# SKINNING FUTURE TEXTILES

## through living material technologies and electronic multi-sensory experiences


## *ABSTRACT*

This paper presents a set of contemporary art and design practices redefining the traditional aesthetic and functional qualities of textile surfaces.

The framework created by drawing parallels between textiles and the unique characteristics of skin allows us to contextualise and link works spanning from adaptive non-woven second skins to recyclable and biodegradable living surfaces, from emotive and kinetic skins to interfaces of bodily and cognitive perception.

These innovative interdisciplinary approaches seem to transform the relation between textiles and bodies. The article discusses how technological advancements in the life sciences and communication technologies urge the field to devise seamless forms of integration with our body.

My investigation suggests that the rich haptic qualities of textile materials allow intimate connection with our sensory perception. When merged with electronic technologies, such enhanced haptic language has the potential of transforming surfaces into interactive interfaces for self-expression and sensory augmentation.



## *KEYWORDS*

***textiles, e-textiles, interactive interfaces, multi-sensory, responsive, skin, liminal, body, intimate***

# INTRODUCTION

## SKIN AND ITS BOUNDARIES

Skin is a biological substrate characterised by incredible functional and aesthetic qualities and responsive behaviours. As described by curator Ellen Lupton, skin is 'a multilayered, multipurpose organ' (2002:29) that adapts to the landscape of the body by varying tautness, tone and thickness. As pointed out by artist Zane Berzina (2006), skin also has a rich haptic texture that intelligently shifts from soft to rough, lubricated to dry in response to our needs. Skin reacts promptly to damages by self-replicating, self-repairing and self-healing its surface. It also mediates between body and environment, constantly sending and receiving stimuli in both directions. Such reconciling role seems to resolve the static oppositions between body and environment in a dynamic interconnection. Skin also melds in its stratified layers newly generated cells and dead cells, functionally balancing apparently opposite states. Appearing senseless and inert on the surface, the compact strata of dead cells composing the outer layer protects instead the inner tissue flush with nerves, glands, and capillaries (Lupton, 2002). Due to its transformative nature, skin can only be defined as liminal[1], transitional and constantly in becoming (Zylinska, 2002).

## SKIN AND TEXTILES

In 'Skin: surface, Substance, and Design' Lupton describes the biological substrate as the 'surface where bodies and products merge' (2002:33). The publication collects examples of product, furniture and fashion designs as well as architectural practices that expand our understanding of surfaces by emulating skins or enhancing its characteristics. This analysis stimulates the comparison of textiles with other design practices. Textile products indubitably hold the most intimate connection with bodies: merging with our skin they act as interfaces with the external environment. Hence, It is not a case that the fascinating aesthetic qualities characterising fabrics brought to the metaphorical description of the textile surface as a second ornamental skin: the close relationship between the two surfaces naturally determines their functional and aesthetic assonances.

This paper aims at identifying contemporary textile practices informed by the functional and aesthetic qualities of skin. As our understanding of the epidermis is evolving from a static protective surface to an interactive sensory membrane[2] new discussions on the role of contemporary textile surfaces is stimulated. Furthermore, due to the groundbreaking innovations in the material sciences, life sciences and electronic engineering, new materials, production processes and technological Hybridisations are possible. 'It is no longer sufficient that the new dress, winter coat or upholstery have the right design and match the trendy colours of the season.'(Degn Hansen et al, 2011). The ornamental cloth needs reform.

In the following chapters I will map the impact of cutting-edge technologies on textile research, observing at the same time the evolving relation between skin and crafted surfaces. The first section will investigate interdisciplinary research exploring new chemical and biological processes for textile production. The second section will critically discuss wearable technologies and electronic textiles. I will conclude by contextualising my current interdisciplinary textile practice within the discussion.

# BIO-TEXTILES

## FROM WOVEN FABRICS TO NON-WOVEN SECOND SKINS

Synthetic fabrics have been in production since 1924, when Rayon filament was first derived by a liquid solution (Quinn, 2010). For decades these polymers have taken the shape of yarns with the purpose of enhancing various properties of traditional fabrics. However, constant innovation in the field has brought to more innovative applications of such polymers. An example are liquid-based materials like silicons and pvc, that were originally applied as even coating layers to protect textile surfaces.

1. Fabrican textile

Exploiting the thermoplastic properties of these fluids, polymers are now able to take the place of woven fabrics. Through innovative techniques, these materials can be shaped as three dimensional surfaces with subtle relief patterns, substituting cloth with adaptive non-woven second skins (Braddock and O'Mahony, 1998). Other techniques available on the market aim at reproducing similarly adaptive surfaces with an instant procedure. For instance Fabrican is an aerosol solution composed of a suspension of polymers and textile fibers (ibid, 2010) capable of forming a seamless flexible substrate on any shape (Quinn, 2010). Developed by designer and researcher Manel Torres in collaboration with chemical engineer Paul Luckham, this patented spray-on fabric is suitable for direct application onto the body of the wearer. Its fibres have the unique feature of instantaneously adhering to skin and aggregating in a uniform layer that perfectly follows the body shape (Seymour, 2009).

## BIOLOGICAL AND SYNTHETIC SKINS

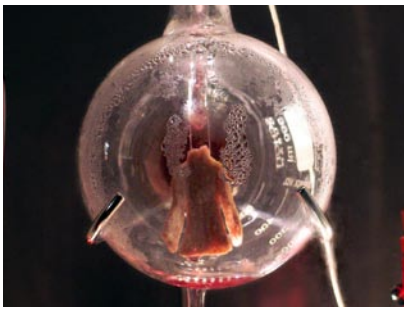
Although the function of these engineered polymers challenges traditional textiles, more radical and sustainable approaches are being investigated. Designer Carol

2. Suzanne Lee's fermented material

Collet draws attention to the new field of synthetic biology as a fertile ground of interdisciplinary experimentation for innovative textile production strategies. As stressed by Sir John Sulston, Nobel prize in 2002 (in Von Glasgow, 2008) and partner of Collet in the Nobel Textiles project[3], for the first time in history biology is not limited to the observation of natural processes, and as a result scientific tools are turning into tools for creation. Although the use of biotechnology is not new to textiles since microbes and bacteria have been part of the dyeing and finishing process for a long time (Braddock Clarke and O'Mahony, 1998:144), the new branches of biotechnology allow practitioners to reprogram biological materials to satisfy our needs (and fantasies).

Collect suggests that by collaborating with synthetic biologists textile designers could envision ground-breaking approaches to textile production. The 'bio-hacking approach', as named by Collet (2012:4), will enable practitioners to create living textiles with a bottom-up rather than top-down technique (ibid, 2012), optimising the use of resources and waste material through reprogrammed natural processes. This high-tech craft will take advantage of living cells as the new textile factory, a bio-industry programmed to 'grow' textiles as plants and bacterial colonies.

Fashion designer Suzanne Lee took a step in this direction by collaborating with a biologist to grow in her bath tub a 100% recyclable and biodegradable living surface. Green tea, water, sugar, yeast, few microbes and time are the only ingredients in the recipe. After boiling tea in water, Lee leaves the mixture to ferment. The cultured micro organisms form a thick layer in the solution, which is then dried out at the sun. The substrate can be cut or sewn with conventional methods, or modelled around three dimensional shapes by joining various layers seamlessly with a wet cloth (TED 2012b). Depending on the dosage of the bio elements and time, Lee obtains a material with a texture similar to light paper or leather, resembling skin in colour and consistency.



3. Victimless leather jacket

Whereas Lee deploys microbes and bacteria to produce leather jackets that look like skin, artists Oron Catts and Ionat Zurr use animal and human cells to produce small leather jackets controversially made of skin (Zwijnenberg, 2009). Likewise Collet's and Lee's work, the 'Victimless Leather' project reflects on the process laying behind the product, but the investigation aims at encouraging public discussion on the applications and implications of living technologies. The bare aesthetics of skin used in their installation immediately communicates the strong cultural, political and ethical implications of culturing tissue in labs. Bio artist Eduardo Kac contributes to the discussion, arguing that by working with bio media[4] practitioners like Catts and Zurr invent ideas and forms beyond achievement of previous technologies (cited in Zwijneberg, 2009:XX). Similarly to Collet and Sulston, Kac draws attention to the shifting boundary between technically possible and impossible, highlighting its frightening and exciting potential.

### *HACKED BODIES*

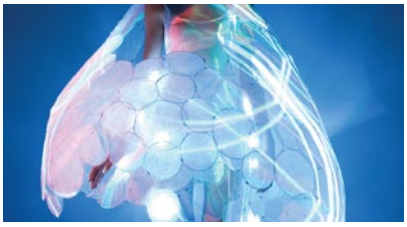
As static contours between natural and synthetic materials (and bodies) seem to blur, a brave new scenario is created. With his work, Stelarc has pioneered the idea of technologically hybridised bodies. The artist has stated in various interviews that our body cannot be defined by static boundaries anymore, and therefore it cannot be physiologically nor conceptually crossed or transgressed (Stelarc 1995). This statement suggests that artists and designers are allowed to directly penetrate the body with technology[5] (ibid, 1995). Hence, as Stelarc demonstrates by transferring his works of art from an extra surface to his vivid flesh, his 'Ear on Arm' piece being the most iconic example, future practices will be able to investigate the body as material of creation.

Body-architect Lucy Mcrae explores the poetic integrations of technology with the body with the same body-hacking approach devised by Stelarc. The designer produced in fact a swallowable perfume pill in collaboration with a synthetic biologist. Using biomedical procedures McRae hacked the functionalities of skin: as the body transpires sweat, the fragrance contained in the pill comes out through the pores. In this work the body becomes a boundless platform of self-expression (TED 2012a), and skin a material crafted with the bio-hacking approach envisioned by Collet.

## *ELECTRONIC TEXTILES*

### *ELECTRONIC TEXTILES AND FASHIONABLE TECHNOLOGY*

The miniaturization of information and communication technologies increased the degree of intimacy between electronic devices and our bodies, bringing to the integration of these elements 'in the fabric of our clothes, skins and lives' (Schiphrost, 2009). The contact with electronic engineering, nanotechnology, information science and communication technology offered the opportunity to the textile field to engage in interdisciplinary research that resulted in the development of electronic textiles and smart materials. Following these advancements, fashion designers interested in augmenting the functionalities of garments took advantage of enhanced textiles to produce electronic clothes, emotive garments and kinetic dresses[6.] This 'intersection of design, fashion, science and technology' (Seymour, 2009:12)


4. Philips' wearable technology, SKIN:dresses

generated the field of 'fashionable technology', term coined by Sabine Seymour in year 2000.

Seymour sees technologically enhanced garments as contemporary extensions of skin with 'unlimited potential' (2009:12). In my opinion, fashionable technology is one of the many forms of integration of enhanced textiles with our bodies. Furthermore, the medium chosen by Seymour actually limits the expressive possibilities of the new technologies to a predominantly visual form of communication, bound to an aesthetic rather than multi-sensory expression, concept that I will expand upon in the following paragraph.

## *VISUAL AND TACTILE VALUES*

In Understanding media (1964), Marshall McLuhan describes a variety of technological enhancements that affect the way we perceive, communicate and live in society. Seymour refers to the words of McLuhan to support her vision of the influential role of the new field, quoting a passage (2009:12) in the chapter of the book dedicated to clothing. The chapter's title misleadingly influences the understanding of the analysis of the clothing medium operated by the media theorist. Although McLuhan recognises clothing as a powerful medium that extends human skin, he also suggests that it has created a disequilibrated perception of nudity and a divorce from the the 'audile-tactile values' connected to bodily experiences, in favour of more abstract visual values (McLuhan, 1994:120-122). Enthusiastic of the possibilities of new technologies, the author suggests a new relationship with the epidermis, focused on recovering the integrity of experience compromised by the excesses of Western visual cultures.

*'After centuries of being fully clad and of being contained in uniform visual space, the electric age ushers us into a world in which we live and breathe and listen with the entire epidermis' (Mcluhan, 1994:122)*

While clothing fails at evaluating and extending skin in its wholeness through its visual aesthetics, the textile medium has the chance to integrate wearable technologies with our bodies with an approach more similar to the one suggested by McLuhan. In fact, whereas fashionable technology predominantly uses enhanced textiles to construct visual identities, the textile field values the aesthetic qualities of materials as much as their haptic feel. Better expressed, the aesthetic language of textiles is embedded in the material itself.

## *DIRECT COMMUNICATION VERSUS PLAYFUL EXPERIMENTATION*

As a practitioner in the field of electronic textiles, researcher Joanna Berzowska comments on the lack of interest of funding institutions in 'playful experimentation' (2005:4) with the new technology. Although wearables and e-textiles interest a growing number of designers, they have been applied more successfully to health, sports, military and computing areas, where innovation is supported by funds (Berzowska, 2005:6-9). Berzowska gives insight of this tendency with her own experience (2005:5), as she started her research in enhanced textiles at the MIT Wearable Computing Lab. The interest of the staff in innovative materials was in fact driven by the need of developing more durable and flexible surfaces than printed circuit boards, for the purpose of incorporation of personal computers on the body. As Berzowska illustrates, the final outcome of the research was mainly the functional integration of devices with our bodies without intermediaries. Sensors and circuits are embedded in fabrics to help creating more ubiquitous[7] communication technologies integrating seamlessly in our everyday lives. As researchers are starting to explore interface-less possibilities through the direct application of communication technologies inside our bodies[8] or in the environment surrounding us[9], the e-textile implementation seems a transitory breakthrough.

## *BODILY EXPERIENCES THROUGH TEXTILE INTERFACES*

Another practitioner that stresses on the need of playful applications of wearable technologies is Techla Schiphrost. In her article 'Body matters: the palpability of Invisible Computing' the media artist introduces the value of 'designing for technology as [bodily] experience'(2009:1). In the same paper Schiphrost also devises design experiments that bring into focus sensory perception and give access a wider range of cognitive experiences.

The practitioner identifies in enhanced textile (e.g. e-textiles, sensors, actuators and programmable materials) a prolific set of tools for creative experience-led experimentation. In her Softn project, the artist has deployed e-textiles to enrich tactile experience with sonic stimuli, haptic and light feedback. The additional functionalities provided by the wearable set of tools allowed users to enhance their cognitive perception and body awareness through textile interfaces. Drawing on preceding paragraphs and expanding on Schiphrost's observations, I suggest that the already intimate connection held by bodies  towards textile materials is a key element in the successful implementation of Schiphrost's 'playful' practice and, more generally, in the re-shaping of interactive textile practices.

## *CRAFTING HUMAN PERCEPTION*

5. Crafting human perception panel as worn by a visitor

Crafting Human Perception is an interactive wearable soft sculpture that explores the use of electronic textiles for the creation of expressive interfaces. The wearable panels function as second enhanced skins that sense the vibrations produced by our hands while stroking, squeezing, moving, touching or scratching the surface. An embedded electronic circuit amplifies such haptic vibrations in real time, playing them back in our own ears.

The work aims to re-think the traditional relationship between bodies and crafted textile surfaces through interdisciplinary tools. Inspired by the liminal nature and responsive functionalities of skin, I implemented similar characteristics in the artwork through the use of e-textiles and sensors. As a result, Crafting Human Perception illustrates how enhanced textile interfaces can act as interactive membranes, interfacing users both with their internal sensory system and the external environment.

Likewise McRae's and Schiphrost's work, the installation constitutes a platform for bodily self-expression and enhancement of sensory perception. The interactive features of the work build on artist Lygia Clark's definition of 'relational objects'[10]. As Clark's Bichos and Sensorial Masks, these textile artifacts can be described as entities of indefinite nature, with latent interactive and transformative potential. Their boundaries are continuously negotiated and their functionality is constantly re-defined by the subjects interacting with them.

6. Testing process

During the production of the piece, a number of experiments have been conducted to effectively design the interactive interface to stimulate intimate multi-sensory experiences. Both the haptic design of the surface and the design of the experience have been tested through cycles of observation of participants' behaviours. In particular, the users have been asked to test the immersive qualities of various prototypes, to report their level of concentration on the three senses involved (sound, touch, vision) and to comment on the immersive qualities of the experience. Critical observation of the interactions have informed the production of the artwork. In the initial tests, in which the setting of the experiment allowed participants to see the crafted textiles while touching them and hearing the sound, the integrity of the experience was compromised by the visual aspects of the installation. The visual element seemed to shadow completely the tactile perception, therefore the work was conceived in two exclusionary phases: one where the visitor can uniquely experience the audile-tactile features of the piece and one where the visual field is stimulated. The most appropriate form to achieve such selective stimulation was identified in a hanging panel. Whereas on one side of the installation the visitor is faced with a white surface, a pair of sleeves and a set of headphone - challenging him to interact without expectations based on visual hints - , on the other side he/she can only observe the crafted surface. After having engaged with the installation, active participants reported a sharpening of their sensory perception, bodily awareness and kinaesthetic perception.

Electronic technologies serve as tools for experience design and playful interaction design. As a result, intimate immersive exploration take place, and cognitive feedback loops between the internal perceptive systems of touch and hearing are created.

## *CONCLUSION*

This paper has explored contemporary interdisciplinary textile practices challenging traditional functionalities and material aesthetics of textile surfaces. The increasing degree of intimacy of information and communication technologies with our skin, and the blurring of the distinction between natural and synthetic materials has influenced the development of hybrid design approaches. On the one hand bio technologies seems to allow practitioners to redesign fabrication processes for more sustainable textiles production, although ethical challenges are presented. On the other hand electronic technologies allow designer to extend the expressive possibilities of textiles through electronic implementation, although current research seems to concentrate on functional implementations.

The analysis of skin has served the purpose of creating a parallel between the remarkable characteristics of skin and innovations in the textile field. Concepts of liminality, responsiveness, mediation between body and environment were used as source of inspiration in the research of cutting-edge work and in the development of new work. The artistic project presented exemplifies my position in relation to the context delineated in the paper and represents my current approach to interdisciplinary textile practices.

## FOOTNOTES

1. Term introduced by Julie Clarke. Please consult (Clarke, 2002:35-36). The author introduces the notion of 'liminal beings' without boundaries, a concept highlighted in this essay in relation to the integration of technology in human bodies.

2. See Damasio (2010:89-96). The neuroscientist stresses on the importance of the role of skin in the interactive relationship between body and mind.

3. In 2008 five textile designers were paired with Nobel prize-winning scientists to produce textiles that celebrated their scientific discoveries.

4. Term coined by Eduardo Kac.

5. Please visit: http://stelarc.org/?catID=20247 for examples of Stelarc's work. *Ear on arm*, the *Stomach sculpture* and the *Suspensions* series illustrate the concept expressed by the artist.

6. For examples please consult Seymour (2009:30, 59, 114).

7. See Weiser's definition of Ubiquitous Computing. Available at: lhttp://sandbox.xerox.com/ubicomp/

8. For more information, see interview to Kevin Warrick, where the scientist illustrates his experiment of wireless internet communication through a microchip implanted in the forearm. Available at: http://www.youtube.com/watch?v=Fhu0VBCAW6k.

9. Please consult *Our noise is My command: Sensing gestures using the Body as an Antenna* (Cohn et al.,2011). The paper illustrates the use of the body to control electromagnetic noise present in home environments, turning whole ambients in interactive canvases.

10. For detailed information please consult BORJA-VILLEL, M. et ali (1998) *Lygia Clark*.

## IMAGE LIST

1. FABRICAN (2010) fabrican spray-on shirt [Online image] Available from: http://www.dailymail.co.uk/femail/article-1312399/The-shirt-spray-For-clothes-fit-like-secondskin-try-instant-fabric-can.html [Accessed 09/05/12].

2. BIOCOUTURE (n.d.) BioMaterial [Online image] Available from: http://www.biocouture.co.uk/ [Accessed 09/05/12].

3. SEEDMAGAZINE (n.d.) Victimless Leather Jacket [Online image] Available from: http://seedmagazine.com/slideshow/paola-antonelli_20090411/ [Accessed 09/05/12].

4. PHILIPS (2006) SKIN: Dresses [Online image] Available from: http://www.design.philips.com/philips/sites/philipsdesign/about/design/imagebank/skin_dresses.page [Accessed 09/05/12].

5. PERONA, F. (2012). Personal archive.

6. PERONA, F. (2012). Personal archive.

# *REFERENCE LIST*


BERZINA, Z. (2006) Zane Berzina: Skin Stories II -y Archaeology of skin. Riga: Jel-gavas Tipografija

BERZOWSKA, J. (2005) Electronic Textiles: Wearable Computers, Reactive Fashion, and Soft Computation. Vol. 3, Issue 1. London: Berg Publishers.

BORJA-VILLEL, M. and BRETT, G. and GULLAR, F. and HERKENHOFF, P. and ROLNIK, S. (1998). Lygia Clark. Barcelona: Fundacio Antoni Tapies.

BRADDOCK CLARKE, S. E. and O'MAHONY, M. (1998) Techno Textiles 2 -y revolutionary fabrics for fashion and design. London: Thames & Hudson Ltd.

CLARKE, J. (2002) The Human/ Not human in the work of Orlan and Stelarc. In: ZYLINSKA, J. (ed.) (2002) The Cyborg Experiments the extensions of the body in the media age. London: Continuum.

COLLET, C. (2012) BioLace : An Exploration of the Potential of Synthetic Biology and Living Technology for Future Textiles. Studies in Material Thinkin, Vol. 7, February, pp1-12. [Online] Available from: http://www.materialthinking.org/papers/71 [Accessed 12/05/12].

COHN, G. et al. (2011) Your Noise is My Command: Sensing Gestures Using the Body as an Antenna. CHI 2011 - Session: Gestures, Body & Touch, May, pp. 791-800.

DAMASIO, A. (2010) Self Comes to Mind Constructing the Conscious Brain. London: William Heinemann.

DEGN HANSES, A. L. and HANSEN, M. and TROLES JENSEN, H. (2011) Future Textiles Trends Inspirations Drivers&Barriers Smart textiles. [WWW] Knowledge Centre for Smart Textiles. Available from: http://viewer.zmags.com/publication/5cae4ae2#/5cae4ae2/1 [Accessed 7 April 2012].

E-SKIN LAB (2012) E-skin lab home page. [WWW] Available from: http://www.e-skin.ch/start.html [Accessed 7 April 2012].

HAUSER, J. (ed.) (2008) Sk-interfaces exploding borders - creating membranes in art, technology and society. Liverpool: Liverpool University Press and FACT.

LUPTON, E. (ed.) (2002) Skin: Surface, Substrate + Design. New York:Princeton Architectural Press.

MCLUHAN, M. (1994) Understanding Media The Extensions of man. 2nd ed. London: MIT press.

NOBEL TEXTILES (2008) Nobel textiles - Marrying Design to Scientific Discovery. [WWW] Available from: http://www.nobeltextiles.com/nobeltextiles_/Home.html [Accessed 12/05/12].

QUINN, B. (2010) Textile futures fashion, design and technology. Oxford: Berg.

SCHIPHROST, T. (2009) Body Matters: The Palpability of Invisible Computing. Leonardo, Vol. 42, no. 3, pp-225-230.

SEYMOUR, S. (2009) Fashionable technology The Intersection of Design, Fashion, Science, and Technology. Wien: Springer-Verlag.

SILICON.COM (2010) Kevin Warwick, Human Cyborg. [online video] Available from: http://www.youtube.com/watch?v=Fhu0VBCAW6k [Accessed 7 April 2012].

STELARC (1995) Extended Body:interview with Stelarc. Interviewed by ATZORI, P. And WOOLFORD, K. [online interview] CTheory website. Available from: http://www.ctheory.net/text_file.asp?pick=71 [Accessed 7 April 2012].

TED (2012a) Lucy McRae: How can technology transform the body? [online video]. Available from: http://www.ted.com/talks/lucy_mcrae_how_can_technology_transform_the_human_body.html [Accessed 12/05/12].

TED (2012b) Suzanne Lee: Grow your own clothes. [online video]. Available from: http://www.ted.com/talks/lang/en/suzanne_lee_grow_your_own_clothes.html [Accessed 12/05/12].

VON GLASGOW, K. (2008) Nobel Textiles [CD-ROM] Palladio films.

WEISER, M. (1996) Ubiquitous Computing. Computer Science Lab Xerox Parc. [WWW] Xerox PARC. Available from: http://sandbox.xerox.com/ubicomp/ [Accessed 7 April 2012].

ZWIJNENBERG, R. (2009) Preface. In: REICHLE, I. (2009) Art in the Age of Technoscience. Genetic Engineering, Robotics and Artificial Life in Contemporary Art. Wien: Springer-Verlag. pp. XIII-XXIX.

# *BIBLIOGRAPHY*


ANTONELLI, P. (ed.) (2011) Talk to me: Design and the Communication between People and Objects. [Catalogue of an exhibition held at the MoMa, 24 July - 7 November 2011]. New York: MoMa.

BERZINA, Z. (2006) Zane Berzina: Skin Stories II - Archaeology of skin. Riga: Jelgavas Tipografija.

BERZOWSKA, J. and Coelho, M. (n.d.) Kukkia and Vilkas: Kinetic Electronic Garments. [pdf] Available from http://www.xslabs.net/papers/iswc05-berzowska.pdf [Accessed 7 April 2012].

BERZOWSKA, J. (2005) Electronic Textiles: Wearable Computers, Reactive Fashion, and Soft Computation. Vol. 3, Issue 1. London: Berg Publishers.

BERZOWSKA, J. (2012) Joanna Berzowska website. [WWW]
Available from: http:// www.berzowska.com/ [Accessed 12/05/12].

BONNINGTON, C. (2011) Skin Like Sensors Could Bring Tactile Sensations to Robots, Humans. Wired online [Online] 24 October. Available from:
http://www.wired.com/gadgetlab/2011/10/stretchy-capacitive-skin/ [Accessed 12/05/12].

BONNINGTON, C. (2012) Apple Patent Filings: Creepy Haptic Feedback, a 'Jelly Roll' Battery and Desktop Mini. Wired online [Online] 3 May. Available from:
http://www.wired.com/gadgetlab/2012/05/apple-patents-haptic-more/ [Accessed 12/05/12].

BORJA-VILLEL, M. and BRETT, G. and GULLAR, F. and HERKENHOFF, P. and ROLNIK, S. (1998). Lygia Clark. Barcelona: Fundacio Antoni Tapies.

BRADDOCK CLARKE, S. E. and O'MAHONY, M. (1998) Techno Textiles 2 - revolutionary fabrics for fashion and design. London: Thames & Hudson Ltd.

BULATOV, D. (ed.) (2009) Evolution Haute Couture: Art and Science in the post-biological age. Kaliningrad: KB NCCA.

CARR, N. (2010) The Shallows How the Internet is changing the way we think, read and remember. London: Atlantic Books.

CENTRAL SAINT MARTINS COLLEGE OF ART AND DESIGN (2012) Textile futures course website. [WWW] Available from: http://textilefutures.co.uk/ [Accessed 12/05/12].

COHN, G. et al. (2011) Your Noise is My Command: Sensing Gestures Using the Body as an Antenna. CHI 2011 - Session: Gestures, Body & Touch, May, pp. 791-800.

COLCHESTER, C. (2007) Textiles today - a global survey of trends and traditions. London: Thames & Hudson Ltd.

COLLET, C. (2011) Carol Collet <> Design Led Research. [WWW] Available from:
http://www.carolecollet.com/Carole_Collet/carolecollet.com%3E.html [Accessed 12/05/12].

COLLET, C. (2012) BioLace : An Exploration of the Potential of Synthetic Biology and Living Technology for Future Textiles. Studies in Material Thinkin, Vol. 7, February, pp1-12. [Online]
Available from: http://www.materialthinking.org/papers/71 [Accessed 12/05/12].

CRAFTS COUNCIL (2011) Block Party. Contemporary craft inspired by the art of the tailor.
[WWW] Available from: http://blockparty.org.uk/ [Accessed 12/05/12].

DAMASIO, A. (2010) Self Comes to Mind Constructing the Conscious Brain. London: William Heinemann.

DEGN HANSES, A. L. and HANSEN, M. and TROLES JENSEN, H. (2011) Future Textiles Trends Inspirations Drivers&Barriers Smart textiles. [WWW] Knowledge Centre for Smart Textiles. Available from: http://viewer.zmags.com/publication/5cae4ae2#/5cae4ae2/1 [Accessed 7 April 2012].

DUNNE, A. and RABY, F. and GORMAN, M. J. (eds.) (2010) What if... Future form, future function? [Catalogue of an exhibition held at the Science Gallery, 08 October - 13 December 2009]. Dublin: Science Gallery.

E-SKIN LAB (2012) E-skin lab home page. [WWW]
Available from: http://www.e-skin.ch/start.html [Accessed 7 April 2012].

FABRICAN LTD (2012) Fabrican Ltd website. [WWW]
Available from: http://www.fabricanltd.com/history.php [Accessed 12/05/12].

GEARY, J. (2002) The body electric an anatomy of the new bionic senses. London: Weidenfeld & Nicholson.

GEERE, D. (2011) Senseg's haptic touchscreen technology lets you feel your apps. Wired online [Online] 12 December. Available from:
http://www.wired.co.uk/news/archive/2011-12/12/senseg-preview [Accessed 12/05/12].

GEERE, D. (2011) Portable bioprinters proposed to aid battlefield casualties. Wired online [Online] 21 February. Available from:
http://www.wired.co.uk/news/archive/2011-02/21/inkjet-skin [Accessed 12/05/12].

HAYLES, K. (ed.) (2004) Nanocultures implications of the new technoscience. Bristol: Intellect Books.

HARRISON, C. and TAN, D. and MORRIS, D. (2011) Skinput: Appropriating the Skin as an Interactive Canvas. Communications of the ACM, August, Vol. 54, no. 8, pp. 111-118.

HAUSER, J. (ed.) (2008) Sk-interfaces exploding borders - creating membranes in art, technology and society. Liverpool: Liverpool University Press and FACT.

LEE, S. and DU PREEZ, W. (2005) Fashioning the Future: Tomorrow's Wardrobe. London:

Thames and Hudson.

LEE, S. (2012) Biocouture or how to grow a frock. Weblog [Online]
Available from: http://biocouture.posterous.com/ [Accessed 12/05/12].

LUPTON, E. (ed.) (2002) Skin: Surface, Substrate + Design. New York:Princeton Architectural Press.

LWIN, M. (2006-7) Episkin. [WWW] Available from: http://martalwin.com/work2.html
[Accessed 12/05/12].

MARZANO, S. et al. (2000) New nomads An exploration of wearable electronics by Philips. Rotterdam: Koninklijke Philips Electronics N.v.

MCLUHAN, M. (1994) Understanding Media The Extensions of man. 2nd ed. London: MIT press.

MCQUAID, M. (2005) Extreme Textiles - designing for high performance. London: Thames & Hudson Ltd.

MCRAE, L. (2012) Lucy McRae website. [WWW] Available from: http://www.lucymcrae.net/
[Accessed 12/05/12].

MEDIA ART NET (n. d.) Jill Scott <<e-Skin >>. [WWW] Available from:
http://www.mediaartnet.org/works/e-skin/ [Accessed 12/05/12].

MIAH, A. (ed.) (2008) Human futures: art in the age of uncertainty. Liverpool: Liverpool University Press and FACT.

MOONDIAL (2012) Moondial website. [WWW] Available from:
http://moondial.com/materials/materials-library-1/ [Accessed 12/05/12].

MURA, G. (2004) Intelligent Interfaces : Transformation of Self-expression, Communication and Fashion with Wearable Technologies. In PMISEA2004 Conference.

NOBEL TEXTILES (2008) Nobel textiles - Marrying Design to Scientific Discovery. [WWW]
Available from: http://www.nobeltextiles.com/nobeltextiles_/Home.html [Accessed 12/05/12].

OXMAN, N. (2007) Digital Craft: Fabrication-Based Design in the Age of Digital Production. [pdf]
MIT Media Lab. Available from:
http://ambient.media.mit.edu/transitive/ubicomp07papers/oxman.pdf [Accessed 7 April 2012].

OXMAN, N. (2011) Neri Oxman website. [WWW]
Available from: http://web.media.mit.edu/~neri/site/index.html [Accessed 12/05/12].

PAKHCHYAN, S. (2012) Fashioningtech. Weblog [Online]
Available from: http://www.fashioningtech.com/ [Accessed 12/05/12].

POST, E. R. et al. (2000) E-broidery: Design and Fabrication of Textile-baesd Computing. IBM Systems Journal, 39, pp. 840-860.

QUINN, B. (2010) Textile futures fashion, design and technology. Oxford: Berg.

REICHLE, I. (2009) Art in the Age of Technoscience. Genetic Engineering, Robotics, and Artificial Life in Contemporary Art. Wien: Springer-Verlag.

SCHIPHROST, T. (2009) Body Matters: The Palpability of Invisible Computing. Leonardo, Vol. 42, no. 3, pp-225-230.

SCHIPHROST, T. (2012) Techla Schiphrot website. [WWW]
Available from: http://www.sfu.ca/~tschipho/ [Accessed 12/05/12].

SCHWARTZMAN, M. (2011) See yourself sensing. Redefining human perception. London: Black dog publishing.

SCIENCE DAILY (2010) Native-like Spider silk produced in Metabolically engineered bacterial.
[WWW] Available from: http://www.sciencedaily.com/releases/2010/07/100727121940.htm
[Accessed 12/05/12].

SEYMOUR, S. (2009) Fashionable technology The Intersection of Design, Fashion, Science, and Technology. Wien: Springer-Verlag.

SHANKEN, E. A. (ed.) (2003) Roy Ascott telematic embrace visionary theories of art, technology, and consciousness. London:University of California press.

SHARP, L. A. (2007) Bodies, commodities, and biotechnologies Death, Mourning, and Scientific Desire in the Realm of Human Organ Transfer. New York: Columbia University Press.

SILICON.COM (2010) Kevin Warwick, Human Cyborg. [online video] Available from:
http://www.youtube.com/watch?v=Fhu0VBCAW6k [Accessed 7 April 2012].

SKINSHIP ™ (2012) SKINSHIP ™ Collaborative practices. [WWW]
Available from: http://skinship.co.uk/ [Accessed 12/05/12].

SOLOMON, R. (n.d.) Rhian Solomon. [WWW] Available from: http://www.rhiansolomon.co.uk/
[Accessed 12/05/12].

SORREL, C. (2010) Skinput Turns Your Arm into a Touch-Screen. Wired online [Online] 3 March.
Available from:
http://www.wired.com/gadgetlab/2010/03/skinput-turns-your-arm-into-a-touch-screen/ [Accessed 12/05/12].

STELARC (1995) Extended Body:interview with Stelarc. Interviewed by ATZORI, P. and
WOOLFORD, K. [online interview] CTheory website. Available from:
http://www.ctheory.net/text_file.asp?pick=71 [Accessed 7 April 2012].

TED (2009) Janine Benyus: Biomimicry in action. [online video]. Available from:

http://www.ted.com/talks/janine_benyus_biomimicry_in_action.html [Accessed 12/05/12].

TED (2011) A primer on 3D printing [online video]. Available from: http://www.ted.com/talks/lisa_harouni_a_primer_on_3d_printing.html [Accessed 12/05/12].

TED (2012a) Lucy McRae: How can technlogy transform the body? [online video]. Available from: http://www.ted.com/talks/lucy_mcrae_how_can_technology_transform_the_human_body.html [Accessed 12/05/12].

TED (2012b) Suzanne Lee: Grow your own clothes. [online video]. Available from: http:// www.ted.com/talks/lang/en/suzanne_lee_grow_your_own_clothes.html [Accessed 12/05/12].

TEDMED (2010) Hugh Herr. [online video]. Available from: http://www.tedmed.com/videos-info?name=Hugh_Herr_at_TEDMED_2010&q=published&year=all&loader=false [Accessed 12/05/12].

V2 (2012) Is Wearable technology just bad fashion?. [WWW] V2. Available from: http://www.v2.nl/lab/blog/is-wearable-tech-just-bad-fashion [Accessed 7 April 2012].

VON GLASGOW, K. (2008) Nobel Textiles [CD-ROM] Palladio films.

WEISER, M. (1991) The Computer for the Twenty-First Century. Scientific American, September pp. 94–100, p. 94.

WEISER, M. (1994) Building Invisible Interfaces. Computer Science Lab Xerox Parc. [WWW] Xerox PARC. Available from: http://www.ubiq.com/hypertext/weiser/UIST94_4up.ps [Accessed 7 April 2012].

WEISER, M. (1996) Ubiquitous Computing. Computer Science Lab Xerox Parc. [WWW] Xerox PARC. Available from: http://sandbox.xerox.com/ubicomp/ [Accessed 7 April 2012].

WELLCOME COLLECTION (2010) Skin. Wellcome Trust [WWW] Available from: http://www.wellcomecollection.org/whats-on/exhibitions/skin.aspx [Accessed 12/05/12].

CLARKE, ZYLINSKA, J. (ed.) (2002) The Cyborg Experiments the extensions of the body in the media age. London: Continuum.