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Wearable Technologies: Between Fashion, Art, Performance, and Science (Fiction)

Nosljive tehnologije: med modo, umetnostjo, performansom in znanstveno fantastiko

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Abstract

Our clothes and accessories are our primary interfaces with the world around us. In the 21st century, the technology that lives in our pockets or in our bags has changed dramatically. Today, the interactive systems that can be found almost constantly in our clothes are so close to our body that they sometimes actually feel like a part of us. Electronic devices are getting tinier and can be bought ready-made for any purpose. Power-supply solutions are smarter and wireless technologies allow communication without cables. Wearable technology is becoming widely used in healthcare, care for the elderly and wellness, in the military, in workwear and sportswear for added security or performance characteristics, in sci-fi and fantasy movies and big-arena entertainment, and in award shows or pop concerts for its spectacular visual effects. Through technological advances, the most innovative designers and artists re-evaluate the very basic premises of a dressed body, such as weight, scale and texture or movement. They demonstrate that design is not just about the visual: clothes can also be stimulating to touch, hearing, smell and taste. Wearable technology can turn clothing into a multi-sensorial experience and make it drift between categories. Wearable technology can be perceived as a body architecture, a second skin, nonmaterial clothing, a personal scenography or display, a body extension, an interactive or emotional garment, etc. Some of the most important examples of wearable technology were analysed in this research. They were divided into three different categories according to a garment's principal technological concept or function as it relates to material and external and internal stimuli, such as movement, light, sound, touch, sight, smell, taste, biometrics and emotions. It was concluded that garments act as a bridge between visual, physical and perceptual experience, and provide the wearer and onlooker with a kinaesthetic, proxemic and haptic experience. Since the late 1990s, many projects devised within the field of fashionable technology have a strong performative connotation, as they move, change shape, or emit light, sound or scents. It wasn't until the last decade, however, that Wearable technology designers really began to explore the potential of clothing as social interaction, emotional sensing and biomimetics.

Keywords: wearable technologies, responsive, active, interactive garments, emotional sensing

Izvleček

Naša oblačila in dodatki so naši primarni vmesniki za svet, ki nas obdaja. Tehnologija, ki jo imamo v žepih in torbah, se je v 21. stoletju dramatično spremenila. Komunikacijski sistemi, ki danes skoraj vedno naseljujejo naša oblačila, bivajo tako tesno ob našem telesu, da se včasih zdi, da so del nas samih. Elektronski deli postajajo čedalje manjši, kupimo jih lahko že za katerikoli namen, napajanje je razrešeno elegantno in brezžične tehnologije omogočajo komuniciranje brez kablov. Nosljive tehnologije so zaradi svojega spektakularnega vizualnega učinka čedalje bolj

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prisotne v zdravstvu, oskrbi starejših in velnes centrih, v vojaških, delovnih in športnih oblačilih za dodatno zaščito in boljšo zmogljivost, znanstvenofantastičnih in domišljijskih filmih, na stadionskih in gala prireditvah ali pop koncertih. Z napredkom tehnologij najbolj izvirni oblikovalci in umetniki na novo vrednotijo najosnovnejše predpostavke oblečenega telesa, kot so teža, merilo, tekstura ali gibanje. Kažejo nam, da pri dizajnu ne gre le za vizualno, oblačila lahko stimulirajo tudi dotik, sluh, voh in okus. Oblačilne tehnologije lahko spremenijo oblačilo v veččutno doživetje, ki lahko drsi med različnimi kategorijami. Oblačilne tehnologije lahko dojemamo kot arhitekturo, osebno scenografijo, drugo kožo, zaslon, nematerialno oblačilo, podaljšek telesa, interaktivno ali čustveno oblačilo … V preglednem članku so razčlenjeni nekateri najpomembnejši primeri oblačilnih tehnologij. Glede na glavno tehnološko idejo ali funkcijo samega oblačila v povezavi z materialom oziroma zunanjimi ali notranjimi dražljaji, kot so: gib, svetloba, zvok, dotik, vid, voh, okus, biometrija in čustva, so razdeljeni v tri skupine. Ugotovljeno je bilo, da je obleka most med vizualno, fizično in zaznavno izkušnjo, ki uporabniku in gledalcu zagotavlja kinestetično, proksemično in haptično doživetje. Od poznih devetdesetih let prejšnjega stoletja ima veliko projektov na področju modne tehnologije velik performativni pomen, saj se oblačila premikajo, spreminjajo obliko, oddajajo svetlobo, zvok ali vonjave, vendar so šele v zadnjem desetletju oblikovalci nosljive tehnologije resnično začeli raziskovati potencial oblačil kot družbene interakcije, čustvenega zaznavanja ali biomimetike.
Ključne besede: nosljive tehnologije, odzivna, aktivna in interaktivna oblačila, čustvena zaznava

1 Introduction

Our clothes and accessories are our primary interfaces with the world around us. In the 21st century, the technology that lives in our pockets or in our bags has changed dramatically. Today, the interactive systems that can be found almost constantly in our clothes are so close to our body that they sometimes actually feel like a part of us. Electronic devices are getting tinier and can be bought ready-made for any purpose. Power-supply solutions are smarter and wireless technologies allow communication without cables. Wearable technology (WT) is becoming widely used in healthcare, care for the elderly and wellness, in the military, in workwear and sportswear for added security or performance characteristics, in sci-fi and fantasy movies and big arena entertainment, and in award shows or pop concerts for its spectacular visual effects.

Through technological advances, the most innovative designers and artists re-evaluate the very basic premises of a dressed body, such as weight, scale and texture or movement. They demonstrate that design is not just about the visual: clothes can also be stimulating to touch, hearing, smell and taste. WT can turn clothing into a multi-sensorial experience and make it drift between categories. WT can be perceived as a body architecture, a second skin, nonmaterial clothing, a personal scenography or display, a body extension, an interactive or emotional garment, etc.

The objective of the presented research was to study, analyse and classify WT according to the factors that best define them. The content analysis and synthesis of key cases were applied for that classification.

2 WT: Fashion, Performance, Art or Science (Fiction)

According to Susan Elizabeth Ryan [1] (2014, p. 96), the term 'wearable technology' or WT applies to work that is functional in application and potentially commercial in distribution or experimental and conceptual in nature to aid the awareness of embodiment. Many of the works cited here are what she calls 'critical WT' or 'critical dress', even when they are the result of experimentation with technology as a means of expression for fashion designers, such as Hussein Chalayan [2], Anouk Wipprecht [3], Ying Gao [4] or CuteCircuit [5], to name but a few. The majority of those projects only exist as artworks or research prototypes, with a non-commercial content and clear conceptual and performance character. They are exhibited in art and fashion galleries and museums, or are presented at trade fairs or academic conferences and workshops.

In the last decade, wearable technology appears to be a major trend in fashion. It is, however, far from something new, innovative, avant-garde or the invention thereof. There are examples of wearable electronics from the 1960s, 1970s and 1980s, and most of them were created by fine artists and performers, not by fashion designers. Some of them, such as Atsuko Tanaka [6], Rebecca Horn [7] Stelarc [8], Jana Sterbak [9], or Marcel·lí Antúnez Roca

[10] created their art pieces as direct critique of fashion system or the mainstream canons of beauty. The study of wearable computers was born in the realm of universities and research labs some 60 years ago, but created its platform through new artistic movements like performances, events or body art and festivals such as Ars Electronica, which has been bringing the audience closer to the artist since the 1980s. However, it took someone really visionary to combine heavy, large and rigid computers and lightweight, soft, sensuous textiles. In the mid-1990s, Maggie Orth and Rehmi Post [11], who led a team of researchers at MIT's Media Lab, began to explore how digital electronics could be integrated into clothing by using sewable conductive materials. In 2007, Leah Buechley created the first flexible Lilypad Arduino circuit [11].

Wearable technology is, in its essence, anti-dress and anti-fashion. WT's ultimate goal is to make clothing durable, self-cleaning and adaptable to all situations or seasons. Ryan [1] (2014, p. 105) claims: 'WT rehearses an age-old dialogue between society and the body that proposes a process of invisibility based on an ideal of pure functionality and pure information, and ultimately a uniformity of dress.'

The synergistic link between fashion and technology is beneficial for both elements. Fashion gives WT a bigger projection, informs a wider audience of its potentials and can even create new commercial niches, which in turn can result in funding for new research. Bradley Quinn [12] (2012, p. 12) asserts that technology and fashion are a perfect match: 'when associated with garments, which are by nature portable, wireless technology becomes even more mobile, and as technologized fashions wirelessly connect garments to remote systems, they extend both their own functionality and technology's reach. Together, the two are finding new uses for traditional materials and techniques, while also inspiring new types of tailoring and high-tech fashion fabrics.'

Ryan [1] (2014, p. 11) observes that: 'More and more designers and artists utilize garments empowered with their own abilities to act or react, to reveal the moment-by-moment nature of dress and the ironies in our hybridized, digital/physical relations.' They believe that clothes are as important as the way in which they are represented. Garments made of responsive materials or embedded with sensors and actuators that emit sounds or light or create physical movement have a clear performance aspect. WT sometimes gives clothes a form of scenography, narrative or a character, which can make for a great marketing tool. For this reason, many fashion collections feature at least one unwearable WT piece that makes catwalk theatrical and ends up as a spectacular promotional photograph.

According to Johannes Birringer [13] (2008, p. 215), the role of fashion and clothing directly relates to the complex social and theatrical concept of 'performance'. Many designers, engineers, artists and performance-artists base their work on the relationship between a performing body, material, movement and the observer. By redefining the meaning of a dressed body, they are merging the boundaries of theatrical performance, fashion and contemporary art, resulting in new approaches, hybrid practices and new terminology, such as fashionable technology, scientific couture, wearable art, conceptual clothing and critical costume.

Some artists and textile designers experiment with immaterial [14] and disintegrating clothing [15] made using projections [16], smoke [17], gel, balloons, bodily fluids [18], hair and garbage. Some, apart from searching for a material, aesthetic and somatic experience, base their work on exploring key scenographic elements related to costume: time, space, movement, light and sound, which give identity to an otherwise inanimate garment.

By examining the performative qualities of alternative materials, they question the spatial and temporal limits of body/dress or body/costume. Alexandra Cabral and Manuel Figueiredo [19] (2014: 2431) state that 'both space and garments become fictional projections of body limits, as they are conceptual interventions and physical extensions of a performer'. Sofia Pantouvaki [20] (2014: 117) speaks of a 'scenographic costume' or 'spatial costume', while Jessica Bugg [21] (2014: 39) calls it 'body located scenography' and Dorita Hannah [22] (2014: 15) discusses costume as 'a spatial body-object'.

Johannes Birringer and Michèle Danjoux [23] (2009, p. 5) said that interdisciplinary advances in smart materials and wearable design will result in 'a future of sensing/communicating clothing that can express people's personalities, needs and desires, or augment social dynamics through the use of wearables as 'theatre' and as emotional 'tools'.' They distinguish between two categories of wearables used in a performing sense: *intelligent* (reactive materials and garments with shape-changing or display character)

that do not require particular performance techniques, and *interfacial* (sensing and actuating) garments that interact with the performer or/and audience. Similarly, Michaela Honauer [24] (2017, p. 281) speaks of *active* and *interactive* costumes.

Artists have been using WT as an expressive and critical tool for decades, especially when dealing with themes of privacy, disembodiment, invisibility, and augmented and virtual realities. Birringer and Danjoux [23] (2009, p. 5) explain: 'the artistic experimentation with smart technologies is of course not market-oriented and has no end-user. Rather, the mobilization of smart technology concerns sensorial experience and expression (involving transformations of the performer-audience relations), a more experimental and playful adaptation of the digital medium as a wearable medium.'

New media artist Melissa Coleman (in Rebeccah Pailes-Friedman [25], 2016, p. 13) asserts: 'One of the functions of fine art is to create a discourse around subjects that are already happening in society, or that are looking to start happening. And anything related to textiles is never separated far from issues around body.'

No matter how advanced the technology, the point is to connect people, just like fashion and clothing. Birringer and Danjoux [23] (2009, p. 5) speak of the Japanese notion of *kansei* (emotion design) that 'implies a stronger emphasis on the wearable as a social medium, capturing user subjectivity and intimacy.' Fashion tech designer Anouk Wipprecht says (in Kaplan [26], 2015): 'The position that technology has in our society – the role to please us – will get more and more intimate. [...] As technology crawls closer to the skin we will need to rethink and recreate the relation that we have towards technology.'

Back in 1999, Stefano Marzano, the CEO of Philips Design Probes, suggested (in Ryan [1], 2014, p. 112) that the fashion industry must be transformed so that clothing design is no longer simply a choice of colours and styles, but a choice of functions, and the technology industry will have to learn to think emotionally, until functional applications can be incorporated directly into our bodies.

3 Classification of WT

Some of the most characteristic examples of wearable technologies are presented below. This research focused on the content analysis and categorisation of WT, which until now have not been implemented in this form. The presented classification represents an innovative approach to understanding the importance, usefulness and application of WT.

Garments are defined by the material from which they are made. They represent the frontier and the connection between the body and the environment around it. They have an internal (personal) and an external (social) side.

The examples presented here were chosen for the technological concept behind the garment. Some of the examples are made of responsive materials, while some of them are active. The majority of examples, however, are interactive garments. All examples have been classified into one of three categories: material, external stimuli or internal stimuli. Each category has several subcategories: responsive material and 'immaterial' garments in the material category; movement, light, sound and touch in the external stimuli category; and biometrics/emotional sensing and biomimetics in the internal stimuli category.

Many of the examples could be classified to two or three different categories, as they have diverse functions and could be used and interpreted in different ways. What all of them have in common is that in a few years' time all of these garments will be outdated and outshined by more innovative garments, and forgotten.

2.1 Material

Responsive material

- Material changes its colour or transparency when lit or touched, and due to body heat or sweat, or drops of water. It glows in the dark, changes texture or shape, emits light or sounds, conducts electricity and data, and stores energy.
- Hydrochromic ink, thermochromic ink, glow in the dark ink, conductive paint, shape-memory alloy, disintegrating materials, mechanically collapsible textures, phase-changing materials, stimuli-responsive polymers, printable circuits that transfer data, etc.
- Examples:
  - Catalytic Clothing (Herself): Material sucks and eliminates pollutants from the air surrounding it; dress in the form of a lung (Figure 1, [27]).
  - DuoSkin: Tattooed circuit transfers data and lets the wearer control their devices directly from their skin (Figure 2, [28]).

Figure 1: Helen Storey & Tony Ryan. Catalytic Clothing (Herself), 2010 [27]

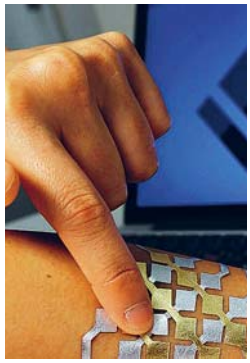

Figure 2: MIT Media Lab / Cindy Hsin-Liu Kao, Christian Holz, Asta Roseway, Andres Calvo, Chris Schmandt. DuoSkin, 2016 [28]

'Immaterial' garments

- Immaterial garments create an illusion of immateriality.
- Garments are made by light, smoke, mirrors, two-phase foils, projections, motion-tracked body mapping, hologram, and virtual and augmented reality.
- Examples:
  - Smoke dress: Dress is activated by proximity sensors. When someone steps into the personal space of the wearer, the dress creates a veil of smoke. By obscuring personal boundaries, the dress creates a dialogue between the wearer and their surroundings. The smoke can be scented so anyone can smell and taste the dress as they inhale it (Figure 3, [17]).
  - Apparition: A performer wears a motion-tracking body projection mapping, which moves in unison with their dancing body. Immaterial performance costumes can be the most sustainable option: they are comfortable, cheap to make, easy to maintain and do not occupy storage space (Figure 4, [16]).
  - Apparel VO.9A: This garment is an augmented reality prototype. The 'wearer' will neither wear nor physically feel the garment. They and the onlookers will only see or feel it with help of special glasses or a special glove. It embodies the concept of the body as a continuously changeable display that reacts to the wearer's biometrics and social media profiles in real time. The designer does not have to deal with textiles and construction limitations anymore: shape, volume and texture are replaced by graphics and animation (Figure 5, [14]).

2.2 External stimuli

- Input comes from outside of the garment (changes in the garment activated by proximity, movement, light, projection, sound, voice, gaze and touch).

Movement

- Moving dress, vehicle dress, flying dress, disappearing dress, dress moving as if it were a part of

Figure 3: Anouk Wipprecht. Smoke dress, 2011-13 [17]

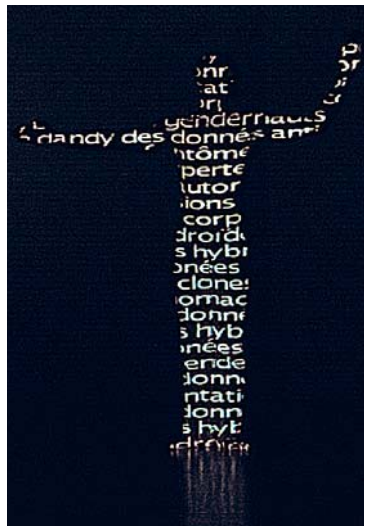

Figure 4: Klaus Obermaier. Apparition, 2004 [16]

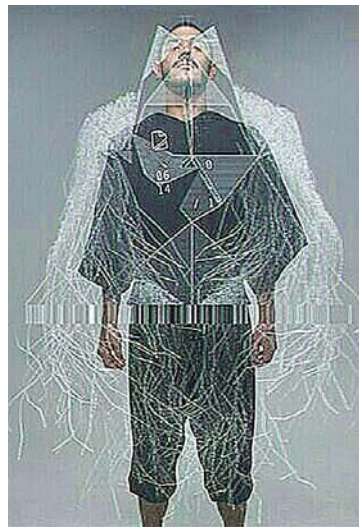

Figure 5: Normals. Apparel VO.9A, 2012 [14]

the body, lighting dress, instrument dress, dress as choreography, etc.

- Sensors: movement, proximity, accelerometer, gyroscope, piezo, tilt, ultrasound, infrared, microphones, eye-tracking cameras, motors, speakers, LEDs, EL wires and panels, inflatables, drones, etc.
- Garments that are activated by the movement of the wearer. Garments that start to move (get, bigger, smaller, change shape and texture, etc.) when activated by some external stimuli, usually not controlled by the wearer. A garment that moves, but it is the garment that wears the performer (who does not touch the ground); controlled by the wearer or from a distance.
- Examples:
  - One hundred and eleven: Dress progressively disappears into a hat using a motor (Figure 6, [29]).

Figure 6: Hussein Chalayan & Adam Wright. One hundred and eleven, 2007 [29]

  - Butterfly dress: Dress transforms or partially disintegrates as someone moves towards it. Forty butterflies start to flutter and then fly away, activated by a proximity sensor or via a mobile device that communicates with the dress over a wireless network (Figure 7, [15]).

Figure 7: Ezra & Tuba Çetin. Butterfly dress, 2015 [15]

  - Volantis, world's first flying dress: Remotely controlled flying platform dress is moved by six large drones (Figure 8, [30]).

Figure 8: Studio XO. Volantis, worlds first flying dress, 2013 [30]

Light

- Garments are activated by light or other external stimuli such as voice, ambient sound, touch or gaze that makes garments emit light or pre-programmed or interactive images.
- Dress that lights up a wearer's personal space, dress that turns on/off ambient lights, dress as a display, dress as a projection screen, dress as a projector, dress as a text message, dress as moving pictures, etc.
- Examples:
  - (No)where (Now)here: Dress turns off lights and illuminates when someone looks directly at it (Figure 9, [31]).

Figure 9: Ying Gao. (No)where (now)here, 2013 [31]

  - Bono's Laser jacket: The jacket is equipped with dozens of laser spot lights that are projected on audience members individually, thus

connecting a performer with a spectator on a personal level (Figure 10, [32]).

Figure 10: Moritz Waldemeyer. Bono's Laser jacket, 2010 [32]

– Twitter dress: Dress allows one to wear online comments. Full-colour LED pixels show the most popular tweets about the dress, the wearer or the event in real time (Figure 11, [33]).

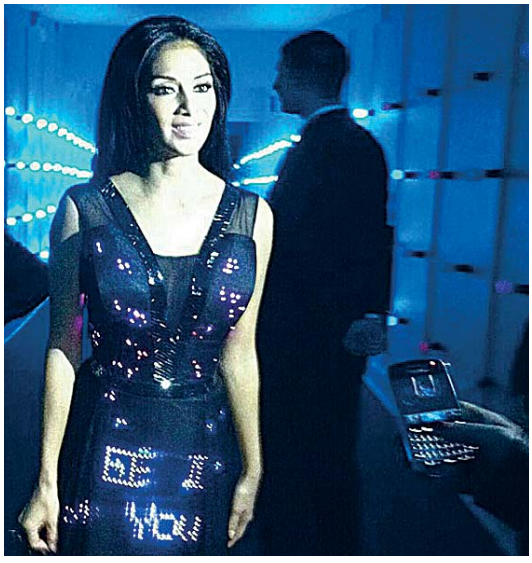

Figure 11: CuteCircuit. Twitter dress, 2012 [33]

Sound

- Garments are activated by sound, voice, talking, singing, clapping, ambient sounds, music, touch or proximity to make them emit sounds (amplified, in real time or pre-recorded, interactive).
- Dress as an instrument, microphone, speaker, etc.
- Examples:

– Sonifica: A wearable bustier and a prosthetic leg turn multimedia performance artist Viktoria Modesta's body into an instrument. Both pieces use open-source hardware and software that recognises gestures, and a six-axis accelerometer and gyroscope to track movement and interact spatially and sonically with her environment and participating audience, creating an intimate and collaborative show (Figure 12, [34]).

Figure 12: Viktoria Modesta & Anouk Wipprecht. Sonifica, 2017 [34]

– Soundshirt: Shirt helps deaf people feel music thanks to 16 micro actuators embedded in the fabric of the garment. These actuators receive the music that the orchestra is playing wirelessly and in real-time. Transformed into data, for example, violins can be felt on the arms and drums on the back. An entire composition comes to life as a series of haptic (touch-like) sensations across the torso of the person wearing the shirt. 'What you hear... I can feel!' Kassandra Wedel (in CuteCircuit [35] 2016), deaf dancer and actress, (Figure 13, [36]).

Figure 13: CuteCircuit. Soundshirt, 2016 [36]

Touch

- Garments are activated by human touch, raindrops, proximity and haptic touch from a distance.
- Dress as a music player, dress as a text messenger, dress as a flickering lamp, dress as a hug from a distance, etc.
- Examples:
  - Hugshirt: Shirt delivers a 'hug' from a distant hugshirt using Bluetooth and sensor technology. By applying pressure to certain points on the body, the shirt recreates the haptic sensation of the touch, warmth and emotion of a hug. It is designed to be worn by both caller and receiver, and represents the physical dimension that phone-based digital communication lacks (Figure 14, [37]).
  - Puddle jumper: When raindrops hit the coat, the sensors activate EL lamps. A flickering pattern of illumination mirrors the rhythm of rainfall (Figure 15, [38]).

Figure 14: CuteCircuit. Hugshirt, 2004 [37]

Figure 15: Elise Co. Puddle jumper, 2001-02 [38]

  - Coded sensation: Garments that are made from fabric that carries information from magnetic tape cassettes serve as a music player. Music, stories or poems start to play when the surface of the garment is touched by a glove device (Figure 16, [39]).

Figure 16: Martin Rille. Coded sensation, 2009 [39]

2.3 Internal stimuli

- Input comes from the inside of the garment, while changes in the garment are activated by the wearer's biometrics.
- Garments are activated by breathing, heartbeat, muscle movement, blinking of the eyes, voice vibration, perspiration, skin pH and EEG brain activity to make them move, blink, glow, make photos, or emit light, sound, music, smoke, scents or liquids.
- Concepts of multi-sensory surfaces and social interaction design: a garment acts in accordance with the wearer's psychological and emotional state. For this reason, it seems to act on its own and as if it were part of the wearer's skin or body.
- Technically, this type of garments is much more advanced and requires many more electronic components, programming and sensors: movement, proximity, muscle strain, ultrasound, infrared, breathing, heartbeat, perspiration, skin temperature, brain activity, microphones, eye-tracking cameras, motors, speakers, LEDs, EL wires and panels, inflatables, etc.

Biometrics and emotional sensing

- Garments are activated by somatics, small gestures, breathing, heartbeat, skin temperature, perspiration, muscle tension, voice recognition or visual focus (all are indicators of anxiousness, insecurity, blushing, unease, stress, distraction, lying, etc.) to make them light up, change colours, inflate or deliver an electric shock.
- Examples:
  - The holy dress: The dress starts to glow and increases in intensity using data from a speech recognition system and voice stress analysis. When a lie is detected, the garment lights up fully and delivers an electric shock to the wearer as punishment. In this way, the garment trains the wearer to live an honest life and become a better person (Figure 17, [40]).

Figure 17: Melissa Coleman, Leonie Smelt & Joachim Rotteveel. The holy dress, 2016 [40]

– Smart second skin dress: This therapeutic garment is integrated with a wireless sensor network that uses nanotechnology and microfluidics. It senses the wearer's body heat and other indicators of stress, and releases aromas to boost the limbic system in the brain or deodorant when sweat is detected. The dress, conceived as a second skin, can alter mood, encourage sleep or energise action, increase self-esteem and stimulate the imagination (Figure 18, [18]).

Figure 18: Jenny Tillotson & Adeline André. Smart second skin dress, 2003 [18]

– Trans-For-M-Otion: The garment immediately reacts to how the wearer is feeling in a changing environment. Heartbeat, body temperature, respiration and muscle-tension are sensed and processed. When the wearer feels anxious or insecure, small air cells in the garment fill up like little cushions, so that the garment immediately fits closer to the body and the wearer feels safe and protected. LED lights also respond directly to the wearer's movements and emotion to soothe them (Figure 19, [41]).

Figure 19: Eunjeong Jeon. Trans-For-M-Otion, 2010 [41]

Biomimetics

- Garments are activated by proximity, increased heart rate, breathing, perspiration, body temperature, or an observer's facial expression to make them move, inflate, glow, and emit light and sound.
- Garments mimic natural forms, animal movements and behaviours, such as an animal raising its fur to make it look bigger or attack in self-defence.
- Examples:
  – Robotic spider dress: A device worn on the shoulders, which consists of six mechanical spider legs, acts on behalf of the wearer and can attack using the same viewing angle as the wearer when someone enters their personal space. Using wireless biometric signals from proximity and breathing sensors, the system makes inferences based on the stress levels in the wearer's body and can differentiate between 12 different states of behaviour. The system knows how the wearer feels and can adapt its behaviour to those feelings. The system's own opinion is based on the logic and data programmed through social studies and environmental psychology. In this way, the robotic spider dress becomes a part of the person, instead of something separate that stands alone (Figure 20, [42]).

Figure 20: Anouk Wipprecht & Daniel Schatzmayr. Robotic spider dress, 2014 [42]

– Opale: The dress senses aggression and bristles its 'fur' as a defence mechanism or as a form of intimidation when under threat, or purrs when stroked. Inspired by cat, dog or mice fur, the outfit is equipped with facial tracking technology, which detects an observer's facial expressions (happiness, sadness, surprise, anger or neutral),

an interactive pneumatic inflatable system (six motors and CO_2 capsules) and a forest of fibre optics embedded in silicon that react by movement and sound (Figure 21, [43]).

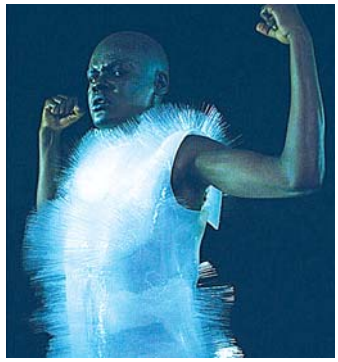

Figure 21: Behnaz Farahi. Opale, 2017 [43]

3 Discussion

Through existing literature and internet research, the best-known and innovative examples of technology-embedded clothing from the last 30 years were gathered to analyse the increasing interdisciplinary relationship between fashion, performance, art and science, and to identify some characteristics and draw conclusions about the current state of WT. Two thirds of the examples were created by women. Only 35% of the examples came from fashion (presented as a part of a fashion collection, catwalk or red-carpet event), while 25% of examples were presented in an art gallery or museum, 20% on stage, in musical concerts or theatre performances, and 20% were conceived as a scientific research prototype or are still in the experimental stage.

The most important characteristic of wearable technologies is team collaboration, as WT is an interdisciplinary undertaking. Teams are formed by designers, technologists and engineers. Many designers today have backgrounds in science or technology, fashion, interface design or art, but still require help and advice from material or biomimetics scientists, electronic and robotics engineers, nanotechnologists, neurologists or anthropologists.

Collaborations between Hussein Chalayan, Moritz Waldemeyer [44], Adam Wright [45] or Karolina Cengija [46] are some of the most fruitful. The Chalayan-Cengija collaboration is just one of many exceptions to the stereotype of multidisciplinary teams, combining the traditionally female practice of dress-making with the previously male-dominated disciplines of technology and materials science. An interesting phenomenon is actually occurring: a new breed of fashion designers/electronic engineers is emerging and will break gender barriers forever. Young women such as Anouk Wipprecht [47], Becca McCharen [48], Kate Hartman [49], Sabine Seymour [50] and Limor Fried [51] have their own hi-tech fashion brands, lead their own WT labs or electronic supply companies, and are paving the way for the next generation of women fashion tech designers.

Another aspect of collaboration is that in order to ensure the best use and reach of their work, WT artists and studios are joining forces with some of the most famous and most avant-garde pop stars, such as Lady Gaga, Björk, Viktoria Modesta, Black Eyed Peas, Pet Shop Boys and other celebrities for their music videos, tours, advertising campaigns and red carpets events. In this way, WT takes advantage of three different media channels to reach the masses: fashion, music and art/design.

However, it is in large-venue concerts where WT is tested to its very limits, not just for its spectacular effects, but above all for its functionality, durability, safety and comfort. It is these performers who challenge the designers to create ever more innovative designs for their next tour. WT is a great tool to connect with the masses in big-stage productions where the audience can be hundreds of meters away from the performer, as 'interactive and responsive costumes can transform performance on both a larger stage scale, as well as the intimate and relational scale of the costume.' (Pantouvaki [52], 2014, p. 193).

Another important characteristic of WT is the fact that electronic devices are becoming smaller and cheaper every day, and that there is an open-source coding community willing to share their knowledge free-of-charge. Anyone interested in working with WT with a minimum budget and minimum sewing and programming skills can create a great and innovative design or artwork. There are also books, online blogs and tutorials for beginners and professional WT makers. Fashionable technology entrepreneur Sabine Seymour (in Quinn [12], 2012, p. 164) believes in the model of open innovation and argues that 'it is important for creators to have access to the new materials, processes and methodologies that are developed by such corporate entities. Safeguarding and restricting access to new techniques do not

produce innovation but rather hinder it. Not only is creativity stifled, but also the potential for financial returns of investment to the investors is limited.'

There are still many challenges and limitations for WT. To stay innovative, the fashion world requires deeper knowledge about tools, materials and manufacturing, but very few designers have total access to the latest advances in technologies. Trend expert Anne Marie Commandeur (in Quinn [12], 2012, p. 226) argues that technology is advancing rapidly in all areas of design, except fashion and that 'textile technology, textile designs, garment manufacturing, finishers, fashion designers and now scientific researchers work without a common platform that would enable them to build bridges between these processes.' WT designer Becca McCharen of Chromat (in Kaplan [53], 2015) claims that the biggest problem is getting their designs into production. She says: 'We know we can do amazing things with materials, we know it enables a completely new aesthetic … [but] it's getting it into the hand of the consumer, and that's a manufacturing and distribution problem.'

Short deadlines for creating seasonal collections and the quick reversal of trends often discourage fashion designers from transforming their research into new materials and aesthetic and performative values that result in wearable technology. Sometimes, designers simply show no interest in wearable technologies. Conceptual fashion designer Ying Gao (in Pailes-Friedman [25], 2016, p. 140) argues that designers themselves are not brave enough to experiment and asserts: 'We have lost this critical thinking that people have in other fields such as media design and cinema.' Moreover, there are still practical issues to be resolved: wires and batteries are not soft and do not have flexible joints, so they are still unable to stretch and bend with the body. Electronic circuits are still not tough enough to stand up to wearing, washing and repairs. With regard to wearability, the challenges faced by costume designers are even greater, as they are creating for a known end-user, the performer. The appearance has to fit metaphorically into the character played and be visible for all audience members, regardless of where they sit. In addition, costumes must be robust enough to be worn multiple times, and to be dressed or undressed quickly. They have to be durable, comfortable, safe, not too hot and allow for freedom of movement.

Another negative characteristic is the lack of criticism in WT literature. Almost every year, lushly illustrated books are published demonstrating the current state of WT and big-named "fashion" exhibitions such as Manus X Machina take place [54]. Ryan [1] (2014, p. 6) claims that 'the WT literature testifies to an enormous and growing field', but that much of its 'activity has gone untouched by historical and cultural examination.' She blames it on literature's 'consistently affirmative and advocative tone, reminiscent of marketing and journalism, and the absence of any negative remarks, or any critical perspective whatsoever.'

4 Conclusion

Clothing embedded with WT can generate a specific body-mind involvement. We can perceive clothing with all of our senses: sight, touch, hearing, smell, taste, even multi-sensory or synesthesia. Garments represent a bridge between visual, physical and perceptual experience, providing the wearer and the observer with a kinaesthetic, proxemic and haptic experience.

Since the late 1990s, many of the projects devised within the field of fashionable technology have a strong performative connotation, as they move, change shape, or emit light, sound or scents. It wasn't until the last decade, however, that WT designers really began to explore the potential of clothing as social interaction, emotional sensing or biomimetics.

The mass production of WT garments will probably never occur, and although it may have sounded like science fiction 20 years ago, somewhere some teenage cosplayer is 3D printing materials and clothes that we saw as a crazy futuristic idea in a movie, comic or video game right now in their own room.

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