76 The Aesthetics of Data for IoT Wearables

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Abstract

The Internet of Things (IoT) ecosystem proposes a seamless connection of the digital-physical, increasing the scope of networked entities that produce and exchange data. An emerging landscape of contemporary networked fashion urges us to consider what it means for clothes to be interconnected with other entities, in an enmeshed ecology, in contrast to just being worn. Design approaches to wearable technology (wearables) span a broad spectrum. However, the impact, evolution and direction of IoT interconnected wearables has not received enough attention. Functional and imaginative applications for fashion and textiles have begun to explore the connective potential of dynamic interfaces for IoT compliant systems. Collectively, these works indicate a need to understand how computational material contributes to aesthetic expression and plays a critical role in articulating empowered data transactions from a fashion perspective.

This paper describes an IoT connected dress, used to broaden the design inquiry of big data information visualisation for wearables, according to aesthetic criteria of haute couture. Electronics and cloud computing wirelessly transform time series data into visual and kinetic expression on the garment. Textile behavioural characteristics are foregrounded to design a specific aesthetic interaction with remotely sourced, quantified weather phenomena. The author examines material cultures that blend digital technologies with the creation of highly refined artefacts, such as new materialism. In the context of dynamic performativity, materials and time series data engage temporal movement and state-change structures. Moreover, the performativity inherent in this framework can be useful to support an analysis of rich making and socio-cultural display practices derived from fashion couture for wearables design.

Introduction

No objects, spaces, or bodies are sacred in themselves; any component can be interfaced with any other if the proper standard, the proper code, can be constructed for processing signals in a common language (Haraway, 1985; 173-204).

The Internet of Things (Ashton, 2009) is a physical-digital networked ecology based on notions of computational ubiquity (Weiser, 1991), technologies invisibly intertwine with everyday things and space. The result of not one, but several compliant technologies and capabilities within a paradigm of communicative 'pervasive presence' (Atzori et al., 2010). However, research in (Koreshoff et al., 2013; Sterling, 2014), focus on technology deployment has overlooked human perspectives, particularly embodied entanglements.

The interconnected bodily experience of *worn things* needs investigation, in order to fully understand its dynamic topologies, beyond technical and functional considerations. An increasing number of entities and environments are equipped to collect, aggregate and transfer data within complex networks. Though researchers have addressed the design potential of IoT interconnected artefacts (cf. Jung et al., 2008; Wakkary et al., 2018), the lived social body at the core of *dynamic worn things*, is an increasing issue that has been overlooked. As our garments become platforms that enable staggering networked data transactions, the IoT illustrates a current zeitgeist to analyse issues surrounding worn engagement with technologies for wearables design. Prevailing IoT frameworks and debates around the material turn (Robles & Wiberg, 2010) confront a fashion-led wearables practice with unfamiliar challenges and opportunities. How can we explore these issues more deeply, specifically the material and expressive aesthetic potential of data in a fashion wearables practice in the IoT? In what ways do we want to initiate, engage and employ significant sources of data?

This paper begins with an assumption of wearable technologies as fashion. Based on this assumption, the paper aims to explore appropriate methods to investigate compelling computational material-immaterial alliances. As wireless computing technologies, sensors and software are increasingly installed into worn artefacts; it is also vital to consider functional aspects of emerging technologies, such as data collection and aggregation, in order to access how they are materially embedded. In what follows, aesthetic inquiry and material investigations through exploratory work, the construction of an IoT connected dress, are conceived around the refined embellishment practices of haute-couture. Crafting this adornment style to employ computational material, such as data, works to collapse disciplinary and physical-digital boundaries.

Data practices in IoT

Data privacy vulnerability is a growing concern for IoT device usage. Human concerns about the impact on social things loom, as internet-enabled object security is susceptible to tampering. Establishing trust and safety amidst posed privacy harms is a key issue. A growing number of works investigate the scope of IoT intimate objects, *Morse Things* (Wakkary et al., 2018; Worthy et al., 2016), *Cayla the Doll* (Thomas, 2017), and smart vibrators (Wynn et al., 2017). In an increasingly datafied, socio-technical landscape, it is crucial to assess the pervasive communicative ability of wearables outfitted for remote communications. *Hug Shirt* and *Twitter Dress* (Cute Circuit, 2002; 2012), or accessories that amass personal health or location data as a commodity to third parties (Rössler, 2015) explore these conditions. The functional capacity for information disclosure via the skin and clothes is refashioned in quantified self-tracking practices (Kelly, 2007; Swan, 2013; Gilmore, 2016), location sharing practices (Valentino-DeVries et al., 2018) and surveillance and security (Wynn et al., 2017). Baker's argument is useful because it points out these big data transactions of knowability serve 'frightening invisible data exploitation' (2017: 179) led by political motivations of institutions and individuals. The quantified self movement defines data tracking points, situated in a 'monitored and surveilled approach to the body' (Atkinson, 2017: 152). Historically, the practice of garment patternmaking has quantified body data, zoning the body to create data sets for flat pattern construction, standardising sizing methods and body ideals. The shift, Gilmore reads, is toward a 'body more institutionally and individually known' (2015: 2527).

There are many considerations in the life-cycle of an IoT *worn thing*. In the thing-centred investigation of Wakkary et al. (2017), networked artefacts perform emergent, autonomous actions that interrupt our intimate lives. Similarly, Kranz et al.'s (2010) artefacts communicate status, including details of what one has recently listened or spoken. The social capacity these 'things' exhibit, arouses human attachment, in stark contrast to previous understandings of passive, non-networked objects. Locating unknown and dynamic topologies of *worn things* within an IoT infrastructure is another challenging feature. Delicato et al. (2013) point to sophisticated mechanisms that support dynamic location systems needed to track or trace objects. Also, a system architecture that addresses the complexity of use, namely interaction between objects and heterogeneous parts (Atzori et al., 2010; Hachem et al., 2011; Koreshoff et al., 2013). Collectively, these studies present a timely assessment to approach an *Internet of Worn Things*, to consider existent boundaries of the body, empowered articulations of aesthetic expression and meaningful information flow.

New materialism

The cyborg world might be about lived social and bodily realities in which people are not afraid of their joint kinship with animals and machines, not afraid of permanently partial identities and contradictory standpoints (Haraway, 1985: 163).

Haraway's insights marked a challenge to preconceived notions of binary dichotomies such as human-non-human, or physical-digital. The concepts of *disassembly* and *reassembly* are applied to boundaries and structured relations. Additionally, Haraway's (Ibid.) coded realities, and interconnected networks prepare an orientation for the body and materials, giving rise to fashion wearables making, wearing practices and performative behaviours. For example, wireless data connection in IoT fashion wearables (McMillan, 2018), or changeable patterns and surface structures, that programmable smart fabrics afford (Orth, 2007; Worbin, 2010). Barad's notion of 'intra-action' (2007), a theoretical departure to address material forces. Where relationships are formed and mutually influenced within their meeting, in 'becoming'. This insight contributes to dynamic aesthetic and material conditions. New materialism (Barrett & Bolt, 2013; Bennett, 2009; Coole & Frost, 2010; Dolphijn & Van Der Tuin, 2012) represents a strategy for the union of human and non-human entities. Collectively, these researchers articulate material tensions, compositions and alignments of effect and agency in dynamic becoming. Contributing vocabulary such as 'thing-power' (Bennett, 2009), or 'agentic capacities' (Coole, 2013), they theoretically respond to issues of saturation of our intimate and physical lives by digital, wireless, and virtual technologies. Boundless assemblages and disintegrations are possible when patterns of data, textiles, wireless technologies, lived bodies and fashion production systems interweave. Coole and Frost observe formations and pattern creation in the process of assembling and disintegrating, in 'choreographies of becoming' (2010: 10).

Researchers increasingly recast fashion through a new materialist lens (Bruggeman, 2017; Smelik, 2018), since it acknowledges the potent influence of technologies within a fashion practice. On the one hand, new materialism represents a communal reaching towards an ontology that negotiates shifting material boundaries and relations. Both Smelik (2018) and Bruggeman (2017) point to visible forms that emerge and unexpectedly reform when unique material properties intra-act with the body. Formations of bodies,

space, material and technology propose new affiliations and dimensions. Non-human forces, the animate and inanimate, mingle with the dynamic agency of making and wearing wearables. Smelik (2018) further hints at an uncanny agency; a theory introduced by Mori (1970) to characterise the affective, behavioural expression autonomous technologies engender, to otherwise inanimate garments. Pinpointing performativity of matter in new materialism frames temporal immaterial subtlety for data visualisation, usage and meaningful interactions in interconnected worn things. Fashion designers such as Van Herpen (2018) employ technologies to capture immaterial forms, sculpting fashion garments with coded natural phenomena. Designer Iris Van Herpen speculates on future fashion materiality, describing 'ways to dress in substances that are not touchable or stable, but move and change with the wearer's moods and expressions' (Van Herpen cited in Quinn, 2012: 50). Issey Miyake's pleated garments (c.f. Penn 1988) foreground the moving body. Miyake acknowledges the body's active form that continuously re-formed, creating pleated structures that respond to a process of changing and becoming.

The material turn in HCI

In the field of Human-Computer Interaction (HCI), several researchers focus on reconciling the physical-digital (Robles & Wiberg, 2010; Vallgårda & Redström, 2007). Robles & Wiberg, 2010 question the strategy of ubiquitous computing, a human-centred, future of embedded technologies, where the 'computational aligns with material and social practices' (Ibid. 2010). From Robles and Wiberg's perspective, this hints at an 'aesthetics of disappearance' (Ibid. 2010), challenging the visibility of computational forms. For example in smart textile research where computation disappears into the very fibres or lies concealed in accessories (Kao et al. 2017). As research builds on IoT paradigms of ubiquity in fashion wearables design, more embodied perspectives that examine relations between worn things, their aesthetic practices as fashion and their context of interconnectedness are needed. Several studies do not directly mention the terms of networked ecologies (Brueckner & Friere, 2018; Gao, 2017; Kan et al. 2015, Lamontagne, 2005; Mann, 2004), although their critical approach to wireless technologies, surveillance, the quantified self, quantified natural phenomena, provides insights for the personal, physical and intimate interconnectedness of *worn things*, to this paper.

Distinguishing computational ubiquity, Vallgarda & Redstrom give voice to 'computational composites' (2007) where the computational is read as material, and immaterial properties take visible form alloyed with physical materials. Similarly, Dourish & Mazmanian's metaphoric articulations of material properties; 'fragility, visibility, density, heft' (2011), imbue felt, sociocultural associations beyond tangible experience. Together, these views pinpoint a paradigm shift to collapse physical-digital ontological distinctions. Robles & Wiberg (2010) and Wiberg et al. use the material and social composition of textures to metaphorically focus on aesthetic alliances or similarities in physical-digital material features as opposed to 'disruptions' (2013). This gesture departs from a dominant perspective of digital-physical as distinct entities, toward a perception of people, computational and non-computational materials as inseparable. From this vantage, commonalities, particularities, surfaces, and flows between computational material parts become evident through intra-action, in alliance or assemblage. Wiberg et al. (2013) read this as a shifting of the user interface into the material realm, the digital out into the physical. Markers or symptoms of autonomous computation are described in the New

Aesthetic (Bridle, 2013) as glitches. The New Aesthetic calls attention to patterning hidden in the computational; wireless artefacts; encoding errors; data-sets; installations using sensors; physical movement and gestures; haptic forces with notable digital forms. Sterling assigns the mediated, temporal, grainy expressions to 'corruption artefacts', or 'failures of machine processing' (2012). In effect, the luminous forms afforded by organic light-emitting diode (OLED) screen-based devices are a computational, medial affordance. However, the New Aesthetic supports sculptural and tangible physical manifestations of immaterial digital forms, as opposed to the screen-based output of new media disciplines. In the context of material turn, Berry & Dieter reconsider the role of the practitioner to 'curate, interpret and transcribe' (2015) pattern recognition techniques of the new aesthetic, to reveal engagements as artefacts for reflection.

The dressed body

Drawing from Entwistle's *dressed body* (2015), Atkinson elaborates adorned, modified, disguised or exposed bodies as a 'complex interplay of trends, inescapable socio-cultural influences and personal expression which all contribute to the way we clothe and manipulate or adapt our bodies.' (2017: 147). Entwistle points out that nudity is seldom tolerated, bodies that meet within social contexts 'are likely to be adorned, if only by jewellery, or indeed, even perfume' (2017: 31). Historically, researchers have faced challenges regarding the exclusion of fashion from institutional aesthetic realms, primarily due to its bodily tactile matters, practical function of protection, or ephemeral transformations. Negrin (2012) points to Kant's notions of distanced, reflective objectivity toward an object, where aesthetic judgement transpires through sight and hearing. An intentional transcendence of the flesh, this view attributed a disembodied understanding of aesthetics.

Fashion as an expressive medium lay rooted in its visual appeal, in its fluid imagery and abstracted templates of desirable bodies, as opposed to honest representation. Entwhistle views 'fashion is an aesthetic practice even if that aesthetic is less about lofty ideals of beauty'(2015: 129-148) than driven by idiosyncrasies of forever unfolding clothing style. Shifting away from strategies of iconographic fashion that neglects the lived body, Hanson (1990) describes an inseparable corporeal awareness, pointing out 'when cloth, metal and stones are used in clothing, their aesthetic characteristics are at least partly a matter of their relation to the body'. Rocamora (2015) views fashion as a conspicuous realm, where the practice of dressing negotiates material-social objects and conditions. Entwhistle broadens contemporary fashion industry cultural, economic, political and technological conditions with an account of 'aesthetic economy', with a distinctly 'fashionable aesthetic' (2009). A system where designers and fashion buyers exploit embodied, tacit aesthetic knowledge of style for economic advantage. Practising aesthetic mechanisms and calculations, fashion designers curate and commercialise materials, silhouettes, and style fluidity for a market product. The aesthetic economy, however, pays attention to tactile aesthetics and body awareness. Within the industry, the sampling process (prototyping) involves a series of rigorous embodied interactions, garment testing adheres to trend specific qualities - looking, handling, examining, trying on, fitting, shape, sizing. These assessments are consequential to market-driven price point parameters, for example, the association between haute couture and quality. Fashion design practice involves the heterogeneous assemblage of materially networked elements to find coded meanings;

different kinds of objects, processes, understandings, assumptions and knowledge (Entwistle 2009: 107-128).

Garments contribute ease or restriction of movement to aesthetic considerations. In Negrin's (2012) view, a broader conception of aesthetics would include the dynamic body and felt experience. Performative technologies, clothing can support, influence and determine movement and gestures. Edelkoort describes garments as a tactile form with inescapable social cues that impress upon 'the way we walk, stand and flirt' (2017). Moreover, Miller gives voice to the value of fashion as empathetic experience, an embodied material practice 'luxuriating in the detail: the sensuality of touch, colour and flow. A study of fashion cannot be *cold*; it has to invoke the tactile, emotional, intimate world of feelings (2010: 41). Miller elaborates: 'what it feels like to wear a sari, where it presses on the body, and where you sweat. How you flirt and how to keep modest' (2010: 41). This observation invokes a textural richness of wearing that is highly characteristic of dress. Atkinson posits fashioned, dressed bodies 'conform and perform to socially defined standards' as 'performative agents in the act of making' (2017: 158).

Therefore, understanding fashion as a situated practice of the lived body highlights a significant shift. Read by Thornquist as 'wear (object) at the boundary between self and other to fashion as the practice of wearing (activity) connecting body and the other through interacting' (2018: 291). Similarly, in Craik's view 'clothes are activated by the wearing of them just as bodies are actualised by the clothes they wear. … Through clothes we wear our bodies and fabricate ourselves'. (2003: 16). The embodied practice of everyday dress is so closely entwined with the moving, materially present body, and coupled with the cultural interpretation of body (Entwistle, 2017).

Computational dress

Broadhurst (2017) draws our attention to unknown boundaries of bodily interaction with computers. Seymour (2010) defines functional aesthetics for wearables, as fashionable aesthetic garments augmented with technological functionality. Embedded technologies in the surface of the garment render wearables a 'dynamic interface', denoted by a changeable display, actuated by programmable data output, engaging many bodily senses. Dynamic display calls for wearer control and data exposure confirmation, a point worth emphasising considering the issues surrounding big data transactions. Gemperle et al. (1998) read dynamic wearability specifically for wearables development, examining active, diverse, changeable body states, from a physiological and biomechanical perspective. Further, Gilmore responds literally to metaphoric notions of 'a world in which the body has been decisively reimagined as a site of networked computation' (2016: 2525) by probing worn 'routines and social aesthetics'. Everyday routines and habits are quantified, traced by wireless devices and felt; with anxiety, weight, lightness, irritation or comfort. Moreover, digital layers extract and transmit information about wearer data status increasing garment capacity as an information medium.

Ebb (Devendorf et al., 2015) is guided by textile material properties and fabric construction methods to construct an alternative display concept. Textile processes of weaving and printed thermochromic inks explore the nuances of personal style. *Ebb* lies in aesthetic contrast to screen-based devices such as smartphones and provides a fascinating insight

into mediative qualities of technologies that respond to the feel of textiles for personal data display. Layered meanings become encoded within landscapes of personal style. Although remarkable, referring to garments as a canvas for computational display reinforces a familiarity with the screen. Edelkoort hints at aesthetics of disappearance, arguing 'the more screens we have, the more our figures are afraid we are going to disappear' (2012), stirring a yearning to engage the tactile senses. Petrecca (2017) acknowledges the demise of tactility in digital interactions through distanced engagement. Asserting movement and gesture in the creative fashion design process is compelling. Growing interest in embodied material ideation (Höök, 2018; Wilde et al., 2017) highlights the critical importance of bodily-sense practices in the conceptualisation of wearables. Joseph et al. (2017) couple a similar approach with new materialist ontologies to probe digital materialities for soft wearables in *Darling*. Multiple streams of research develop around the potential for weaving physical and digital material relations for novel, tactile computation; *textures* (Robles & Wiberg, 2010), *soft mechanics* (Cohelo & Maes, 2009; Cohelo & Zielgelbaum, 2011), *soft wearables* (Tomico & Wilde, 2016) *etextiles* (Buechley et al., 2008, Kobakant, 2019; Baker, 2017; Post et al., 2000; Posch, 2018), an *internet of soft things* (Kettley et al., 2019). Collectively, this landscape is fundamentally tactile. Dress is reliant on the bodily senses as an expressive meaning system that 'has to feel right' (Miller, 2010).

Methodology

Drawing upon Frayling's Research through Design approach (1993) Live:scape BLOOM, an IoT connected dress, challenges disciplinary architectures of practice. In this antidisciplinary (Ito 2014), and prototyping (Sanders & Stappers, 2014) investigation, wireless technologies are customised for wearables design practice to examine and communicate data as computational material, in composite (Vallgårda & Redström 2007) with other physical materials such as textile. The author discusses some central peculiarities of data material artistic expressions, as they relate to IoT connected *worn things*. What is it like to *wear* the wind? The author hypothesised that a high-tech approach to wearables design would benefit from high-level construction, fabrication methods and materials than from low-tech methods.

Embellishment is a potent and visual way of working with garment decoration. In Live:scape BLOOM (McMillan, 2018), the practices of haute couture afforded an aesthetic and construction criterion from a fashion perspective, that differs from LEDs, lasers, or screens. Embellishment typically purposes light, colour, volume and tactility with a sense of improvisation and experimentation. Novel materials renew practice by introducing material components 'not necessarily predestined for it' (Kamitsis 2000). Artisan skilled knowledge shaped physical material properties to reimagine computational forms sensitive to the nuances of textile.

Fig.1 Video still of Live:scape BLOOM.

However, traditional notions of haute couture embellishment are challenged through computational material, making, installation, performance. Strategies used for *Live:scape BLOOM* articulated a break away from conventional working methods of fashion aesthetic economies, perpetuated by industry. Although a fashion perspective evoked original methods; material investigation, sketching, mood boards, toiling, and fittings; the approach within the practice shifted and expanded to accommodate 'antidisciplinary' (Ito, 2014) practice. With no previous experience working within the fields of robotics, electrical and software engineering, many unfamiliar materials, software and hardware were applied, forging a radical basis for experimentation. Data aesthetics were considered with equal importance as the aesthetic qualities of the physical materials. For example, traditional materials such as silk, feathers and polyester were positioned alongside wireless technologies, quantified weather phenomena and cloud computing to expand material selection for fashion wearables design. Atkinson (2017) argues this regrounds 'physical and material awareness', while Petreca reads such improvisation as 'part of a designer's know-how' (2017). Motivated by 'material explorations rather than functional objectives' (Jung & Stolterman, 2011), favoured material selections are woven together. Unique materials and patterns find expression through refined haute couture embellishment techniques. Employing computational material disrupts these practices in the context of fashion. Coding, electronics, and hardware for kinetic, robotic mechanisms were crucial to observe data materially. A parameter of quantified weather phenomena, coded to avoid discernible autonomous movement, set the patterns and values for the machine to recognise.

Waldemeyer reflects on engineering Hussein Chalayan's robotic garments by 'keeping the integrated technology lightweight yet strong enough to maneuver different fabrics and materials' (2007). Hard-soft connections were constantly negotiated for desired aesthetic expression in *Live:scape BLOOM*. A number of hard-soft material improvisations were involved; 1) silk organza was favoured both for its elegant, lightweight yet architectural appearance and an association with refined, luxury garments; 2) feathers for their silky fur

exaggerated the traces of movement through space and the mechanical glitch; 3) jewellery wires replaced mechanical joints for delicate metal, beaded structure appearance; 4) foam paper structures for machine sewable structures; laser-cut polyester prevented fraying, increased volume and provided three-dimensional support; 5) laser-cut leather as a robust fabric base of quality and long-term use; 6) rotational servo motors for slight mechanical simplicity and minimal electronics; 7) laser cut acrylic with transparency and shine, as custom appliqué pendants to sustain the robotic structure; 8) a mechanical glitch to amplify the digital patterns created. On the other hand, a number of trials were rejected; 1) 3D printed plastic for its clunky weight, size and involved mechanical structure; 2) actuators and components that required bulky and heavy hardware; 3) complex electronic circuits requiring significant battery power; 4) debugging software for an aesthetic of seamless technological functionality.

Fig.2. a-c Techniques of refinement in the prototyping process.

Textile fabric, mixed media embellishment trims and data were mediated through servo motors, blurring material boundaries. Although the overall soft, temporal, kinetic surface echoes the reference origin of haute couture embellished flowers, computational material forces are distinct. Photographic and video-prompted edits of the making process were used as a performative analysis tactic that directly countered technological functionality. Posing the question: If the wicked expressions that manifest in technological mediation, notable glitches, were built earlier in the wearables design development, how might this impact material and aesthetic expressions of data? Staying with the undesirable outcomes has produced a space for aesthetic counter-manifestation, to critique, question and explore in future work. In turn, it unearths valuable insights for empathetic responses to wearables that probe desired interaction, social communication or artefact validation.

Discussion: the potential of performative analysis

Several exhibitions, catwalk, and wearer-led investigation of Live:scape BLOOM sought to leverage the rich socio-cultural performative practices of fashion. The author focused on presentation modes to observe latent attitudes toward IoT wearables. Exhibiting garments with refined presentation aesthetics and fashion adornment style afforded focus on material properties and skilful technique. However, Craik (2003) rightly questions the context and presentation of clothes on display, bereft of the experiential bodily matters that co-occur with worn things. Craik points to Symons: 'A dress that's been on display for too long is different to a dress that's been too much worn. Somehow a dress is "fed" the warmth of the body of the person who's been wearing it. … worn clothes had an "energy".' (Symons, 1987, cited in Craik, 2003: 15).

The special kinetic effect of Live:scape BLOOM evoked curiosity. Many visitors liked to see if their movements triggered response, which to make functional would require embedding an additional layer of sensors. It was mentioned that the dress was flirting, revealing that people care about social presentation, projecting individual perceptions and desires. This preliminary study made clear that people quickly discern what is acceptable in displays of fashion. Craik attributes 'particular codes of behaviour and rules of ceremony and place. It denotes conventions of conduct that contribute to the etiquette and manners of social encounters' (Ibid. 2003).

Exhibiting *Live:scape BLOOM* only took the investigation so far and constrained feedback on potential bodily matters of IoT wearables. Consequently, the opportunity to investigate acts of wearing was useful to observe material appropriateness for the dressed body's dynamic topologies. Also, to grasp the potential of live data and haute couture amalgams, informing future design processes of an IoT connected garment. Encounters with participants through wearer-led investigations of *Live:scape BLOOM* were held during Berlin Fashion Week, and the National Gallery of Victoria Friday Nights party series, Melbourne. Initial results made visible what had been invisible, how it feels to wear an IoT connected dress. What one participant complained about (electronics placement inside the front neckline because it felt really hot), another described as pleasant (because it was a reminder of the mechanisms that were working away inside, like they were harbouring an exciting secret). Participants were asked to compare and contrast physical-digital material and aesthetic qualities of wearing data. They mentioned the subtle presence of the technology, without visible screens or wires or lights it felt more 'human' or 'natural' than previously encountered. It was described as a special experience (to wear the wind in a remote location), and satisfying to see the reactions of people (because of their fascination when they learned about how data was interacting with it). Some talked about how refreshing it was (because they could engage with others beyond 'that's nice, where did you get it?' and embark on a discussion surrounding data collection and use).

Responses prompted speculation about future wearables design beyond the electronics-garment tailoring processes, sensory data output possibilities, and the pertinence of IoT wearables in the aesthetic economy of fashion. While *Live:scape BLOOM* was feasibly worn for short periods, what was also noticeable in this study were technical issues that would require development in software, power supply, hardware robustness and textile tailoring to tolerate prolonged, everyday wear. Future work would benefit from longer periods of habitual wearing in everyday contexts, extended to a larger participant group for varied accounts of tactile, networked, dynamic fashion wearables. This contribution

values the body techniques that fashion articulates for design insights, desired interactions and etiquette of IoT wearables.

Conclusion

Fashion wearables that emerge from paradigms of ubiquitous computing incompletely investigate boundaries and relations with other things and bodily matters within an *Internet of worn Things* ecosystem. Through the material turn, IoT technologies such as data alter the conditions, mechanisms, and production of fashion IoT wearables, but not its performative character. Moreover, computational materials of an IoT ecosystem do not account for the social practice of fashion. From these findings, haute couture displays with temporal dimensionalities opened up the performative testing space of wearable data beyond the limits of the gallery and catwalk.

Fig.3. a-c Wearer-led investigation of *Live:scape BLOOM*.

Live:scape BLOOM customises IoT technologies for an alternative to model to quantified data practices. It presents an opportunity for designer-researchers to better understand the use of data as raw material for aesthetic expression. While employing a sensor layer to extract connected and quantified environmental or personal physiological data may be desirable, one's experience of surveilled exploited personal data may be less desirable. Thus, a connection to outsourced weather phenomena for aesthetic expression within an enmeshed, networked data environment was proposed. The focus *of Live:scape BLOOM* was to connect couture embellishment to quantified weather phenomena, to allow *wearing* the wind. To wear live, open source wind data offers a design alternative that facilitates ways to imagine IoT *worn things* for empowered personal use, rather than an extractive model that stores and exploits personal data in the cloud. It confronts issues of data ownership, amidst concerns of tracking and monitoring for the benefit of third-party efficiency and profits. Furthermore, participants in this study commented that IoT connected clothing could have intuitively human experiential qualities, interact with remote environments, or engage discussion surrounding current data issues.

Experimentation with computational material for IoT embellishment is a laboured process, as is the refined handwork in haute couture textile design. Mastering material potential is a critical step to become skilled in cross-disciplinary techniques. For example, soldering

delicate and fragile components, tweaking code, or hand-stitching beads, feathers and silk. Identifying the particularities of working with emerging IoT technologies, such as data, supports a deeper understanding of the design potential of haute couture adornment styles. If practitioners can look back through cross-disciplinary design choices and process of an IoT connected garment, they can critically respond in future work and participate in a design dialogue.

References

Ashton, K. (2009), That 'internet of things' thing. RFID journal, 22(7), 97-114.

Atkinson, D. (2017), Post-industrial Fashion and the Digital Body. In *Digital Bodies* (147-160). Palgrave Macmillan, London.

Atzori, L. et al. (2010), The internet of things: A survey. Computer networks, 54(15), 2787-2805.

Baker, C. (2017), Critical Interventions in Wearable Tech, Smart Fashion and Textiles in Art and Performance. In *Digital Bodies*. Palgrave Macmillan, London.

Barad, K. (2007), *Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning.* Duke University Press.

Barrett, E. & Bolt, B. (Eds.). (2013), *Carnal knowledge: towards a 'new materialism' through the arts.* Ib tauris.

Bennett, J. (2009), *Vibrant matter: A political ecology of things.* Duke University Press.

Berry, D. M. & Dieter, M. (2015), Thinking postdigital aesthetics: Art, computation and design. *In Postdigital Aesthetics: Art, Computation and Design* (pp. 1-11). Palgrave Macmillan.

Bridle, J. (2013), The new aesthetic and its politics. booktwo. org June, 12.

Broadhurst, S. & Price, S. (2017), *Digital bodies: creativity and technology in the arts and humanities,* London: Pal-grave Macmillan.

Brueckner, S. & Freire, R. (2018), Embodisuit: a wearable platform for embodied knowledge. In *Proceedings of the 2018 ACM International Symposium on Wearable Computers*, 242-247. ACM.

Bruggemann, D. (2017), Fashion as a New Materialist Aesthetics. In *Delft Blue to Denim Blue: Contemporary Dutch Fashion*. London: I.B. Tauris

Buechley, L. et al. (2008), The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, 423-432, ACM.

Coelho, M. & Zigelbaum, J. (2011), Shape-changing interfaces. *Personal and Ubiquitous Computing*, 15(2), 161-173.

Coelho, M. & Maes, P. (2009), Shutters: a permeable surface for environmental control and communication. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*. 13-18, ACM.

Coole, D. & Frost, S. (2010), Introducing the new materialisms. *New materialisms: Ontology, agency, and politics,* 1-43.

Coole, D. (2013), Agentic capacities and capacious historical materialism: Thinking with new materialisms in the political sciences. *Millennium*, 41(3), 451-469

Craik, J. (2003), *The face of fashion: Cultural studies in fashion*. Routledge.

Cute Circuit. Retrieved January 6, 2018 from http://cutecircuit.com/

Delicato, F. C. et al. (2013), Towards an IoT ecosystem. In *Proceedings of the First International Workshop on Software Engineering for Systems-of-Systems*. 25-28, ACM.

Devendorf, L. et al. (2016), I don't Want to Wear a Screen: Probing Perceptions of and Possibilities for Dynamic Displays on Clothing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 6028-6039, ACM.

Dolphijn, R. and Tuin, I.V.D. (2012), *New materialism: Interviews & cartographies.* Open Humanities Press.

Dourish, P., & Mazmanian, M. (2011), Media as material: Information representations as material foundations for organizational practice. In *Third international symposium on process organization studies*, 92.

The Business of Fashion. Anti-Fashion: A Manifesto for the Next Decade | Li Edelkoort (2017) YouTube video, viewed 6 August 2018 <https://www.youtube.com/watch?v=LV3djdXfimI>

Li Edelkoort. Super technology is going to ask for super tactility (2012) video, viewed 28 February 2019 <https://www.dezeen.com/2012/12/28/super-technology-is-going-to-ask-for-super-tactility-li-edelkoort-at-dezeen-live/>

Entwistle, J. (2009), *The aesthetic economy of fashion: Markets and value in clothing and modelling.* Berg.

Entwistle, J. (2015), *The fashioned body: Fashion, dress and social theory*. John Wiley & Sons.

Entwistle, J. (2017), Addressing the body. *In Fashion Theory*. Routledge.

Frayling, C. (1993), Research in art and design.

Gemperle, F. et al. (1998), Design for wearability. In *Wearable Computers, 1998. Digest of Papers. Second International Symposium on wearable computers* (cat. No. 98EX215). IEEE.

Gilmore, J. N. (2016), Everywear: The quantified self and wearable fitness technologies. *New Media & Society,* 18(11), 2524-2539.

Gao, Y. (2019), Retrieved January 6, 2018 from http://yinggao.ca/possible-tomorrows/

Hachem, S. et al. (2011), Ontologies for the internet of things. In *Proceedings of the 8th Middleware Doctoral Symposium.* ACM.

Hanson, K. (1990), Dressing down dressing up—the philosophic fear of fashion. *Hypatia*, 5(2), 107-121.

Haraway, D. J. (1985), *A manifesto for cyborgs: Science, technology, and socialist feminism in the 1980s, (173-204),* San Francisco, CA: Center for Social Research and Education.

Höök, K. (2018), *Designing with the Body: Somaesthetic Interaction Design.* Design Thinking, Design Theory.

Ito, J. (2014), Antidisciplinary, *MIT Media Lab Blog* October, 2, 2014.

Joseph, F. et al. (2017), Digital materiality, embodied practices and fashionable interactions in the design of soft wearable technologies*. International Journal of Design*, 11(3), 7-15.

Jung, H. et al. (2008), Toward a framework for ecologies of artifacts: how are digital artifacts interconnected within a personal life?. In *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*. 201-210, ACM.

Kamitsis, Lydia (2000) Lesage. Paris: Editions Assouline; New York: Universe/Vendome,

Kao, H. L. C. et al. (2017), Exploring Interactions and Perceptions of Kinetic Wearables. In *Proceedings of the 2017 Conference on Designing Interactive Systems*, 391-396, ACM.

Kelly, K. (2007). What is the quantified self. *The Quantified Self*, 5, 2007.

An Internet of Soft Things, Kettley et al. (2019), Retrieved January 6, 2018 from https://aninternetofsoftthings.com/

Kranz, M. et al. (2010), Things that twitter: social networks and the internet of things. In *What can the Internet of Things do for the Citizen (CIoT) Workshop at The Eighth International Conference on Pervasive Computing (Pervasive 2010),* 1-10.

KOBAKANT, How To Get What You Want, retrieved January 6, 2018 https://www.kobakant.at/DIY/

Koreshoff, T. L. et al. (2013), Approaching a human-centred internet of things. In *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration,* 363-366, ACM.

Lamontagne, V. (**2**005), Peau d'Âne.

Mann, S. (2004), Sousveillance: inverse surveillance in multimedia imaging. In *Proceedings of the 12th annual ACM international conference on Multimedia*, 620-627, ACM,

McCarthy, J., & Wright, P. (2004). Technology as experience. *interactions*, 11(5), 42-43.

McMillan, C. (2018), Live:scape BLOOM: Connecting Smart Fashion to the IoT Ecology. In *International Conference on Artificial Intelligence on Textile and Apparel*, 221-227. Springer, Cham.

McMillan, C. Live:scape BLOOM, 2018, November. Retrieved January 6, 2018 from https://vimeo.com/299296620

Miller, D. (2010), *Stuff.* Polity.

Mori, M. (1970), The uncanny valley. *Energy,* 7(4), 33-35.

Negrin, L. (2012), Aesthetics: Fashion and Aesthetics - a fraught relationship.

Orth, M.(2007), retrieved January 6, 2018 from http://www.maggieorth.com/art_RunningPlaid.html

Penn, I. (1988), Iss*ey Miyake: Photographs by Irving Penn*. Boston: New York Graphic Society. (Calloway, N., ed.).

Petreca, B. (2017), Giving Body to Digital Fashion Tools. In *Digital Bodies*, 191-204, Palgrave Macmillan, London.

Posch, I. (2017) The Embroidered Computer, retrieved January 6, 2018 fromhttp://www.ireneposch.net/the-embroidered-computer/

Post, E. R., et al. (2000). E-broidery: Design and fabrication of textile-based computing, *IBM Systems journal*, 39(3.4), 840-860.

Quinn, B. (2012) *Fashion futures*, London: Merrell, 50.

Robles, E., & Wiberg, M. (2010), Texturing the material turn in interaction design. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction.* 137-144, ACM.

Rocamora, A. (2015), *Thinking through fashion: A guide to key theorists*. IB Tauris.

Rössler, B. (2015), Should personal data be a tradable good? On the moral limits of markets in privacy. *Social dimensions of privacy: Interdisciplinary perspectives*, 141-161.

Sanders, E. B. N. & Stappers, P. J. (2014), Probes, toolkits and prototypes: three approaches to making in codesigning. *CoDesign,* 10(1), 5-14.

Seymour, S. (2010), *Functional aesthetics: Visions in fashionable technology* (20). Vienna: Springer.

Smelik, A. (2018), New materialism: A theoretical framework for fashion in the age of technological innovation. *International Journal of Fashion Studies*, 5(1), 33-54.

Sterling, B. (2014), *The epic struggle of the Internet of Things*. Moscow: Strelka Press.

Sterling, B., 2012, An Essay on the New Aesthetic. Group, 1, 1-4.

Swan, M. (2013), The quantified self: Fundamental disruption in big data science and biological discovery. *Big data*, 1(2), 85-99.

Thomas, A. (2017) ‘ Germany Issues Kill Order for a Domestic Spy—Cayla the Toy Doll’, The Wall Street Journal, New York, 13 April, retrieved February 28 from : https://www.wsj.com/articles/germany-issues-kill-order-for-a-domestic-spycayla-the-toy-doll-1492098755

Thornquist, C. (2018), The Fashion Condition: Rethinking Fashion from Its Everyday Practices. *Fashion Practice*, 10(3), 289-310.

Tomico, O., & Wilde, D. (2016), Soft, embodied, situated and connected: Enriching interactions with soft wearables. *The Journal of Mobile User Experience*, 5 (3). https://doi.org/10.1186/s13678-016-0006-z

Valentino-deVries, J. et al. (2018) Your Apps Know Where You Were Last Night, and They’re Not Keeping It Secret’, The New York Times, New York, retrieved January 6, 2018 from https://www.nytimes.com/interactive/2018/12/10/business/location-data-privacy-apps.html

Vallgårda, A., & Redström, J. (2007), Computational composites. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, 513-522, ACM.

Van Herpen, I. (2019), retrieved January 6, 2018 https://www.irisvanherpen.com/

Wakkary, R. et al. (2017), Morse Things: A Design Inquiry into the Gap Between Things and Us. In *Conference on Designing Interactive Systems,* 503-514.

Waldemeyer, M. (2007), retrieved January 6, 2018 http://www.waldemeyer.com/hussein-chalayan-111-robotic-dresses

Wiberg, M. et al. (2013), Materiality matters---experience materials. *interactions,* 20(2), 54-57.

Weiser, M. (1991), The Computer for the 21 st Century. *Scientific american*, 265(3), 94-105.

Wilde, D. et al. (2017), Embodied design ideation methods: analysing the Power of estrangement. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 5158-5170, ACM.

Worbin, L. (2010), *Designing dynamic textile patterns*. University of Borås.

Worthy, P. et al. (2016), Trust me: doubts and concerns living with the Internet of Things. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 427-434, ACM.

Wynn, M. et al. (2017), Sexual Intimacy in the Age of Smart Devices: Are We Practicing Safe IoT?. In *Proceedings of the 2017 Workshop on Internet of Things Security and Privacy*. 25-30, ACM.

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