Body Inspired Design for Knitted Body-Protection Wearables

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DIS'18 Companion, *June 9–13, 2018, Hong Kong*

ACM ISBN 978-1-4503-5631-2/18/06.
https://doi.org/10.1145/3197391.3205425

Figure 1: The fabric tube knitted on the circular knitting machine can have a combination of different patterns and shapes.

Figure 1: Visit factory and headquarters of circular knitting machines.

Figure 3: Results workshop about knitwear where examples of body-forming knits were mapped.

Abstract
In this provocation, we aim to show that body inspired design techniques can be used to inspire the development process of advanced functional knitting technologies. We believe that approaching this area from the perspective of industrial and interaction design spheres, could potentially complement fashion and textile designers' viewpoints. We conclude that interactions with technology go beyond traditional "computer" based systems. In this case, the patterns and functionalities programmed into the material using circular knitting. This is demonstrated by reflecting on an Industrial Design educational module which focused on the design of "Body protection wearables". Students were asked to limit materials by creating designs that could be produced as one single piece, without post-production procedures. Testing their designs with full-scale prototypes at each stage of development, the students could understand potential advantages and drawbacks just by wearing them.

Author Keywords
Embodiment; Interaction Design; Body-Protection; Circular Knitting; Responsive Clothing; 3D printing

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Figure 4: Communicating the design on the arm of one of the tutors.

Figure 5: Dynamic properties of the material become apparent when manipulating the textile.

Figure 6: Using the body as a canvas for pattern design.

Introduction

Fashion and technology have intertwined for many evolutionary cycles, starting from the developments in mechanical engineering that facilitated large-scale manufacturing to the chemical and synthetical developments leading to new material opportunities [1]. More recently, electronic materials with a capability to sense their environment and respond by adapting their behavior enabled the design of responsive wearables using smart textiles [2]. In parallel, developments of advanced textile manufacturing techniques—such as 3D body-forming knitwear machinery—allows the production of almost finalized garments, which require little to no further production steps to finalize the garments [3]. Moreover, advanced knitting technology in combination with new materials enables the integration of localized functionalities within a garment on a 'stitch by stitch level', such as moisture management, compression, and abrasion resistance [4]. For example, by using areas in the garment where elastane (spandex) is inserted to create more stretchable surfaces to almost form a "second-layer" on the skin [5].

These types of new functional properties within garments, offered by both materials and developments of manufacturing technologies, forces a conceptual shift in the way garments are both designed and created. Specifically, regarding the intimate relationship between the role of the body in the interaction with these responsive interfaces. To deliver balanced outcomes in form and function, new design methodologies and material explorations are tested and developed. For example in the field of somaesthetics [6], movement-based interaction [7]-[9], the design of aesthetic experiences [10] and design for embodied soft wearables [11], [12]. Most of these methods are drawing mainly from phenomenology and have in common the appreciation for lived experience and the lived body, in accordance to the unique action possibilities of each person [13], [14].

In this provocation, we aim to show that body-based design techniques can be used to inspire the development process of advanced functional knitting technologies. We believe that approaching this area from the perspective of industrial and interaction design spheres offers an alternative practice, which could potentially complement fashion and textile designers' viewpoints. Knitted constructions provide remarkable diversity and a range of potential end products, however, currently the market is not fully able to absorb and utilize the technological advances [15]. One of the possible reasons for this problem is that the advanced knitting machines capable of producing high-value functional apparel require highly skilled programmers and designers with technical understanding. Knitwear is inherently difficult to describe, as no simple and complete notation exists. The relationship between visual appearance and structure and technical properties of a knitted fabric is subtle and complex [16]. This is an area that has been traditionally problematic within the knitting sector, understanding between technologists and designers is hindered which limits the possibility of dialogues from which design innovation can emerge [4]. Recently there has been interest from the Human-Computer Interaction (HCI) community to narrow the gap between product design and knitwear. For example, by developing a compiler that can automatically turn assemblies of high-level shape primitives and even 3D models into low-level machine instructions [17].

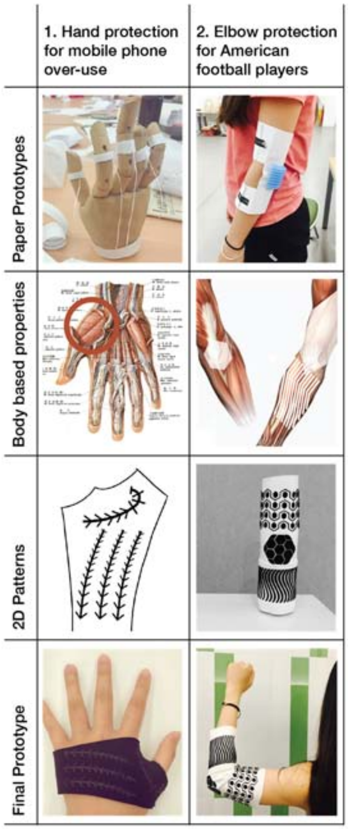

Table 1: Two of the projects developed during the module (columns), several phases in the design process (rows).

1) Hand protection accessory that would prevent repetitive movement of the thumb.

2) Elbow protection to prevent impact on the elbow while maintaining enough flexibility for the other arm movements.

Exploring Body Protection Wearables

During the Sustainable Design module Industrial Design students focused on the design of "Body protection wearables", produced on circular knitting machines. This module took place in 2017 as a collaboration between a Chinese University in Suzhou, an Italian world-leader in manufacturing of circular knitting machines in Shanghai and a textile designer who focusses on the design of body-forming knitwear. 12 Industrial Design, Year 4, undergraduate students worked individually on developing a project related to protection for a specific body part for an application of their own choice. Constraints were set based on the context of circular knitting machines [18]: all the constructions are restricted by a tubular shape (Figure 1). Variations in shape and functionality can be realized by making changes in the materials (the yarns) and structures (the specific knits) within this tube. The students were asked to limit materials use by creating designs that could be produced in one single piece from the machines, without any cut-and-sew procedures. Furthermore, reasoning about the material use (yarns and coatings) had to be provided based on the functional properties or environmental considerations.

(1) The students visited the manufacturer of circular knitting machines and attended a demonstration of programming and operations with a range of circular knitting machines (Figure 2). Also, yarn materials and samples of applications were explored. (2) A professional textile designer specialized in body-forming knitwear introduced the assignment with a 3-hours intensive workshop on knitwear design, including market analysis, concept generation, and user testing (Figure 3). (3) After identifying a type of wearable body protection to develop, the students started exploring categories of knit patterns (and yarns) associated to specific functions. (4) During weekly design critiques the students showed and demonstrated their concepts to the two tutors, first with paper models and then with roughly sewn together textile prototypes. The students were encouraged to make 1:1 functioning prototypes so that the concepts could be tried on the body from an early stage (Figure 4). (5) Tutoring session on techniques for 3D printing directly on textiles were provided. This allowed the students to explore the combination of rigid/flexible or rigid/stretchable properties on their prototypes. From this point, the students could simulate every functionality typically obtained with knitting machines in a simple way which they fully controlled at the university labs. (6) The final result of this assignment was a functional prototype of a body protection wearable accessory, scale 1:1, with functional properties related to the specific use such as partial rigidity, changes in stretchability and improved wear resistance on specific areas.

It was not viable to prototype all the students' projects with circular knitting machines because it would require too much time to program the machines. However, the prototypes simulated the intended appearance and functionality with the adoption of knitted flat fabrics, which were cut and sewn, and eventually 3D printed patterns on the fabric. The students could progress from "quick and dirty" prototypes to refined functional prototypes, learning to adjust and refine the more relevant functional parameters. In our view, the impossibility to prototype with industrial facilities hasn't limited but rather enhanced the students' freedom of exploration, and their understanding of the physical constraints and design opportunities of the circular knitting technology.

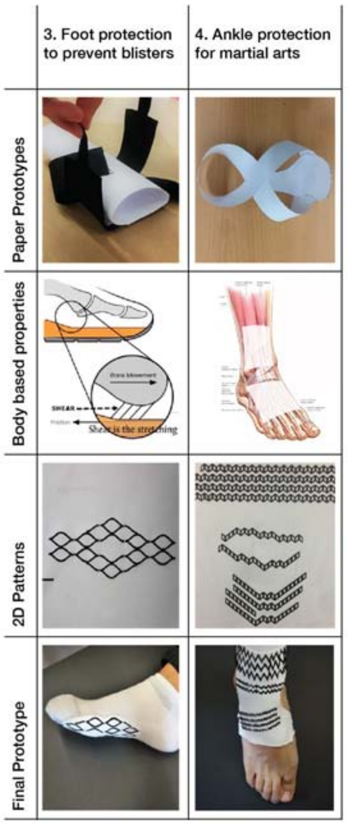

Table 2: Two of the projects developed during the module (columns), several phases in the design process (rows).

3) Foot protection with a texture for preventing blisters when wearing ballerinas.

4) Ankle protection with rigid parts on critical locations while maintaining flexibility of other parts of the foot.

Reflections and provocation

- *Advanced functional material properties are dynamic in nature and can only be evaluated by wearing it on a moving body.* Early in the process students tried to use traditional product design sketching to communicate their concepts. However, this was quickly disregarded as the creation of simple paper prototypes could offer a richer variation in a shorter time. For example, the designer of the elbow protection (column 2 in Table 1), started early in the project to combine paper with other materials to achieve and iterate on the properties.
- *Design inspiration from switching between 2D patterns and 3D tubular shapes.* Some students started with elaborate concepts early in the process. The transition from 3D (paper prototype) to 2D (pattern making) and back to 3D (3D printing) required to respect and play with the constraints of body-forming knitwear. For example, for the hand protection (column 1 in Table 1) the designer started out with a combination of many small tubes. The understanding of all the joints resulted later in an intricate pattern of rigid structures to support the joints of the whole hand.
- *Value of the first-person perspective in evaluating the qualities of the design project.* Some sections on the body should offer flexibility and comfort, such as the open section in the ankle protection project (column 2 in Table 2), while other sections require more stiffness and protective feeling. These characteristics are partly subjective and need to be evaluated continuously by the designer. The final 3D pattern printed over the stretchable textile is the result of several design attempts and subsequent empirical evaluation.
- *Using the body as a canvas by sketching in 3D.* While the students are not educated in pattern-making, they discovered that they could easily take a piece of textile, drape it on the body, and just start drawing the functionalities and patterns they were trying to explore (shown in Figure 6). A good example is the foot protection project (column 1 in Table 2). Due to the complex muscles, joints, and bones in the foot, the student made many pattern iterations on his own foot until the texture well matched the critical areas, while following the foot movements within the shoe.

Historically the design of clothing has not been considered to be part of the design of interactive systems. However, it became clear through the activities and design explorations that interaction with technology goes beyond traditional "computer" based systems. In this case, the patterns and functionalities programmed into the material using advanced manufacturing capabilities of circular knitting. This resulted in combination with specific movements of the body and the context of the user, in novel responsive properties of the clothing. The design of such properties is critical since the machine language is extremely complex and hard to program. While more refined 2D design software and even direct 3D modelling inputs to the machines are under development and will certainly facilitate the evolution of body-forming knitwear design, we believe that the body inspired design approach we are proposing may help designers to understand and play with some of the critical parameters and otherwise overspecialized technological challenges, and is worthwhile to explore further.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (NSFC, Grant No 51750110497). Many thanks for the generous support of Santoni Shanghai, and the enthusiastic participation from the students of Industrial Design module IND302.

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