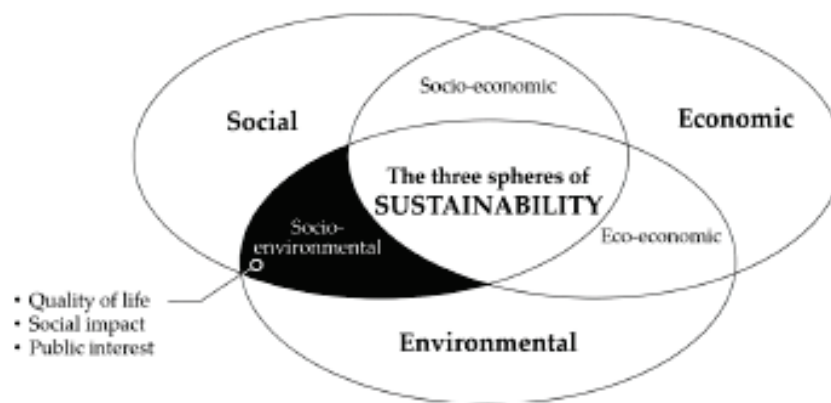


Figure 4: Three spheres of sustainability. Illustration: Lee, Kim, Ryoo and Shin.

Durability

Products based around technology can be open to accusations of creating 'planned obsolescence' that reduce their longevity (van Hinte, 1997). However we are starting to see a number of distinct routes emerge towards creating a greater durability in Wearable Technology. As technology becomes more energy efficient and components flexible and discrete, the aesthetic can be exploited to enhance the wearing experience. Through the use of illumination garments can be developed to change their design, effectively allowing the wearer to constantly alter the appearance of their garment throughout the day. The London-based Cute Circuit is an example of this, creating garments such as the Galaxy Dress (2009) with 24,000 Light-Emitting Diodes (LEDs) and the Twitter Dress (2012). Looking to the future Cute Circuit's Ryan Genz imagines social media moving technology

CIRCULAR TRANSITIONS

23–24 November 2016

to provide a wider environmental benefit enabling greater efficiencies in public transport systems for instance (Black, 2016).

Beyond embedded lighting, designers such as Ying Gao are also creating more dynamic garments that change shape in response to sound and light. Behnaz Farahi is developing garments that respond to gaze using a discrete camera and face-tracking algorithm to detect the onlooker's gender, age and viewing direction. Further, if as Dunne (2010) suggests there is a greater focus on “...interdisciplinary collaborations or multidisciplinary training...” between the technology industry and clothing producers it may be possible to better match the lifecycle of garment and technology thereby improving the durability of wearable technology.



Figure 5: Cute Circuit's Twitter Dress (2012). Photo: Cute Circuit

Repair and recycling

Developing wearable technology that enables the wearer to be “more creatively engaged in the transformation process...” (Earley and Goldsworthy, 2015 p5) may open up the opportunity to extend the life of existing wearable technology products. However as existing literature has shown (Fisher et al., 2008; Gwilt, 2015), support is needed to assist wearers with no or little repair experience.

Wearable Technology has a strong association with the Maker Movement with making, and by extension repair cafés and studio spaces appearing in larger cities. Much of the development is coming from small start-ups who by necessity have to develop not only the concept, but bridge the gap between the working prototype and scaled up manufacturing. This is one

CIRCULAR TRANSITIONS

23 – 24 November 2016

of the most challenging aspects of the field but it does bring with it an intricate knowledge of all aspects of the garment so that design for repair and disassembly can be factored at a very early stage in the process. Environmental and ethical concerns are becoming part of the ethos with brands such as Berlin-based Moon promoting their garments as offering "Intelligent Sustainability" with "top-quality products of long durability and devote our efforts to providing innovative, resource-saving production processes on fair terms" (Moon, 2016).

Emotional engagement

Consumer engagement on an emotional level is challenging for designers when working with man-made materials and with technology. But Wearable Technology has the potential to provide a wearer with a garment that can, as Earley and Goldsworthy suggest, meet three key requirements of "durability, adaptability and personal connection..." (2015, p5). A key challenge in designing for Wearable Technology is creating a bond with the consumer that goes beyond performance and aesthetics. The Digital Futures students at OCAD University were tasked with developing a concept for a biometric shirt and creating a working prototype. Consumer engagement was key and students began the process by creating their own avatar based on the principles outlined by Dunne and Watkins (2015). This was reinforced in asking the students to design for a friend, so the body was very real and fittings involved movement and real-time feedback on comfort and ergonomics. Molly Sayers' Hug Me shirt was conceived and designed to engage with its owner, tracking their body expression and helping to correct negative ones while encouraging positive interactions with other people (Figure 6).

Textiles themselves have a great capacity for emotional engagement and this is likely to increase now that natural fibres are starting to be used in conductive materials. In considering the nature of fabrics in this respect, Diamond argues that "Biological and psychological approaches may contribute to the ontology of textile memory, as textiles are perceptual and cultural" (2015, p.368). She goes on to lament the persistent search by textile and fashion manufacturers to find ways of eliminating stains, wrinkles, odours and other forms of human trace left naturally on clothing. In effect, striving to eliminate the contemporary garment's memory.

CIRCULAR TRANSITIONS

23 – 24 November 2016

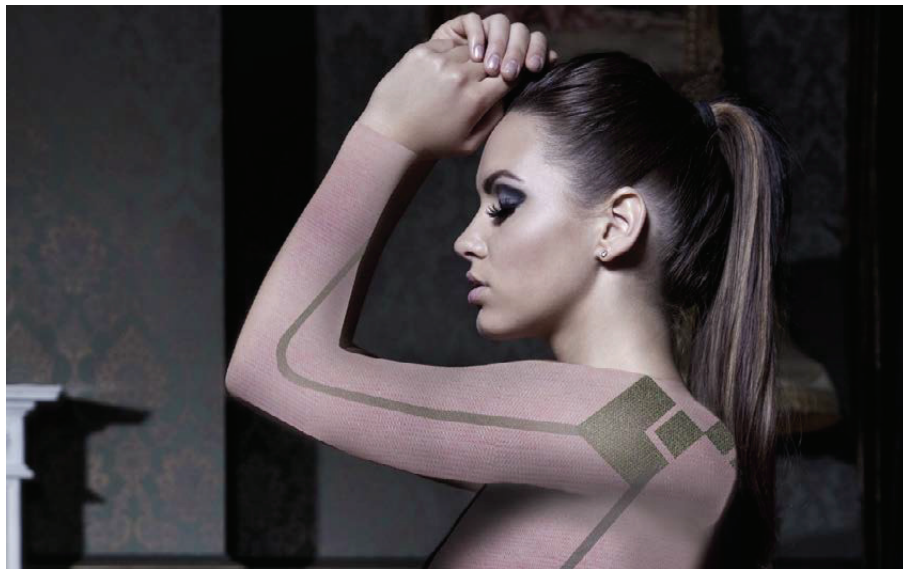


Figure 6: Hug Me biometric shirt concept and prototype design by Molly Sayers, Ontario College of Art and Design (OCAD) University (2015). Conductive fabric sponsored by Noble Biomaterials. Photo: Molly Sayers

Conclusions

Wearable Technology while a relatively immature industry comes with the benefit of a rich provenance from the apparel and computer industries. Although there are barriers to commerciality in fields such as fashion design, there are aspects of the clothing industry that have been making great strides towards an improved integration of technology in garments. Many of the environmental initiatives being adopted (recycling, emotional engagement etc.) have been tried and tested in other related fields. However, because of the hybrid nature and complexity of producing and using wearable technology, there are unique challenges to be faced in creating wearable technology products in a circular economy. Some can be met with design-led solutions, while others require new technological developments or new forms of supply chain. It is apparent that collaboration is proving key whether in academia or in industry.

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CIRCULAR
TRANSITIONS

23–24 November 2016

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23 – 24 November 2016

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