engineering proceedings

MDPI

Proceeding Paper

Second Skins: Exploring the Challenges and Opportunities for Designing Adaptable Garments Using E-Textile †

Malou Beemer [1,2,*], Christian Dils [3] and Troy Nachtigall [2,4]

1 Atelier Mlou, 5921 AV Venlo, The Netherlands
2 Wearable Data Studio, Amsterdam University of Applied Sciences, 1091 GC Amsterdam, The Netherlands
3 Institute for Reliability and Microintegration, Fraunhofer IZM, 13355 Berlin, Germany
4 Industrial Design, Eindhoven University of Technology, 5612 AZ Eindhoven, The Netherlands
* Correspondence: m.beemer@hva.nl; Tel.: +31-6-24608283
† Presented at the 4th International Conference on the Challenges, Opportunities, Innovations and Applications in Electronic Textiles, Nottingham, UK, 8–10 November 2022.

Abstract: The process of making adaptive and responsive wearables on the scale of the body has often been a process where designers use off-the-shelf parts or hand-crafted electronics to fabricate garments. However, recent research has shown the importance of emergence in the process of making. *Second Skins* is a multistakeholder exploration into the creation of those garments where the designers and engineers work together throughout the design process so that opportunities and challenges emerge with all stakeholders present in the process. This research serves as a case study into the creation of adaptive caring garments for sustainable wardrobes from a multistakeholder design team. The team created a garment that can customize the colors, patterns, structures, and other properties dynamically. A reflection on the multi-stakeholder process unpacks the process to explore the challenges and opportunities in adaptable e-textiles.

Keywords: dynamic garments; multistakeholder design; textiles; e-textiles; fabrication

check for updates

Citation: Beemer, M.; Dils, C.; Nachtigall, T. Second Skins: Exploring the Challenges and Opportunities for Designing Adaptable Garments Using E-Textile. *Eng. Proc.* **2023**, *30*, 9. https://doi.org/10.3390/engproc2023030009

Academic Editors: Steve Beeby, Kai Yang, Russel Torah and Theodore Hughes-Riley

Published: 20 January 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Recent research in computer–human interaction using research through design [1] has highlighted the importance of the ideas that emerge [2,3] as fundamental to the design considerations that come together to create the final designed item. Often in the design of dynamic garments, the stakeholders who create the electronics are separate from the stakeholders who design the garment, unless low-level prototyping is taking place [4–6]. The design process that emerges has been shown to be detrimental to the outcomes of a project, yet rarely understood or studied [7]. In this paper, we present our process of formulating and realizing a dynamic garment where technological and aesthetic design considerations are undertaken together in an emergent process. This includes the ideation of the garment, a modular design approach, and whether to visualize a reactive light as a material or the utilization of soft actuators. The authors, as makers, reflect upon the design considerations of the design process and how the final design supports and cares for the wearer, not only on a practical but also on an emotional and social level. The created prototype serves not only as a functional forerunner, but also as a showroom prototype [8], inviting dialog about the process to discuss the trajectories of the research, how it could have been undertaken, and how that informs design spaces still waiting to be explored.

2. Design Process

This research was undertaken in the context of the Re-FREAM pillar of the European STARTS Programme. The project was a collaborative and interdisciplinary research effort that included stakeholders Malou Beemer, Fraunhofer IZM, Profactor, EMPA, and Wear It Berlin [9]. The team worked for nine months to co-create the project, including three

months in the technology partners' labs. Due to the COVID-19 pandemic, the process was mostly online which may have influenced our choice of material and technique used in creating adaptive garment prototypes. Yet at the same time, it enabled new collaboration thanks to the availability of the partners.

2.1. Soft Actuators

Inspired by numerous soft actuator projects that are integrated into textile-based objects by international research teams [9–13], such as the MIT Tangible Media Group or Harvard BioDesign Lab, an intensive literature study was carried out. Several relevant scientific articles were studied, and expert interviews were conducted, including with the Fraunhofer ISC Smart Materials Centre, MIT, and the RCA Soft System Research Group. As a result, five types of actuation methods were further investigated. Shape Memory Alloys, including Nickel Titanium, were rejected because they were not innovative enough and require high power consumption. Pneumatic artificial muscles were not yet considered wearable or convenient due to the pumps and valves required. IPMCs were excluded because samples could not be produced and access to third-party material was not available. Electric fields that triggered soft actuators had a risk of injury to the human body due to high currents and voltages. A new concept, consisting of textile/polymer laminate that deforms due to different coefficients of thermal expansion, was attempted but experiments on this were not successful. An overview of the literature research is presented online [14]. These explorations brought the team to the conclusion that actuators remain overly challenging at this time. Therefore, we decided to focus on using adaptive light integration for the prototypes.

2.2. Modular Design Approach

From the early explorations, we started to explore a modular design approach, as depicted in Figure 1, that leads to new dynamics, interactions, and business models. Taking the disassembly and the end of use into consideration during the design process takes extra effort and brings a lot of challenges, from construction and connection methods to material selection and manufacturing. This was even more essential when we integrate electronics and other technologies into garments, fusing two polluting industries with different waste streams. Our design approach brought a new wave of aesthetics with it that will not only elevate garment designs on a sustainable level but can also evolve into a new language regarding the shape, structure, and overall feel. These ideas were confirmed by our findings when we were exploring the Planetary Design Tool by Max Marwede and Robin Hoske from Fraunhofer IZM [15].

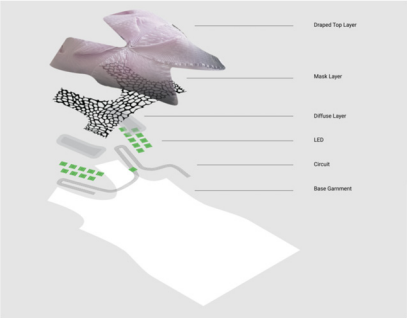


Figure 1. Overview of the garment layers devised for a modular system.

For the final prototype, we developed two undergarments with integrated modules from the Fraunhofer IZM hardware kit for e-textiles [16]. Embroidered conductor tracks, made of insulated conductive thread, connect the circuit boards with LEDs and sensors to the main control via the e-textile-bonding technique [17]. During our user test event, we learned that an input is required to be able to easily change the pre-programmed light or color patterns and to be able to switch the light on and off. This was fully in line with the

concept of adapting to how much you want to attract attention or become less noticeable. We, therefore, use the data from the Inertial Measurement Unit to implement a tap sensor, as displayed in Figure 2. A light-diffusing layer is added to create a soft skin-like light effect, which is covered by an interchangeable mask layer to create different patterns as shadow play in the garment.



Figure 2. Diffuse and mask layer with parametric patterns (**left**) and Undergarment with Embroidered conductor tracks and bonded PCBs (**right**).

2.3. Outergarments

The top garments are a fusion of old craftsmanship and new digital technologies. The ombre color effect is created with sublimation printing on laser-cut textile elements. To create a bigger diffuse effect we used a hand pleating technique to develop three-dimensional textures in the fabric, as shown in Figure 3.



Figure 3. Pleated top garment used as a dynamic projection surface.

3. Reflection and Discussion

3.1. The Gap between Research and Reality

The biggest hurdle in the project was finding a fitting technique and material that responded to the design considerations of the organic change we designed. In the areas of wearable tech, e-textiles, and soft actuators, there is a large gap between existing research and actual technology implementation. Scientific research is often done within the parameters of a lab with specific conditions, which is an achievement. However, multistakeholder exploration of a fluid translation and collaborative connection between the technology and the application is where we can make a big impact.

3.2. The Evolution of Fashion Tech

For centuries, high fashion has been accepted for its aesthetic and expressive value. Fashion tech is a cross-pollination of this field with innovative technologies. The industry of technology is function-driven and often shuns the use of new materials and technological possibilities as insufficient. Instead, the integration of tech in fashion is justified by its purpose and function, which often leads to integration regarding performance improvement,

health, comfort, and safety [18]. We take the next step and create a *caring garment* that goes beyond straightforward functionality into expression and communication. Over the past decade, we developed wearables mainly from the tech perspective with the purpose of solving practical issues. Envision a future where expression and functionality seamlessly merch together. With this project, we demonstrate how stakeholder collaboration from the beginning enables dynamics and aesthetics that go hand in hand.

3.3. The Time Frames of Wearable Innovation

Project partner Thomas Gnahm from Wear it Berlin said it best: innovation takes time [19]. Fashion tech is still in the early days, Gnahm compares it to the development of cars. Previously, the first cars looked like carriages without horses. Once we saw the potential of new materials, manufacturing and even forms of math were created to facilitate the process. Fashion tech is still in an age of experimentation and definition. Yet the knowledge required is often too complex for a single person and requires teams that, together, are good at exploration, playfulness, experimentation, and definition.

3.4. Sustainability Positioning

When we talk about sustainability, there is a lot of focus on material sourcing and manufacturing [20]. This is of course essential; however, we believe we tend to neglect the other parts of the value chain that are equally important. We can shift to using better materials and production processes, but this will remain to be an issue if we do not change our behavior and relationship towards our "properties". If we keep consuming and trashing, it will still be a linear process. If we choose to "own" a product, we also need to take responsibility and take ownership of it, by investing in a longer-term valuable relationship. This is not only up to the wearers themselves, but it is the task of designers, producers, and suppliers to guide consumers into this new headspace and is important to regard this during the design process.

3.5. Sustainability and Creativity Balance and Context

Rapid change is currently occurring in the fashion and textile industry. New EU sustainability regulations demand new design and manufacturing methods, as well as new technological developments that create new possibilities for creation. This asks for a wave of new-generation designers that are trained and literate in new digital technologies and sustainable thinking. While, at the same time, taking the heritage and knowledge of traditional textile craftsmanship into regard. Finding a healthy, productive, and innovative balance between philosophical questioning and existential pragmatic thinking within the design domain is key, keeping the bigger sustainable picture in mind while not losing the aesthetic values we create in design practice.

Author Contributions: Conceptualization, methodology, resources, M.B.; investigation, M.B., C.D.; writing—original draft preparation, writing—review and editing, M.B., T.N., C.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded via the S-T-ARTS Re-FREAM project by the European Union Horizon 2020 research and innovation program under Grant Agreement No. 825647.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Sigrid Rotzler, Pauline Stockmann, and Janin-Anne Schulze for the embroidery of the conductive patterns; Kamil Garbacz for developing and programming the hardware modules; Lars Stagun for bonding the modules onto the textile; and Martin Haubenreisser for laser cutting the designs. Marina Toeters for support and facilities at Fashion Tech Farm Eindhoven, The Netherlands. Julia van Zilt for technical support and (parametric) pattern creation.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Hauser, S.; Oogjes, D.; Wakkary, R.; Verbeek, P.P. An annotated portfolio on doing postphenomenology through research products. In Proceedings of the 2018 Designing Interactive Systems Conference, Hong Kong, China, 9–13 June 2018; pp. 459–472. [CrossRef]
2. Wakkary, R.; Maestri, L. Aspects of Everyday Design: Resourcefulness, Adaptation, and Emergence. *Int. J. Hum. Comput. Interact.* **2008**, *24*, 478–491. [CrossRef]
3. Gaver, W.W.; Krogh, P.G.; Boucher, A.; Chatting, D. Emergence as a Feature of Practice-based Design Research. In Proceedings of the 2022 ACM Designing Interactive Systems Conference: Digital Wellbeing, Virtual, 13–17 June 2022; pp. 517–526. [CrossRef]
4. Frankjaer, R.; Dalsgaard, P. Understanding Craft-Based Inquiry in HCI. In Proceedings of the 2018 on Designing Interactive Systems Conference, Hong Kong, China, 9–13 June 2018; pp. 473–484. [CrossRef]
5. Devendorf, L.; Rosner, D.K. Beyond Hybrids. In Proceedings of the 2017 Conference on Designing Interactive Systems, Edinburgh, UK, 10–14 June 2017; pp. 995–1000. [CrossRef]
6. Berzowska, J.; Kelliher, A.; Rosner, D.K.; Ratto, M.; Kite, S. Critical Materiality. In Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction, Tempe, AZ, USA, 17–20 March 2019; pp. 691–694. [CrossRef]
7. da Rocha, B.G.; Andersen, K.; Tomico, O. Portfolio of Loose Ends. In Proceedings of the 2022 ACM Designing Interactive Systems Conference: Digital Wellbeing, Virtual, 13–17 June 2022; pp. 527–540. [CrossRef]
8. Matthews, B.; Wensveen, S. Prototypes and prototyping in design research. In *Routledge Companion to Design Research*; Paul, A., Rodgers, J.Y., Eds.; Routledge: London, UK, 2014; pp. 262–276. Available online: https://www.researchgate.net/publication/270511639 (accessed on 30 June 2019).
9. Thalman, C.; Artemiadis, P. A review of soft wearable robots that provide active assistance: Trends, common actuation methods, fabrication, and applications. *Wearable Technol.* **2020**, *1*, e3. [CrossRef]
10. Li, M.; Pal, A.; Aghakhani, A.; Pena-Francesch, A.; Sitti, M. Soft actuators for real-world applications. *Nat. Rev. Mater.* **2021**, *7*, 235–249. [CrossRef] [PubMed]
11. Kilic Afsar, O.; Shtarbanov, A.; Mor, H.; Nakagaki, K.; Forman, J.; Modrei, K.; Jeong, S.H.; Hjort, K.; Höök, K.; Ishii, H. OmniFiber: Integrated Fluidic Fiber Actuators for Weaving Movement based Interactions into the Fabric of Everyday Life. In Proceedings of the 34th Annual ACM Symposium on User Interface Software and Technology, Virtual, 10–14 October 2021; pp. 1010–1026. [CrossRef]
12. Sanchez, V.; Payne, C.J.; Preston, D.J.; Alvarez, J.T.; Weaver, J.C.; Atalay, A.; Boyvat, M.; Vogt, D.M.; Wood, R.J.; Whitesides, G.M.; et al. Walsh. Smart Thermally Actuating Textiles. *Adv. Mater. Technol.* **2020**, *5*, 2000383. [CrossRef]
13. Connolly, F.; Wagner, D.A.; Walsh, C.J.; Bertoldi, K. Sew-free anisotropic textile composites for rapid design and manufacturing of soft wearable robots. *Extreme Mech. Lett.* **2019**, *27*, 52–58. [CrossRef]
14. Second Skins Research on Responsive and Adaptive Materials. Available online: https://re-fream.eu/second-skins-research-on-responsive-and-adaptive-materials/ (accessed on 12 December 2022).
15. Planetary Design Circle—A Holistic and Strategic Design Tool—Re-FREAM. Available online: https://re-fream.eu/planetary-design-circle-a-holistic-and-strategic-design-tool/ (accessed on 12 December 2022).
16. Garbacz, K.; Stagun, L.; Rotzler, S.; Semenec, M.; von Krshiwoblozki, M. Modular E-Textile Toolkit for Prototyping and Manufacturing. *Proceedings* **2021**, *68*, 5. [CrossRef]
17. von Krshiwoblozki, M.; Linz, T.; Neudeck, A.; Kallmayer, C. Electronics in Textiles-Adhesive Bonding Technology for reliably embedding Electronic Modules into Textile Circuits. *Adv. Sci. Technol.* **2012**, *85*, 1–10. [CrossRef]
18. Toeters, M. *Unfolding Fashion Tech: Pioneers of Bright Futures 2000–2020*; Onomatopee: Eindhoven, The Netherlands, 2019.
19. Gnahm, T.; Wear it GmbH, Berlin, Germany. Personal communication, 2021.
20. Eppinger, E.; Slomkowski, A.; Behrendt, T.; Rotzler, S.; Marwede, M. Design for Recycling of E-Textiles: Current Issues of Recycling of Products Combining Electronics and Textiles and Implications for a Circular Design Approach. In *Recycling—Recent Advances*; Saleh, H.M., Hassan, A.I., Eds.; IntechOpen: London, UK, 2022. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.