Mannequette: Understanding and Enabling Collaboration and Creativity on Avant-Garde Fashion-Tech Runways

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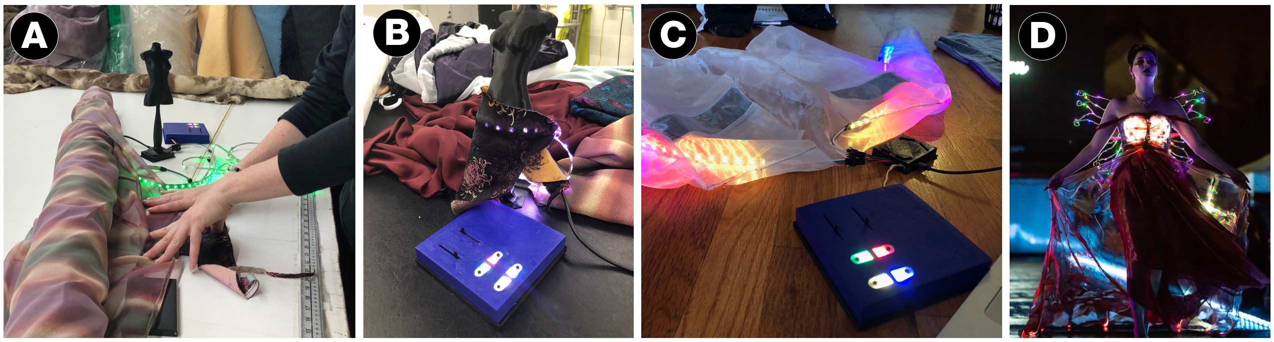

Figure 1. The different usage scenarios of Mannequette. **(a)** In-situ, iterating and deciding upon fabrics at a market; **(b)** Prototyping light (LED) patterns and sensors on a miniature dress form with fabrics by using the mixer; **(c)** Integrating a previously prototyped and now completed pattern and sensor interactions into an assembled garment; **(d)** A completed garment created using Mannequette on a runway.

ABSTRACT

Drawing upon multiple disciplines, avant-garde fashion-tech teams push the boundaries between fashion and technology. Many are well trained in envisioning aesthetic qualities of garments, but few have formal training on designing and fabricating technologies themselves. We introduce *Mannequette*, a prototyping tool for fashion-tech garments that enables teams to experiment with interactive technologies at early stages of their design processes. Mannequette provides an abstraction of light-based outputs and sensor-based inputs for garments through a DJ mixer-like interface that allows for dynamic changes and recording/playback of visual effects. The base of *Mannequette* can also be incorporated into the final garment, where it is then connected to the final components. We conducted an 8-week deployment study with eight design teams who created new garments for a runway show. Our results revealed *Mannequette* allowed teams to repeatedly consider new design and technical options early in their creative processes, and to communicate more effectively across disciplinary backgrounds.

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Fashion-tech; avant-garde; haute couture; wearables

CCS Concepts

• Human-centered computing → Interface design prototyping

INTRODUCTION

Avant-garde describes artistic, intellectual and cultural movements that are characterized by experimental, radical and unorthodox approaches [12]. The capacity in which something goes beyond the boundaries of convention through experimentation and proposes a new way in the creative arts – e.g. art, dance, fashion – is what makes it avant-garde [12]. In the fashion industry, avant-garde has impacted the way designers think and create work, especially around the form, shape and volume of outfits worn today. The fashion industry, along with avant-garde, influences culture and global trends [32], drives social and economic change, and is a fundamental component of everyday life. Today, both are rapidly being transformed with modern technological innovations – such as factory robots which handle garment construction and manufacturing processes, algorithms which predict trends in style and even VR mirrors and installations [20,33].

The expression of fashion (i.e. its *communication mediums)* can be divided into two categories: the *street* (or consumer market) and the *runway* (or catwalk) [32]. Avant-garde runways have incorporated numerous technologies (e.g. robotics, sensors, fiber optic fabrics) for several years, with designers frequently collaborating with technologists, and other disciplines, forming teams that create garments that are infused with technology. Throughout the collaboration and creation processes for a team creating avant-garde fashion-tech garment – *from sketch to runway* – designers, technologists and others, often draw upon a number of different disciplines, such as fabrication, electronics, and programming (among many others). Several tools can also be used to help novices in learning these disciplines that are essential for prototyping and creating avant-garde fashion-tech garments [1,38]. However, these tools also present numerous challenges within creative and collaborative processes of multi- disciplinary teams that create avant-garde fashion-tech garments which appear on runways. Within these teams, designers, technologists (and others) often operate with unique skill sets, knowledge, and vocabularies making collaboration sometimes difficult. Thus, the problem is that these collaborators do not have a common medium to express creative ideas, experiment with sometimes complex technology (e.g. sensors, lights, augmented reality) and communicate with one another about challenges and limitations, particularly in the early stages of constructing an avant-garde fashion-tech garment.

Our approach is to support facilitated communication and prototyping between team members (e.g. fashion designers, technologists) by the introduction of the *Mannequette* (Figure 1). Mannequette is a modular, miniaturized mannequin system, designed to help cross-disciplinary teams in prototyping and experimenting with technology – specifically lights and sensors – from the onset of the garment construction process. With Mannequette, a team can engage in low-fidelity prototyping of sensors and lighting patterns using a simple DJ-mixer like control panel, without the immediate reliance of a technologist or technical skills. A technologist can also adjust the sensors and light patterns created by a fashion designer (or other team members) with the control panel through programming, for demonstrating more complex interactions and effects. Thus, Mannequette serves as a communication medium between team members, as it can be used to create and illustrate temporal effects that may otherwise be difficult to communicate.

To evaluate how avant-garde fashion-tech teams appropriate and use Mannequette in their design process, we conducted a deployment study with Mannequette in the context of an avant-garde fashion-tech runway show. Our research questions focused on (1) *how teams would use it in their early and more tangible processes*; (2) *how teams would use it to translate effects into more concrete concepts*; (3) *how such a tool would impact the communication between cross-disciplinary team members*; and (4) *what benefits, and challenges cross-disciplinary teams would find in such a system for their processes*. Our deployment was conducted with eight teams for 8 weeks. Our findings revealed that teams found Mannequette valuable and used it as a means of facilitating and supporting communication very early in the process of constructing avant-garde fashion-tech garments. They also used it to establish new prototyping and communication routines within their team and even with those in other environments who were not formally part of building the garment. For example, we observed fashion designers using the portable version in fabric stores where with the help of store employees, they quickly iterated and decided upon fabrics for their garment based on different temporal effects and lights (in-situ) without the immediate reliance of a technologist.

In summary, our contributions are: (1) the Mannequette tool that facilitates the prototyping and collaborative processes of the design and creation of Avant-garde fashion-tech garments; (2) findings demonstrating the effectiveness of Mannequette through an 8 week long deployment study that culminated in an avant-garde fashion-tech runway show featuring garments which used Mannequette; and (3) a discussion of how avant-garde fashion-tech can inform the design of wearable (and other) toolkits.

RELATED WORK

In the context of designing and creating tools to facilitate and support the process of constructing of avant-garde (and fashion-tech) garments, we drew upon two primary research areas to inform our design: (i) fashion technology industry and research, (ii) programming tools and construction kits for wearables. We also position our contributions within the space of wearables, fashion tech and existing tools.

Fashion and Technology

The fusion of fashion and technology has transformed garment creation and fabrication processes [8,27], now making it a more critical component and influencer of the consumer wearables industry, and vice versa. One major area in fashion seeing this influence is e-textiles, which incorporate electronics that are woven into the fabric and has a number of applications [13,16,18,19,27,28]. Technologies such as 3D printing sensors, actuators and other components have also begun being incorporated into clothing [26,28,30,31] and even on the skin [11,21,22,35,36]. In this context however, several fundamental challenges still exist, such as the need for technology to be lightweight or finding sufficient and long-lasting sources of power. These challenges and the ability to solve them creatively, rely on a cross pollination of skills between design, engineering and other disciplines. In the world of avant-garde and fashion tech, the experiences and lessons learned in creating garments can lead to or inspire more innovative wearable solutions to these challenges.

In the broader context of HCI research, prior work has examined several application areas in fashion using technology, such as in-store environments [7], while other researchers have focused on the relationships between fashion and clothing [15], understanding the design of electronics with fashion lenses [14] and design principles from fashion itself [24]. Pan and Stolterman described scenarios for HCI driven by fashion from different perspectives, such external fashion concepts influencing the field, as well as fashion concepts that go in and out of fashion within the field itself [25]. Okerlund et al., ran an interdisciplinary maker fashion show at a university campus as a lens to study empowering a campus Maker community [23]. We build upon the approach of using a fashion show as the context for conducting research, as well as the work of Pan and Stolterman, but focus on the underexplored avant-garde fashion-tech area and its cross disciplinary collaborations.

Toolkits for Designing Wearables

A large number of electronics and wearable construction kits, such as the Adafruit Flora [1,39], the LilyPad [5,6] ,the BBC Micro:bit [2] and other Arduino-based electronics kits [40] have opened up a new space for children and adult hobbyists to begin exploring and building new kinds of wearables and integrate electronics into clothing. However, many of these toolkits and electronics still have high barriers of entry, requiring knowledge in areas such as electronic circuits, an understanding of lower-level digital and analog I/O (especially if sensors for interactivity are used) as well as programming. Several toolkits have been designed to overcome these issues especially with regards to programming and electronics [40]. However, only a limited subset is aimed towards avant-garde fashion-tech, and even less are appropriate for the constraints that come with designing for and building garments that are worn a runway. For example, using conductive threads to link components, a common approach for several toolkits (e.g. [5]) is not ideal due to: (i) movement of garments on a runway; (ii) the wear and tear of a garment over its lifetime as it travels to different runway shows, while also being worn by different models.

One approach to address the difficulties in programming, electronics and runway constraints is to consider tangible and modular approaches. MakerWear is an example of using a tangible and modular approach for wearables [17], similar to littleBits and others [2,3,41,42]. While MakerWear is targeted towards building wearables for children and demonstrated value in enabling children to begin working with basic programming and sensors for wearables, its focus and design is not targeted towards fashion designers, technologists (i.e. avant-garde fashion-tech teams) or the runway environment. We build upon this and prior work in tangible construction kits [1,6,17,42], where the construction experience (both user input and output) for Mannequette is tangible, serving as a means of communication, creative expression and experimentation without many barriers at the onset of constructing an avant-garde fashion-tech garment.

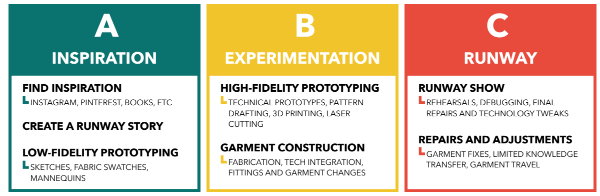

Figure 2. Our observed practices of avant-garde fashion-tech

DESIGN CONTEXT

To ground our research within the context of real-life practices of avant-garde fashion-tech runways, we collaborated with a fashion-tech collective (MakeFashion [43]) that produces multiple international avant-garde runway shows per year. We built our relationship with MakeFashion over a 2.5-year period through 7 separate runway shows in Canada, USA, Germany, Ireland and China. Each show contained 8-15 design teams, where each team created up to three avant-garde garments per runway show. Design teams were typically comprised of at least one self-identified fashion designer, and one self- titled technologist. The construction of teams (and their self-identification with titles) are specific to the context of MakeFashion; thus, the bifurcation of technologists and fashion designers does not necessarily reflect the broader community of avant-garde fashion-tech, many of whom have cross-disciplinary skills. For the purpose of this paper, we use these labels to describe and reflect the people we studied. We return to the issue of generalizing beyond this community later in our discussion.

To understand the challenges and process of avant-garde fashion-tech and runways, we embedded ourselves in three key roles for runway shows: first as a *technologist*, then as a *fashion designer,* and finally as a *producer* and *director*. Thus, the lead author used a participant observer process in different roles within this organization to understand the practical problems faced by members of each group. As a trained computer scientist, the lead author began involvement in the organization as a technologist within a design team. After three runway shows in this role, the lead author then organized a new design team, and played the role of a fashion designer on the team for another three runway shows. In total, the involvement as a technologist and designer resulted in 14 garments, and interaction with 30 other designers and technologists. Since then, the lead author has been a producer and technical director for MakeFashion, managing and meeting with teams over the course of 4 months prior to the runway show. As a consequence, the lead author has worked with over 20 teams, producing over 40 avant-garde fashion-tech garments.

Next, within the context of MakeFashion, we describe in detail, our observations of common practices in avant-garde fashion-tech garment creation.

Observed Practices of Avant-garde Fashion-Tech

Based on our observations and experiences over the 2.5-year period, we saw three distinct phases based on increasing technical complexity and involvement of a technologist. This process is briefly summarized in Figure 2, where each of the lettered phases circumscribes different processes that are commonly happening within a cross-disciplinary team that typically consists of at least one self-identified fashion designer and one self-identified technologist.

Phase A: Inspiration

Before creating a garment, a team (typically the fashion designer) explores different sources of *inspiration*—Instagram, Pinterest, magazines, pattern drafting books, music—with the goal of creating a story that describes the garment on a runway. Story plays a critical role for avant-garde garments on a runway, as it is ultimately translated into the design of the garment, the technology used to support it, the music chosen for the runway, as well as how the model walks and poses on the runway. Furthermore, while fashion has a long history and set of materials to draw upon for inspiration, avant-garde fashion-tech is a relatively newer space, thus fashion designers and teams are more limited in examples and materials they can draw upon for inspiration.

Once a concept has been settled upon, *low-fidelity experimentation* is used to explore possibilities for implementing the idea. Tangible and physical techniques are also used to prototype different elements of a garment, such as testing different fabrics and materials to understand how well lights diffuse them, color combination of fabrics and the draping of fabrics on a mannequin. Fashion designers typically create sketches for the concept of the garment, which is occasionally combined with a limited description of what is expected from technology.

This phase is typically characterized by limited involvement from a technologist, and any progress is revisited once the technologist becomes more deeply involved. In this phase, limited technical engagement creates two challenges: (i), since sketches and creative ideas are initially developed without a clear understanding of technical limitations, ideas often need to be scaled back drastically later in the design or construction process; (ii), since designers are rarely well-versed in how or what technologies could be deployed, their ability to communicate is limited, meaning communication opportunities are lost.

Phase B: Experimentation

Once a garment (story and concept) has been defined, a fashion designer and a technologist begin using *high-fidelity techniques* and technical “prototypes” are also built — often independently. Teams typically face challenges when trying to integrate these prototypes, owing to situations where intentions of the design were unclear, or limitations of the technology were not clearly communicated earlier.

Here, fashion designers develop multiple iterations and prototypes until they are satisfied with the outcome of their pattern and chosen fabrics. They begin with sketches, and draft with patterns appropriate to the design. Those with access to fabrication skills (i.e. laser cutting and 3D printing) use them to speed up or augment different parts of their pattern drafting process (e.g. using laser cutting to quickly prototype modifications to a pattern).

In parallel, technologists’ experiment with different electronics and components (e.g. motors, haptics, lights, sensors), create programs, and occasionally design new electronics entirely for a garment. For example, with a light strip, they may explore different light patterns, their timing or colors. Typically, a technologist’s role does not have a large contribution to the design itself, and thus it is extremely common for the technologist to misunderstand an idea articulated by the fashion designer. Thus, the technologist might develop the technical prototype in ways that are unexpected or unwanted by fashion designers.

Once the designer and technologist are respectively satisfied with their choices, they begin *garment construction* and integration. Teams run into significant problems in this step, many of which are due to poor communication practices, and some due to practical problems of deployment. Typically, the technology integration (i.e. microcontrollers, wiring, sensors) occurs after the garment has been constructed, which has negative consequences. For example, many teams fail to consider where sensors should be placed (or sewn into the fabric), or where (or how many) batteries must be placed on the body. This means that garments require additional work, such as constructing pockets for batteries or sensors, potentially designing new 3D printed and sewable casings for microcontrollers or building housing for extremely messy wiring. This problem is even more difficult for novice teams of fashion designers and technologists, who have limited experience designing for wearability on the runway—sometimes, their early fixes to the garment are inadequate (e.g. gluing LED pixels vs. building an LED layer), meaning they make harmful compromises to the garment itself.

Phase C: Runway

An entirely new set of challenges present themselves when the garment is worn by a model in preparation for a *runway show*. While the garment may be functional, teams can encounter problems during rehearsals. Here, practical challenges of wearability present themselves again—for instance, was the fabric chosen for the design flexible enough to accommodate the model’s walking movement or poses, is there enough slack in the wiring for electrical signals to pass through during choreographed movement (as may be required by the story), and does sweat from the model damage or cause problems for the technology used?

We frequently observed that when a garment was involved in dance or other choreography, electronics were at risk. These issues were typically uncovered during rehearsals. For example, wires may have broken or stretched underneath a casing, or the movement programmed into accelerometer to cause an effect, is too sensitive for the walk of a model. This meant that designs adjustments and technical adjustments needed to be debugged and made on the fly. This was especially challenging if the design of the garment did not account for the ability to make necessary changes when something breaks down, such as a wire or sensor. For novice teams of fashion designers and technologists, these issues were magnified because of the late integration of technology, with consequences now including the removability and reparability of the garment. Overall, many teams also do not have prior experience in understanding potential runway show issues for avant-garde fashion-tech and their solutions.

Following a runway show, a garment typically requires *repairs and adjustments* which might again require taking apart the piece. Furthermore, garments commonly travel between shows and are worn by different models, presenting additional challenges. For instance, garments often need to be put on a model in a certain way or in a certain order (e.g. some pieces have multiple layers) and transferring this knowledge to others who do have not the necessary background or experience with garments incorporating technology is difficult. Additionally, technical knowledge of avant-garde fashion-tech garments is not well maintained or documented. This becomes a problem when a garment requires repairs, and its creators have not travelled with it. This also creates several issues around communication between different groups of technical and fashion expertise and can substantially hinder the success of the garment in the highly-competitive avant-garde fashion world.

The Challenges of Avant-Garde Fashion-Tech

Traditional fashion runway shows are messy and hectic by their very nature and by combining avant-garde culture with technology to the mix, a variety of challenges have been created. We distill many of these challenges we observed previously into three themes.

Limited Technology Literacy. A wide range of technology – from sensors, to augmented reality, to artificial intelligence – is available for teams to create garments. However, because some members of the team may have limited technology awareness or skills, it is difficult for them to come up with concepts that use technology. Also, the gap in technology literacy between a designer and technologist makes it difficult for them to communicate concepts in an effective manner. For example, communicating different technical choices to a fashion designer can be difficult, particularly when they may not understand the alternatives and their implications on the design.

Inadequate Vocabulary for Creative Expression. Avant-garde fashion is an extremely expressive form, with fabrics, colors and other aspects serving as the fundamental language to tell the story of a garment. For avant-garde fashion-tech, creative expression and language comes in many forms due to technology (e.g. robotics, VR, lights, sensors). However, for fashion designers (especially those that are novice), the ability to experiment with different languages and expressions through technology is difficult, particularly when there is limited technical literacy. Designers often rely heavily on technologists to assist in creative expression (e.g. creating custom electronics or light), emphasizing the importance of facilitated communication tools. For technologists, this also means there is a lack of contribution to design choices for the garment itself, as their involvement in the construction process typically occurs much later.

Balancing Wearability and Troubleshooting. Building garments for runway conditions is difficult, particularly when garments are also worn by different models in its lifetime. This makes designing for wearability extremely important when considering the types of sensors, fabrics, lights and batteries that can be used in constructing a garment. However, a balance needs to be struck between the wearability and the ability to fix the garment, as they break down and need repair overtime. Because technology is incorporated later in the design process, these considerations are not thoroughly accounted for by the designer or technologist in the early stages, resulting in garments that are wearable but not repairable (or vice versa).

MANNEQUETTE

Currently, wearable kits support a wide range of sensors and outputs, but they do not necessarily support or properly consider the range of described activities in avant-garde fashion-tech, nor the audience: multidisciplinary teams consisting of fashion designers, technologists and others. We envisioned designing a tool built around the processes we observed while also building upon prior research [6,9,10,17]. Thus, we designed a miniature mannequin-based tool called *Mannequette*, with the name referring to mannequins (of all sizes) that fashion designers build around, combined with a marionette which is controllable by a puppeteer. Thus, Mannequette is a mannequin with a controllable piece.

Mannequette allows teams (especially fashion designers) to test, experiment and quickly iterate upon light patterns, interactions and fabric techniques (e.g. diffusion testing with light or dark fabrics) in a rapid and ad-hoc manner without technical knowledge, at the onset of the construction process. Certainly, the space of availability of technologies for creative expression in avant-garde fashion-tech is large and while examples of avant-garde fashion-tech garments do exist using different methods of expression (such as [4]), we specifically chose to focus our tool on *sensors* as the means of input, and *lights* as the primary means of output for garments. This is because in the 2.5 years of our work with MakeFashion, lights and sensors were the most common form of input and output chosen by design teams for their garments shown on their runways, due to their visual nature. Additionally, teams working with illuminated materials (and their interactions) contributed to some of the challenges we observed. Mannequette also facilitates communication and creativity between the team members through a shared and tangible medium of communication. Next, we describe our design principles for tools within the avant-garde fashion-tech space and our Mannequette system, and how it works.

Design Principles and Goals

Informed by prior informal interviews through our relationship with MakeFashion, as well as our experiences with avant-garde fashion-tech runways, and their associated technologies (including [1,5,6,39]), as well as relevant prior work (e.g., [17,29,34,37]), we synthesized the following key goals for a tool designed to facilitate communication and creativity between multi-disciplinary teams:

Leverage existing models and processes. While several toolkits for wearables exist and provide a rich number of components [2,39,42], many don't consider the creative and construction processes within avant-garde (for both designers and technologists) or runway environments. In contrast, we aim to focus our tool on leveraging specific

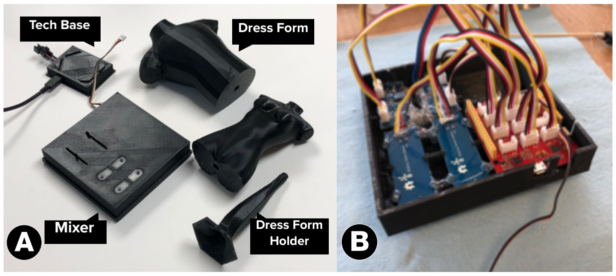

Figure 3. (a) The components of Mannequette; (b) Seeeduino based internals of the mixer control panel.

processes that exist within avant-garde and fashion – for example, a tool could be designed around a mannequin (and the practice of *maquette*, which plays a role in the areas of ideation, prototyping and discussion in art and fashion.

Tinkerability. Avant-garde fashion-tech teams rely on their combined team skills, supplemented with additional skills from others (e.g. craft, fabrication, design, programming) to create a garment. Similar to wearable toolkits for children, emphasis should be placed on allowing quick tinkering and prototyping regardless of available skills on a team [34,37], especially in the areas of lighting (LED) patterns and sensors. Tinkering occurs heavily in the early phases of the garment construction process we observed (e.g. when choosing fabrics), so tools must be able to accommodate for a wide range of tinkering tasks within the construction process.

Low floors, high ceilings, wide walls. Building upon design cues from [17,29], tools must support teams in the creation of increasingly complex designs as they gain experience. Not all avant-garde fashion-tech teams have technical experience in relation to garment construction, so accommodating differing levels of skills with multi-disciplinary teams is important in designing a tool.

Augmenting avant-garde. Avant-garde fashion-tech is heavily focused on aesthetics, story and culture, much more than traditional wearables which focus on practicality. Given the highly experimental nature of Avant-garde, we aim to support and augment as wide a variety of designs as possible that emphasize look (and occasionally simplicity) while also allowing for creative exploration and incorporation of sensors and lighting in a meaningful way.

Modularity. Modular wearable kits and systems have proven to be successful in the past [17]. For the processes we observed, where dress forms, fabrics, and tools are continually swapped, building upon these principles can provide value. Fashion designers (and technologists) should be able to quickly swap between components (i.e. sensors and lights) and interactions. Additionally, using a modular approach from a fashion and technical perspective, allows a team to collaboratively create garments in a more systematic manner (e.g. a dedicated and removeable technology layer, removeable casing for wiring). This also helps with adjustment or repairs for a garment if and when technology breaks down in the garment (e.g. loose wiring, or an electrical short), compared to unsewing or entirely redoing

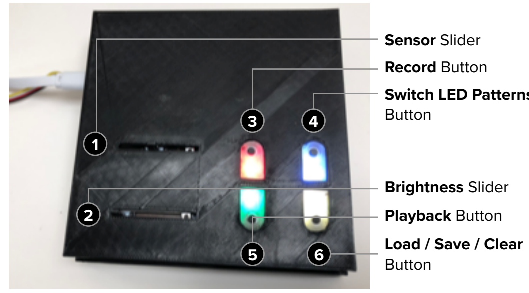

Figure 4. The mixer control panel's button configuration.

parts of a garment. Furthermore, for runway conditions when the environment is stressful for a design team, a modular system can enable quicker and easier debugging.

Mannequette System

Based upon our design goals, we created Mannequette (Figure 3a), which is comprised of three parts: (iii) a custom I²C-based DJ mixer-like interface that allows designers and technologists to dynamically prototype behaviors with (virtual) sensors and light patterns, which can then be integrated and used by a proper physical sensor in the final garment; (ii) a tech-infused base that supports a plug and play system of grove-based I²C sensors which are used to create interactive behaviors; (iii) a swappable miniaturized dress forms. The dress forms are 3D printed and scaled from open source models, and minimal modification is required for additional 3D printed dress form models.

Mixer. The *mixer control panel* for Mannequette serves as the hub for teams to communicate and quickly experiment with a number of light patterns and interactions. Inside is a Seeeduino Lotus, 4 Seeed Grove I²C-based buttons and 2 Seeed Grove I²C-based potentiometers, enclosed in a custom-designed 3D-printed case (Figure 3b). Each button and slider is mapped to specific functionality regarding a pattern and interaction: saving, recording, play back, and loads/saves/clear, as well as adjusting brightness and sensor values (Figure 4). The control panel connects to the base using an I²C cable, and a custom I²C communication protocol that was written to enable customization of patterns and interactions that are saved/loaded/cleared onto the tech base. We initially explored using a mobile application, as well as a WIFI or Bluetooth-based approaches (e.g. a mobile phone app) but we aimed to support the full set of activities described earlier, particularly runway environments where debugging is critical and Bluetooth and WIFI does not work sufficiently – due to changing or noisy environments– based on our experiences.

Tech Base and Dress Forms. The *tech base* consists of a customized ATMega32U4-based Arduino board inside a custom 3D printed casing, with a slot on its top where the *dress form holder* snaps into place, with *swappable dress forms*. The tech base supports 2 outputs for WS2812b (or similar) LED strips and 1 I²C port, which the mixer uses to program the tech base and is also used for the sensors. The information coded by the mixer (e.g. light patterns and

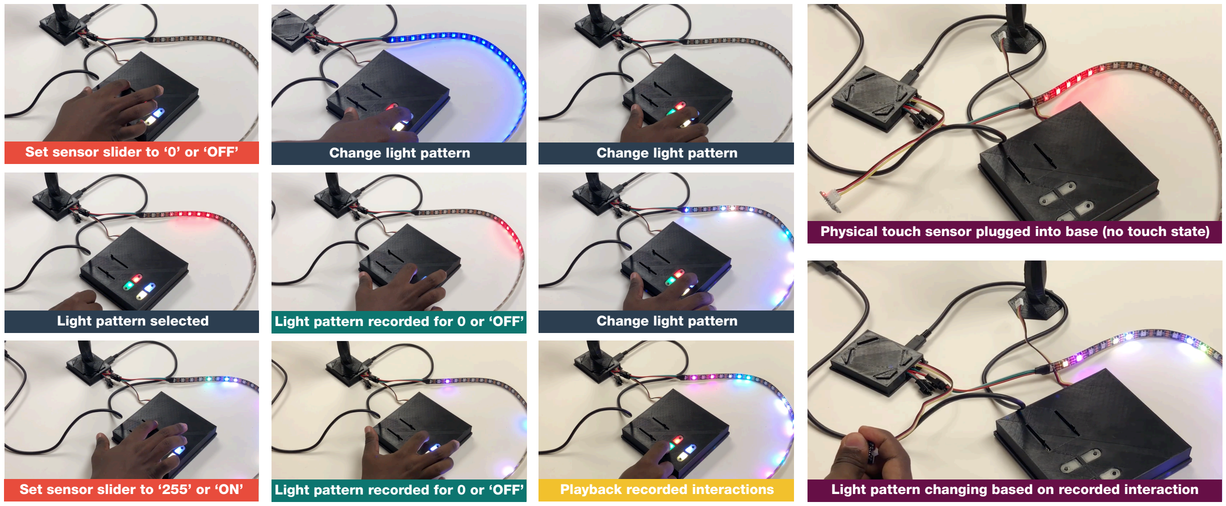

Figure 5. An example of how to prototype and finalize a touch sensor interaction with lights using Mannequette

sensors) is stored on the tech base and saved in memory, allowing for simple modifications to the light patterns or sensor values already stored. The base can also be integrated into the final garment when prototyping is completed.

Supported Sensors. Selecting and abstracting a set of sensors is crucial for enabling teams to create garments. In addition to supporting standard modules used by makers who create wearables (e.g., WS2812b LED strips for lighting), we also focused on supporting sensors that could quickly assist in interactivity for the runway environment [44]. A runway environment constrains the effectiveness of certain sensors (e.g. Light or Sound) and communication technologies (e.g. Bluetooth or WIFI) for garments because as they travel, these conditions cannot be guaranteed, nor is it guaranteed that the team handling a garment at a show will be the same as the original design team. Thus, we emphasized sensors and interactions we knew have worked previously in runway conditions, by examining 5 years' worth of garments from MakeFashion teams, as well as informal interviews. We supported: *body movement* (*proximity*, *motion*, accelerometer), *environment* (light, sound, temperature, heart) and *input* (touch, button, potentiometer and rotation) to start. Our intention was not to immediately explore all sensor possibilities, but to instead begin with those frequently used or requested by teams in MakeFashion.

Prototyping and Finalizing Interactions. Creating different sensor and light interactions generally occurs by using the mixer (see Figure 5). First, a team chooses a pre-defined light pattern from the mixer. We provided 23 pre-defined (but customizable) light patterns chosen based on our prior examination of garments created in MakeFashion. The brightness of light patterns can be adjusted by using the brightness slider on the mixer. After the team (or specifically the fashion designer) has completed experimenting with different light patterns, they configure different sensor interactions. Sensor interactions are mapped to the sensor slider where the values of sensors are mapped to a value in a range. For example, a button (or touch) interaction is mapped to *'off' (or 0)* on the slider, while *'on' (or 100)* is mapped to maximum on the slider. Similarly, for sensors such as light, sound or proximity, ranges can be created for *low*, *medium*, and *high*. For each value (or range) on the slider, an associated light pattern can be recorded and played back. If the team does not like what has been recorded, it can be cleared, or they can save their creation for further (or final) modifications on a garment. The mixer supports 5 ranges.

After a design team is satisfied with their prototyped interaction and it has been saved, the light patterns can be further customized, and a supported sensor can be used, as well as tweaked. To modify a light pattern, the tech base is plugged into a computer running Arduino, and a pre-defined region of Arduino code for its color and other properties (e.g. speed, delay, number of pixels) is modified. Each of the 23 light patterns we provide are modifiable with their own properties. Additionally, the light patterns are templated in a manner such that additional light patterns can be added to the Mannequette system by a technologist (or designer) if they chose. To use a sensor with the interaction that was recorded and saved, the associated sensor is plugged into the I²C port of the tech base. As the sensor values were mapped to the interaction slider, if the sensor values need to be tweaked (e.g. volume level or distance), a predefined section of provided Arduino code can be adjusted by a technologist (or fashion designer) to tweak these recorded values.

DEPLOYMENT STUDY

To gain insight into *how* multi-disciplinary teams consisting of (self-identified) fashion designers and technologists can use, understand and communicate with Mannequette throughout the process of creating an avant-garde fashion-tech garment, we conducted an 8-week deployment study.

Method

We recruited eight teams through our partnership with MakeFashion, which hosted an avant-garde fashion-tech runaway show in Fall 2018. Each team was self-selected and varied in experience with avant-garde fashion-tech (both

Team	Composition	Experience	Prior
1	2 designers (both female), both technologists	Limited	10
2	3 designers (all female), 0 technologists	None	4
3	2 designers (all female), 0 technologists	None	4
4	2 designers (both female), both technologists	Medium	30
5	1 designer (female), 1 technologist (male)	Limited	10
6	1 designer (male, also a technologist	Medium	10
7	1 designer (female), 0 technologists	Limited	2
8	1 designer (female), 1 technologist (male)	Strong	10

Table 1. A breakdown of each team and their experience.

garment and technical), as well as the number of (self-identified) technologists/designers for the team. We also asked each team their perceived level of expertise with technology in fashion, with respect to areas such as 3D printing, laser cutting, electronics and programming. They were asked to rank this in terms of *limited*, *medium* and *strong experience*. Table 1 describes these teams in detail.

Procedure

Over the course of the 8-week period, we engaged our design teams in bi-weekly interviews and discussions, tracking their progress and processes of constructing their garments. We also asked teams to document their creation process. When teams completed their garments and felt they were runway ready (i.e. ready to be worn, technology had been integrated/tweaked and ready for dress rehearsal), we ran a final interview. We did not track team progress beyond the first appearance of garments on the runway.

We deployed a Mannequette to each of these teams following their selection to feature in their annual runway show. We provided each team with the Mannequette system, a 5cm strip of WS2812b LEDs and one USB-C cable for the tech-base. Teams were given 10 tutorial videos for Mannequette that covered topics including assembly, how to use the mixer and how to modify pre-defined code for sensors and lights. Finally, teams were provided sensors and additional LED lighting strips by MakeFashion when needed for experimentation, as well as for their final garments.

Data and Analysis

We employed a mixed-methods approach to assess the effectiveness of Mannequette, as well as the challenges teams faced when constructing their garments using Mannequette. The first interview with design teams collected information about prior experience in avant-garde fashion-tech, and the last collected their overall experience, and how well they felt they accomplished their design (and technical) goals with Mannequette. All interviews were captured and transcribed, and we used a thematic analysis approach to analyze our interview data.

Findings

In total, the eight design teams created a total of 15 garments using Mannequette. Table 2 also provides a brief breakdown

Team	Made	Garment Description
1	2	1 used a **temperature sensor**, 1 used a **heartbeat sensor**
2	2	1 used a **motion sensor**, 1 used a **touch sensor**
3	1	1 used a **touch sensor**
4	2	2 used a **touch sensor**
5	5	3 used a **motion sensor**, 2 used **no sensor**
6	1	1 used a **proximity sensor**
7	1	1 used a **touch sensor**
8	1	1 used a **magnetic sensor**

Table 2. A breakdown of the garments made for each team.

of the garments each team constructed and the types of interactions (i.e. sensors) used in the garments.

We first frame our findings in the context of the process described earlier (and MakeFashion) and discuss themes and common patterns we observed with teams' use of the Mannequette. To illustrate these themes, we highlight individual examples, though stress that these examples are not outliers; rather, they represent common patterns of Mannequette uses including: (i) how and what types of garments were constructed; (ii) the changes in design processes for teams; and (iii) how different teams progressed in their understanding, use and modification of Mannequette.

Inspiration with Mannequette. All teams immediately began incorporating Mannequette in their design processes in a similar manner to traditional mannequins. Several teams also introduced the Mannequette into unexpected environments, such as the fabric market, which allowed them to begin thinking about the impact of the electronics on their final garment designs earlier. As articulated by a member of Team 2: *"…we took the control panel and base with us to the fabric market when we went shopping for fabrics. Since it's small, it fit in my purse, and it was useful for us to try out so many different fabrics suggested by employees in the market with different light patterns immediately. We changed our design because of this, especially the diffusing fabric!"*

This early engagement with the light patterns allowed teams to be even more active in generating and considering new ideas. For instance, we frequently observed teams (especially fashion designers) using the mixer and base to test different fabrics and materials with the provided light patterns. Similarly, because fashion designers were able to quickly iterate through fabrics and wanted to experiment with more complex light patterns at an earlier stage, technologists became involved very early in the design phase, modifying light patterns immediately. A technologist from Team 5 described: *"…in a sense, I am also a designer now too since I can see how things work with the fabrics and make suggestions and modifications right away."*

A new communication practice enabled by Mannequette was the ad hoc creation of videos to illustrate temporal effects. Fashion designers would create video recordings of patterns to communicate ideas about more complex temporal patterns to technologists. These could be visualized with the Mannequette and articulated in-place with the tool, rather than being described verbally or through paper sketches. Some teams even shared their patterns with other teams who were not using Mannequette but were also creating garments for the MakeFashion show. Thus, these videos of the Mannequette acted as inspiration for other teams. A Team 3 member: "*…I thought the pattern I made was very pretty and something that [another] team could modify, since they make interesting things and it would make theirs so much cooler."*

We also observed teams draping fabrics and components of using the dress form of the Mannequette. This allowed them to see how the fabrics would interact with sensors and LEDs early in the design process, as well as plan for the placement of components and batteries. Unlike a traditional mannequin, however, the Mannequette did not allow teams to *pin* fabrics. A designer from Team 3 stated: *"…the miniature size of the dress forms is great, but we can't pin to it directly which makes it a bit challenging sometimes."*

Experimenting with Mannequette. Prior to the introduction of Mannequette, MakeFashion teams only began experimenting with technology late in the process (i.e. distinctively after working through the inspiration phase). With Mannequette, this process changed dramatically: teams (especially fashion designers) experimented with different interaction concepts very early on in their design process, where the delineation between the inspiration and experimentation phases was considerably less distinct. This seems to have been made possible by how Mannequette makes interacting and testing ideas easier.

For example, we observed teams working collaboratively to rapidly iterate through sensor interactions on the miniature dress form (Figure 6). A fashion designer from Team 8 states: *"[the Mannequette] was great because we discussed and prototyped three different sensor ideas before settling on something much simpler. It really made our lives easier before we started doing any of the more difficult work."*

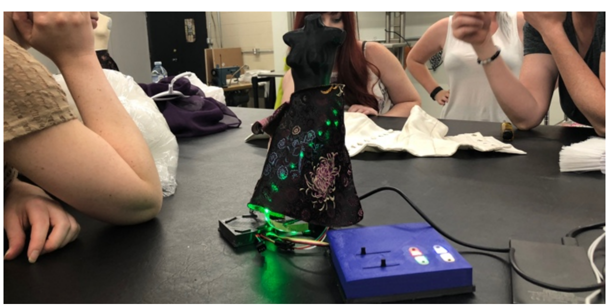

Figure 6. A design team collaborating using Mannequette.

Because teams had Mannequette, they incorporated more conceptual planning around placement of batteries, sensors and general wearability using the dress forms. Previously, teams would generally not consider these issues until quite late in the design process. Both designers from Team 3 stated: *"…we were really new to the tech side of all of this but being able to actually see and plan our piece with tech was helpful for us in designing the casing and pouches that we placed in the garment. It actually makes it so much easier for it to travel as well."*

Figure 7. A fully completed avant-garde fashion-tech garment

One of the biggest benefits of Mannequette was the impact on how and when teams integrated technology into their garments. Because several teams became increasingly technology literate for their garment earlier in the process, and collaborated with their technologist, less time was spent on integration and requirements than garments they previously made for other runway shows. As a result, teams were more satisfied overall and spent more time on the creative aspects of the garment (e.g. nicer light patterns, adding accessories like wings) (Figure 7). A more experienced technologist from Team 8 stated: *"…being able to use the base as a prototyping tool and then just putting it into the final garment was brilliant. We spent less time trying to get things to work vs. knowing it already worked, which meant we spent more time making things look even nicer on the design side… which was a refreshing experience."*

Because Mannequette gave fashion designers earlier access to technology, it impacted the traditional fashion designer vs. technologist role division. Specifically, since it simplified technical work with the sensors, some technologists with prior experience in design teams felt increasingly unclear with their role. A MakeFashion technologist on Team 7 stated: *"…sure, it's great that the designer can do way more now and it's simpler code modifications for me in the end, but then I don't really feel like I contribute as much as I am used too. If anything, my contributions are more design focused than tech focused now, which is quite interesting!"*

The Runway with Mannequette. Teams used the Mannequette (specifically the mixer) to fine-tune their garments for runway conditions, and those with more complex interactions and sensors benefited the most from having the Mannequette. For example, Team 6 (consisting of a single person who was both a designer and technologist) used a proximity sensor, where the concept was that anytime someone approached the model, their garment would react. The proxemic interactions were prototyped and constructed without a clear sense of the runway size, timing for music, and distance that the garment would need to react with another model on the runway. During the dress rehearsal, where garments were tested, this team adjusted their proxemic values ad-hoc using the Mannequette while on the runway itself. They stated: *"…tweaking the ranges to the runway [live] took a matter of minutes versus how I've done things before, where I've had to carry around a laptop, plug it into a garment and continually upload to an Arduino board and tweak. It saved me so much time."*

We also observed teams begin to introduce modular concepts into their design practices and how they fixed garments. For example, Team 3, who specifically designed a removeable technology layer, found a small short in the wiring for an LED strip. This was discovered after a model wore the garment. As they describe: *"…we're really glad we caught this at the rehearsal and that we could diagnose it so quickly and fix it the way we did. Having the mixer allowed us to isolate the problem with the help of a technologist."*

DISCUSSION

Mannequette provides one solution for some of the issues we described in the avant-garde fashion-tech process, but it is not a silver bullet. Our aim was to introduce a complementary tool within this process to aid in overcoming some key challenges in designing the garments — communication and creativity. We discuss the key takeaways when designing tools like Mannequette within the broader scope of wearables, as well as the impact of facilitated communication within avant-garde fashion-tech.

Redesigning Tools for Wearables. Future tools for designing wearables must be inclusive to other design processes and communities to enable richer explorations [38]. While several toolkits for wearable fashion exist, they seem overly focused on maker communities or education. And, although these toolkits have been wildly popular within those communities, they have had comparatively limited uptake in the avant-garde fashion-tech community, particularly because they do not consider pragmatic concerns such as weight, robustness, and power. Tools in the fashion-tech space can incorporate lessons learned from prior work in construction kits [4,5,18,25] to lower the barriers of entry into technical areas. With Mannequette, we still observed some discomfort in programming by designers, despite some becoming interested or even empowered in those activities.

Within and Beyond the Design Team. Maker communities often openly share designs and collaborate, with novices able to build from designs depending on what tools are available to them [12]. With Mannequette, we observed a small step towards this within avant-garde culture, as many designers became increasingly confident and empowered in communicating their ideas with technologists. Designers began to use their own documentation as a means of explaining and comparing temporal, and also demonstrating their work to others (through video and pictures). Several even began to share their creations and construction processes to other designs teams in MakeFashion, as well as the broader avant-garde fashion-tech community through social media (e.g. Twitter, Instagram). This is important because one of the main challenges in the observed process discussed earlier was the lack of examples for novice teams to draw upon. Furthermore, the video and photo documentation created and shared can be used as a means of documentation for the garment itself, especially useful when the garment is handled by other designers and technologists at different runway shows. Ultimately, we envision this approach of using a tool to create expressive visual artifacts, coupled with documentation processes, a valuable way to grow the avant-garde fashion-tech community, similar to [5].

LIMITATIONS AND FUTURE WORK

We discuss the limitations of our work and suggest future research directions for the avant-garde fashion-tech space.

Design Modularity — Our concept primarily focused on creativity and enabling interactions, but we did not fully explore the modular aspects of our design and its benefits in extensive detail. Furthermore, we used existing off the shelf components ([44]) which were already modular but not always ideal for garments (e.g. bulky connectors).

Team Dynamics — The lead author was deeply embedded in the MakeFashion organization, which has unique team dynamics between (self-identified) fashion designers and technologists. MakeFashion specifically creates or finds teams that contain fashion designers and technologists who create garments. Much of our observed and described processes is built upon this, and we recognize this may not be reflected in other organizations and runways. In our future work, we will explore working with other organizations that may have different team dynamics and processes.

Evaluation — While we deployed Mannequette in a real-world setting with design teams, our period of evaluation was limited. We followed the progress of teams from concept to execution, but we were not able to explore the later phases when the garment travels along with its Mannequette.

Alternative Forms— While Mannequette focused on using a whole-body mannequin for prototyping, other singular forms do exist, such as arms, or heads. Exploring these forms individual may enable designers to have even more interesting experimentations and explorations into wearable technologies. We also focused on normative binary body shapes for this initial work, but our future work will explore using different shapes of different bodies for designers.

CONCLUSION

We introduce a prototyping tool for avant-garde fashion-tech garments, designed to address the challenges that arise from designing and experimenting with interactions, sensors and outputs at the earliest stages of the design process. It does this by providing different detachable dress forms, support for different sensors, and a custom baseboard paired with a simple DJ mixer. We first embedded ourselves within a fashion-tech organization, before designing and building our tool, Mannequette. We conducted an 8-week deployment study with eight teams who designed garments, from concept to runway. Our results provide insight into how to design tools that incorporate the avant-garde process and facilitate interdisciplinary communication and creativity.

REFERENCES

[1] adafruit. 2012. Announcing the FLORA, Adafruit's wearable electronics platform and accessories. Adafruit Industries - Makers, hackers, artists, designers and engineers! Retrieved January 10, 2019 from https://blog.adafruit.com/2012/01/20/announcing-the-flora-adafruits-wearable-electronics-platform-and-accessories/

[2] Thomas Ball, Jonathan Protzenko, Judith Bishop, Michal Moskal, Jonathan de Halleux, Michael Braun, Steve Hodges, and Clare Riley. 2016. Microsoft touch develop and the BBC micro:bit. In Proceedings of the 38th International Conference on Software Engineering Companion, 637–640.

[3] Ayah Bdeir and Ted Ullrich. 2011. Electronics as material: littleBits. In Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction, 341–344.

[4] Mary Ellen Berglund, Esther Foo, Md. Tahmidul Islam Molla, Smitha Muthya Sudheendra, Crystal Compton, and Lucy E. Dunne. 2018. MAKE IT BLUE: A Controllable, Color-changing Dynamic Costume. In Proceedings of the 2018 ACM International Symposium on Wearable Computers (ISWC '18), 236–241. https://doi.org/10.1145/3267242.3267304

[5] L. Buechley and M. Eisenberg. 2008. The LilyPad Arduino: Toward Wearable Engineering for Everyone. IEEE Pervasive Computing 7, 2: 12–15. https://doi.org/10.1109/MPRV.2008.38

[6] Leah Buechley and Benjamin Mako Hill. LilyPad in the Wild: How Hardware's Long Tail is Supporting New Engineering and Design Communities. 9.

[7] Paolo Cremonesi, Antonella Di Rienzo, Franca Garzotto, Luigi Oliveto, and Pietro Piazzolla. 2016. Dynamic and Interactive Lighting for Fashion Store Windows. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, 2257–2263.

[8] Nadine Dabby, Aleksandar Aleksov, Eric Lewallen, Sasha Oster, Racquel Fygenson, Braxton Lathrop, Michael Bynum, Mezhgan Samady, Steven Klein, and Steven Girouard. 2017. A scalable process for manufacturing integrated, washable smart garments applied to heart rate monitoring. In Proceedings of the 2017 ACM International Symposium on Wearable Computers, 38–41.

[9] Laura Devendorf, Joanne Lo, Noura Howell, Jung Lin Lee, Nan-Wei Gong, M. Emre Karagozler, Shiho Fukuhara, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. "I Don't Want to Wear a Screen": Probing Perceptions of and Possibilities for Dynamic Displays on Clothing. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 6028–6039. https://doi.org/10.1145/2858036.2858192

[10] Christine Dierk, Molly Jane Pearce Nicholas, and Eric Paulos. 2018. AlterWear: Battery-Free Wearable Displays for Opportunistic Interactions. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 1–11.

[11] Christine Dierk, Tomás Vega Gálvez, and Eric Paulos. 2017. AlterNail: Ambient, Batteryless, Stateful, Dynamic Displays at Your Fingertips. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17), 6754–6759. https://doi.org/10.1145/3025453.3025924

[12] Barbara I Gongini. Avant-Garde Fashion - A Modern Definition. Retrieved January 5, 2019 from https://barbaraigongini.com/universe/blog/avant-garde-fashion-a-modern-definition/

[13] Paul Holleis, Albrecht Schmidt, Susanna Paasovaara, Arto Puikkonen, and Jonna Häkkilä. 2008. Evaluating capacitive touch input on clothes. In Proceedings of the 10th international conference on Human computer interaction with mobile devices and services, 81–90.

[14] Oskar Juhlin and Yanqing Zhang. 2011. Unpacking social interaction that make us adore: on the aesthetics of mobile phones as fashion items. In Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services, 241–250.

[15] Oskar Juhlin, Yanqing Zhang, Cristine Sundbom, and Ylva Fernaeus. 2013. Fashionable Shape Switching: Explorations in Outfit-centric Design. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13), 1353–1362. https://doi.org/10.1145/2470654.2466178

[16] Thorsten Karrer, Moritz Wittenhagen, Leonhard Lichtschlag, Florian Heller, and Jan Borchers. 2011. Pinstripe: eyes-free continuous input on interactive clothing. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1313–1322.

[17] Majeed Kazemitabaar, Jason McPeak, Alexander Jiao, Liang He, Thomas Outing, and Jon E. Froehlich. 2017. MakerWear: A Tangible Approach to Interactive Wearable Creation for Children. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, 133–145.

[18] Hyejung Kim, Yongsang Kim, Binhee Kim, and Hoi-Jun Yoo. 2009. A Wearable Fabric Computer by Planar-Fashionable Circuit Board Technique. In Proceedings of the 2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networks, 282–285.

[19] Julian Lepinski and Roel Vertegaal. 2011. Cloth displays: interacting with drapable textile screens. In

Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction, 285–288.

[20] Yejun Liu, Jia Jia, Jingtian Fu, Yihui Ma, Jie Huang, and Zijian Tong. 2016. Magic Mirror: A Virtual Fashion Consultant. In Proceedings of the 24th ACM International Conference on Multimedia (MM '16), 680–683. https://doi.org/10.1145/2964284.2970928

[21] Joanne Lo, Doris Jung Lin Lee, Nathan Wong, David Bui, and Eric Paulos. 2016. Skintillates: Designing and Creating Epidermal Interactions. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16), 853–864. https://doi.org/10.1145/2901790.2901885

[22] Aditya Shekhar Nittala, Anusha Withana, Narjes Pourjafarian, and Jürgen Steimle. 2018. Multi-Touch Skin: A Thin and Flexible Multi-Touch Sensor for On-Skin Input. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 1–12.

[23] Johanna Okerlund, Madison Dunaway, Celine Latulipe, David Wilson, and Eric Paulos. 2018. Statement Making: A Maker Fashion Show Foregrounding Feminism, Gender, and Transdisciplinarity. In Proceedings of the 2018 Designing Interactive Systems Conference, 187–199.

[24] Yue Pan and Eli Blevis. 2014. Fashion Thinking: Lessons from Fashion and Sustainable Interaction Design, Concepts and Issues. In Proceedings of the 2014 Conference on Designing Interactive Systems (DIS '14), 1005–1014. https://doi.org/10.1145/2598510.2598586

[25] Yue Pan and Erik Stolterman. 2015. What if HCI Becomes a Fashion Driven Discipline? In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, 2565–2568.

[26] Fabrizio Pece, Juan Jose Zarate, Velko Vechev, Nadine Besse, Olexandr Gudozhnik, Herbert Shea, and Otmar Hilliges. 2017. MagTics: Flexible and Thin Form Factor Magnetic Actuators for Dynamic and Wearable Haptic Feedback. In Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology, 143–154.

[27] Irene Posch and Geraldine Fitzpatrick. 2018. Integrating Textile Materials with Electronic Making: Creating New Tools and Practices. In Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, 158–165.

[28] Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, Mustafa Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. Project Jacquard: Interactive Digital Textiles at Scale. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, 4216–4227.

[29] Mitchel Resnick and Brian Silverman. 2005. Some reflections on designing construction kits for kids. In Proceedings of the 2005 conference on Interaction design and children, 117–122.

[30] Michael L. Rivera, Melissa Moukperian, Daniel Ashbrook, Jennifer Mankoff, and Scott E. Hudson. 2017. Stretching the Bounds of 3D Printing with Embedded Textiles. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, 497–508.

[31] Paula Roinesalo, Tuomas Lappalainen, Ashley Colley, and Jonna Häkkilä. 2017. Breaking of the dawn jacket: light in the Arctic Winter. In Proceedings of the 2017 ACM International Symposium on Wearable Computers, 232–237.

[32] Manuel Martínez Torán, Alicia Bonillo, and Emilio Espí. 2018. Future Trends about Fashion and Technology: A Forward Planning. 2, 2: 2.

[33] Kristen Vaccaro, Tanvi Agarwalla, Sunaya Shivakumar, and Ranjitha Kumar. 2018. Designing the Future of Personal Fashion. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18), 627:1–627:11. https://doi.org/10.1145/3173574.3174201

[34] Shirin Vossoughi and Bronwyn Bevan. 2014. Making and Tinkering: A Review of the Literature. National Research Council Committee on Out of School Time STEM: 1–55.

[35] Yanan Wang, Shijian Luo, Yujia Lu, Hebo Gong, Yexing Zhou, Shuai Liu, and Preben Hansen. 2017. AnimSkin: Fabricating Epidermis with Interactive, Functional and Aesthetic Color Animation. In Proceedings of the 2017 Conference on Designing Interactive Systems, 397–401.

[36] Martin Weigel, Aditya Shekhar Nittala, Alex Olwal, and Jürgen Steimle. 2017. SkinMarks: Enabling Interactions on Body Landmarks Using Conformal Skin Electronics. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, 3095–3105.

[37] Jennifer Wyld and Lynn D. Dierking. 2015. Design, Make, Play: Growing the Next Generation of STEM Innovators, edited by Margaret Honey and David E. Kanter. Routledge, New York, NY, USA, 2013. xvii + 238 pp. ISBN 978-0-415-53920-3. Science Education 99, 4: 779–782. https://doi.org/10.1002/sce.21163

[38] FLORA : Adafruit Industries, Unique & fun DIY electronics and kits. Retrieved January 15, 2019 from https://www.adafruit.com/flora

[39] FLORA - Wearable electronic platform: Arduino-compatible [v3] ID: 659 - $14.95 : Adafruit Industries, Unique & fun DIY electronics and kits. Retrieved

January 10, 2019 from https://www.adafruit.com/product/659

[40] Stitch Kit. Stitch Kit. Retrieved January 10, 2019 from http://www.stitchkit.io/

[41] littleBits: Award-winning electronic building blocks for creating inventions large and small. Retrieved January 10, 2019 from https://littlebits.com/

[42] CH MAKER Ed | tech | fun | edu. Retrieved January 10, 2019 from http://en.chmakered.com/

[43] MakeFashion. MakeFashion. Retrieved January 10, 2019 from http://www.makefashion.ca

[44] Grove System. Retrieved January 10, 2019 from http://wiki.seeedstudio.com/Grove_System/