Rethinking the Runway: Using Avant-Garde Fashion To Design a System for Wearables

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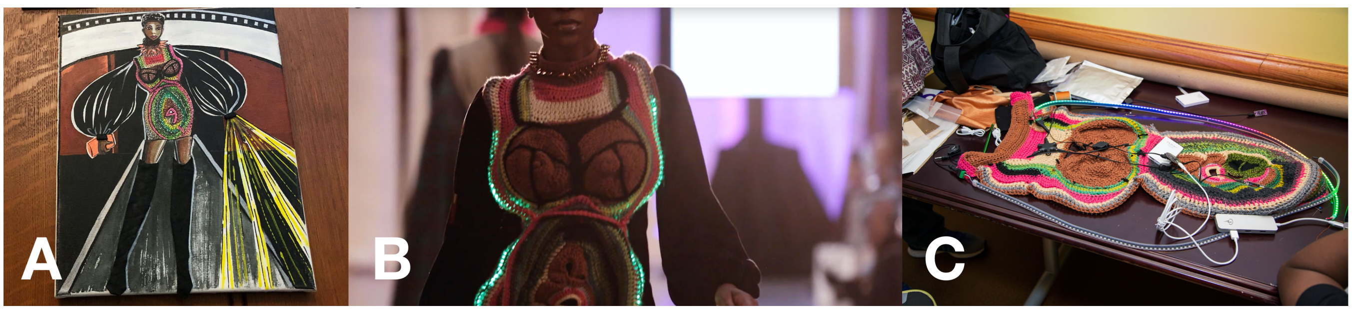


Figure 1: Going from a sketched concept to a runway garment using Brookdale. (a) A sketch of an Avant-garde fashion-tech garment concept inspired by the Herero fashion culture; (b) Physically planning and constructing the previously sketched garment concept, which uses gold-leaf smart tattoo material connected to a Tattoo Bead from to trigger lights from a central, programmable Brain that is programmed using drag-and-drop software; (c) The final garment worn at an avant-garde fashion-tech runway show in New York.

ABSTRACT

Technology has become increasingly pervasive in the creative and experimental environment of the avant-garde fashion runway, particularly in relation to its garments. However, several disciplines are often necessary when exploring technologies for the construction of expressive garments (e.g. garments that respond to their environment), creating a barrier for fashion designers that has limited their ability to leverage new technologies. To help overcome this barrier, we designed and deployed Brookdale, a prototyping system for wearable technology consisting of new plug-and-play hardware that can be programmed using drag-and-drop software. Brookdale was created using a 24-week participatory design process with 17 novice fashion-tech designers. At the end of the 24 week process, designers showcased their Brookdale-enhanced garment collections at an avant-garde fashion-tech runway show in New York City. We report on the experiences, outcomes, and lessons learned throughout this process, and describe results from interviews with the fashion-tech designers 16 weeks after the fashion show, demonstrating the lasting positive impact of Brookdale.

CCS CONCEPTS

• **Human-centered computing** → **Interactive systems and tools**.

KEYWORDS

Wearables, fashion-tech, avant-garde, haute couture, modular, hardware

CHI '21, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05…$15.00
https://doi.org/10.1145/3411764.3445643

ACM Reference Format:
Teddy Seyed, James Devine, Joe Finney, MichałMoskal, Peli de Halleux, Steve Hodges, Thomas Ball, and Asta Roseway. 2021. Rethinking the Runway: Using Avant-Garde Fashion To Design a System for Wearables. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3411764.3445643

1 INTRODUCTION

Fashion has long played a critical role in setting global trends, influencing culture, as well as significantly impacting society and economies [72]. It also enables everyday expression of identity, personal values, and even helps build social connections [20, 54, 69]. While technology and fashion have been intertwined throughout history [30, 71], advances in computational materials and miniature digital technologies have given rise to new forms of interactive digital garments and accessories - often called *wearables*. As these devices are worn on (or near) the body, their appearance and expressiveness are critical because they act as an interface between our bodies and society [11, 35, 71].

With wearable devices such as fitness bands and smart watches becoming established in the consumer marketplace, there recently has been a drive to integrate *fashion* - sometimes referred to as the aesthetic appearance of products which makes them desirable [54] - more broadly with technology, leading to the emerging field of *fashion-tech*. Its aim is to balance human-computer interactions (HCI) with a wearer's aesthetic, expressive and social needs [54, 71].

Wearables and fashion-tech have opened up the design space for fashion designers to create expressive yet fashionable garments. Available to them are new materials that can detect touch input, movement, temperature, pressure and deformation [12, 55]; different forms of embedded lighting [51]; and even smart tattoos that can be expressively matched with clothing looks [26, 36, 37]. Unfortunately, many fashion designers are inexperienced in the use of such technologies. We define inexperienced fashion-tech designers (or novices) as those who are non-experts in incorporating new computational materials or technologies into garments, regardless of their experience in fashion design. These novices don't know how to go about creating an interactive garment [10, 71]; they don't have a good feel for what's possible technically, or how to go about building what they believe to be possible. This in turn, confines the creative process. Gaining the necessary experience involves hands-on *experimentation* and iteration.

The *avant-garde runway* is one area where fashion designers are encouraged to innovate and experiment with different artistic, cultural and expressive approaches to designing and creating garments [31, 67]. What makes a garment avant-garde is its capacity to go beyond conventional boundaries and propose novel ideas about fashion (amongst other areas), such as form, shape, and function [31]. Given its inherent experimental nature, avant-garde fashion-tech designers and runways have created or featured garments incorporating different technologies for expression, such as CO_2 sensors to detect pollution around the wearer [2], servo motors to change the shape and function of a garment depending on the time of day or social situation [3] or projection-mapping to visually display tweets onto a garment [68]. Avant-garde is important in the context of wearables, because it serves as a practical place of experimentation and exploration that can lead to more practical wearables and garments that incorporate various technologies [33].

To aid novices in explorations with wearables and fashion-tech, a number of different tools and techniques have been created to assist in learning different types of skills for creating fashion-tech garments, such as e-sewing tutorials [45], simplified electronics [15], virtual reality prototyping [75], and even modified knitting machines [52]. However, building upon the thinking of fashion driving HCI by Pan and Stolterman [54] and focusing specifically on avant-garde cultures and experimentation, it is clear that many of these tools and garments present additional challenges for inexperienced fashion designers in the context of avant-garde fashion-tech runways [67].

One key challenge is that a multidisciplinary skillset (e.g. combining electrical engineering, computer science and design, among several others) is often required to prototype avant-garde fashion-tech garments, thus limiting the ability of novices to participate, innovate and learn. Ultimately, novices can learn a lot from overcoming the challenges of creating wearables and fashion-tech garments through avant-garde [56, 64].

In this paper, we detail our approach to simplifying some of the technical and design challenges that novice fashion-tech designers face in the experimentation and creation of expressive avant-garde fashion-tech garments, and the runway environments in which they may appear. *Brookdale* consists of a set of new modular, plug and play hardware components that are programmable using a web-based block programming environment. During a participatory design process that was 24-weeks total, we conceived, developed and deployed Brookdale with 17 novice fashion-tech designers, who ultimately used the system to design and construct avant-garde fashion-tech garments that integrated dynamic lighting, movement sensing, capacitive materials (or smart tattoos) and even projectors, that were featured as part of a large avant-garde fashion-tech runway show in Brooklyn, New York (Figure 1). 16 weeks after the show, we then followed up with the fashion designers and found that Brookdale had a positive influence on their careers and community. In summary, our contributions are:

- Brookdale, a novel system for creating avant-garde fashion-tech garments using custom plug-and-play hardware and protocols to assist with different types of technical construction, along with drag and drop software for easier programming of functionality and expression;
- Experiences, outcomes and lessons learned from a 24-week participatory design process of creating and deploying Brookdale for a large avant-garde fashion-tech runway show in New York City, where 17 designers with no prior fashion-tech experience integrated Brookdale into one or more of the garments in their runway collections;
- Insights into how the future directions of some of the 17 designers were influenced after their experiences and introduction to fashion-tech through Brookdale, and reflections on future prototyping tools targeted at avant-garde and the broader space of wearables.

2 RELATED WORK

To place our contributions in context, we briefly discuss relevant background and prior work in fashion-tech and expression, how novice fashion designers learn, and toolkits for wearables.

2.1 Fashion Technology and Expression

In fashion-tech, *expression* can be defined as the product of all the formal decisions a designer makes and how the resulting artifact (garment) presents itself to people, as well as the message it conveys [33]. Computational expression emphasizes how technology can be used for expressive means [29]. For fashion-tech designers, the avant-garde runway is a place for experimentation and expression. The space of technologies for designers to utilize is large, as demonstrated by notable designers such as Iris Van Herpen and Anouk Wipprecht, who used 3D printing, fabrication techniques and servo motors that move a garment, [6, 18] and Hussien Chalayan [60] who created garments that detect and express emotion, embed several hundred embroidered LEDs to create a "video dress", and even motors and wires to make parts of a garment move [73]. Similarily, Ying Gao uses different mechanisms of environment, proximity and other aspects to create robotic garments [28].

In the broad context of fashion, expression is not only confined to garments and accessories; for example, smart tattoos and other methods of skin-based manipulation are an area of fast growing research. Duoskin is a type of smart tattoo that enables users to rapidly prototype different types of interactions (touch input, displaying output) and create tattoo-based systems, such as a music controller [36]. Nittala et al. explored an overlay approach for providing input on skin alongside a design tool for custom shapes and sizes [49]. Other work has explored similar avenues [23, 43, 77, 79].

For many avant-garde garments, an experienced fashion-tech designer takes several months to go from sketch to runway, sometimes working with multi-disciplinary teams [67]. As no two such garments are ever truly alike, many concepts are one-off (or couture) pieces, despite the use of common technologies such as lighting, movement, smart tattoos and other capacitive materials [67]. Thus, we decided to use components that experienced fashion-tech designers have used previously for their expressive garments, such as servo motors and common LED light strips, in our platform. We also chose to use material and techniques from Duoskin's [36] for integrating capacitive interactions and smart tattoos. Finally, as little work has focused on using a runway (and its associated fashion show) as the context for research [50, 67], we used it as the backdrop for designing Brookdale, following a fashion-focused HCI approach described by Pan and Stolerman [53]. While their approach focuses on thinking about what HCI would be like when driven by fashion – based on how fashion concepts can affect what occurs in HCI – we instead focused more on the avant-garde culture around experimentation and designing for a system that incorporates some of the aforementioned technologies into fashion.

2.2 Novices and Wearable Design

Prior work has demonstrated that gaining fluency in computational expression is difficult because of the multidisciplinary skills required [29, 46]. For example, Lundgren et al. found that students lacking programming skills found it difficult to implement working prototypes as part of their design processes. Vallgårda and Fernaues showed that hands-on exploration with sensors and actuators by designers, to learn how to corporate interactivity into their designs, was effective [74]. Mannequette followed a similar approach with a miniature tech-mannequin that encouraged early use of technology and positively affected the design processes of novices [67].

Guiding inexperienced fashion designers through the fashion-tech design process using tools/systems is a major area of research. For textiles, which is the dominant design material for fashion designers [44], researchers have created new techniques that involve embroidery [57], quilting with snap-on components [16], stretchable smart fabrics [76], and conductive yarns with embroidered electrical interconnects [42]. The physical tools of fashion designers have also been modified, as in AdaCAD which allows for the weaving of structures and circuitry in smart textiles [27]. Sketch&Stitch from Hamdan et al. is an interactive embroidery system that allows designers and novices to use traditional crafting processes to create smart textiles [34]. Tutorials have also been provided to teach fashion designers how to sew electronics into fabrics [45].

We build upon several of the aforementioned approaches, but we also strongly considered the design constraints of the avant-garde runway, and how garments and their associated technologies need to function under its conditions. For example, we did not initially focus on using e-textiles for because little work has examined the runway environment for e-textile based garments, where they can be affected by movement on a runway, wear and tear of travel, and multiple wearers [67]. Instead, similar to [45], we focused on providing a simple prototyping tool that could be used throughout the design process, with electronic components whose functionality was clear and could be sewn onto textiles.

2.3 Toolkits for Wearables

Construction-based toolkits for wearables that are designed for novices often include simple components that are combined together to form more complex functionality. One of the earliest examples of such a toolkit, is the Lilypad [15, 17], which enabled hobbyists of all ages to integrate electronics into wearables and clothing. Similarly, MakerWear and MakerShoe from Kazemitabaar et al. provide a modular approach to wearable construction for novices [38, 39]. Moving beyond research, the Adafruit FLORA [5] is a commercial wearable construction toolkit focused on lowering the barrier of entry. It uses custom electronics that can be sewn onto garments, but is not focused on e-textile based-construction like Teeboard [47], I*CATch [48] or Post et al., who created electronic embroidery to enable e-textiles [58]. Many of these toolkits and approaches still present challenges for avant-garde fashion-designers—there is still a need to have a basic understanding of electronics and the ability to write in text-based programming languages. Furthermore, a limited amount of these toolkits have been designed for or evaluated with avant-garde fashion designers, and the runway still presents a challenge for proper deployment for many of these toolkits and approaches [15, 67].

Our approach to address difficulties in programming and electronics construction, while also considering the avant-garde runway environment, was to build upon (1) modular approaches with

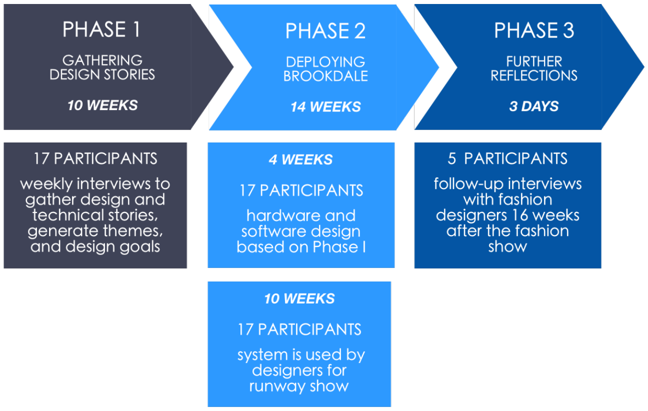


Figure 2: A visual description of the overall timeline and phases for the methodology used for Brookdale.

electronics [9, 70] and (2) block-based programming [62]. Modular electronics and block-based programming has demonstrating significant value in enabling children to program sensors for wearable, with positive learning effects [8, 22, 38]. For Brookdale , we focused on combining these approaches into a deployable system that novices could use for garments on runways, while also being as creatively expressive as possible.

3 DESIGN CONTEXT AND METHODOLOGY

To ground our research in the context of fashion designers and their real-world practices, we collaborated with a fashion academy based in Brooklyn, New York. Every year, the fashion academy hosts a program where they provide a cohort of upcoming designers an opportunity to receive fashion and design mentoring (among other areas) in an effort to showcase their skills to the global fashion community. As part of their participation in the program, each designer is asked to create a number of garments (called a *collection*) that follow a specific theme, which are then showcased on a runway at the end of the program.

The theme of the show was centered around the fashion culture of the Herero women of Namibia, which served as a learning exercise for the designers and the wider Brooklyn community. As part of their collections, the fashion designers were also required to create avant-garde fashion-tech garments that were centered around this theme, through personal reflections and background research, and ultimately expression. No designers were specifically of Herero heritage, nor was anyone of Herero heritage involved throughout any phases of this work.

Using a similar HCI approach driven by fashion [53] – but instead focusing on the subset of avant-garde fashion – our aim was to design a deployable system for prototyping in avant-garde fashion-tech, by closely working alongside experienced fashion designers who had limited (or no) skills with many of the computational materials and technologies previously discussed. We use the label "novices" to reflect the skill-sets of the designers we studied, but also recognize that this does not necessarily reflect the broader community of fashion-tech designers, many of whom have cross-disciplinary skills.

We followed a participatory design process with three phases throughout the creation of Brookdale [19, 65] (see Figure 2 for more details). Phase One consisted of weekly interviews over a 10 week period, followed by Phase Two, where we spent 14 weeks (total) embedding ourselves as technologists in the design and construction processes of the fashion-designers. We did this by taking part in weekly workshops, both virtually and in-person. Throughout these two phases, we designed and deployed a variety of hardware through close interaction with the fashion-designers. Using this hardware, fashion designers physically created garments that integrated dynamic lighting, movement sensing, smart interactive tattoos (and capacitive materials), as well as projectors that appeared on the runway of a New York fashion show. Finally, for Phase Three, we conducted follow-up interviews with 5 of the fashion designers, 16 weeks after the runway show, to understand if and how their future directions had changed after their introduction to fashion-tech and Brookdale. In total, our process lasted 40 weeks.

4 PHASE I: GATHERING DESIGN STORIES

To gain insight into processes of novice fashion-tech designers, inspire and inform them about computational materials that could be used, as well as to determine the design and technical stories they were attempting to convey on a runway, we conducted 10 weeks of semi-structured interviews.

4.1 Method and Procedure

Working alongside the Brooklyn Fashion Academy (BFA) program in New York, we recruited 17 fashion designers (3 male, 14 female), whose ages ranged from 24 to 73. As part of this program, the BFA promoted their program with potential participants knowing there would be a technology aspect to the program, unlike prior years. Participants were invited to apply with design concepts – without any expectations regarding technical expertise or background – which were judged by a panel of experienced fashion-designers. The 17 fashion designers selected for the BFA program had no prior experience in creating fashion-tech garments of any kind, but their experience levels varied with regards to fashion (3-32 years).

Over the course of the 10 weeks, we engaged our fashion designers in weekly semi-structured interviews and discussions. For the first two weeks, our interviews and discussions focused on their current practices and backgrounds, as well as their broad perspectives on technology and fashion. For the next four weeks, we then used our interviews and discussions to introduce them to several different design concepts that we collected from popular fashion-tech designers (e.g. Iris Van Herpen [6]), as well as different technologies that could potentially be used on a runway (previously described in related work). We used these examples as a means of facilitating the inspiration process for avant-garde fashion-tech [67], similar to how fashion designers already collect or create materials for inspiration (e.g. fabric swatches, Pinterest boards, graphics) while also gathering insights from fashion designers as to how prior work could be used on runways. They also sketched various garment concepts during these four weeks. Lastly, we then used another four weeks of interviews and discussions to help designers iterate on fabrics, construction strategies, technical ideas, and appropriate technologies for expression.

Designer #	Proposed Input	Proposed Output
1	Motion	Light
2	Smart Tattoo	Light, Movement (motor)
3	Light sensor, Motion	Light
4	Motion	Light
5	Light sensor, Color sensor	Projection (on fabric), Light
6	Motion	Light
7	Motion	Light
8	Smart Tattoo	Movement (motor)
9	Smart Tattoo	Movement (motor)
10	Smart Tattoo	Light
11	Smart Tattoo, Proximity sensor	Light
12	Smart Tattoo, Environment sensor	Light
13	Motion	Light, Movement (motor)
14	Motion, Environment sensor	Light
15	Motion	Light
16	Motion	Light
17	Motion	Light

Table 1: A summary of proposed input and output mechanisms from each of the fashion designers, based on their design stories.

4.2 Data and Analysis

Throughout our interviews, we captured and transcribed interview and discussion data, which we then used for thematic analysis to generate findings [13]. One author anonymized all data using pseudonyms of participants, and performed open coding on 4 complete sets of interviews from the participants. Next, a second author received the transcribed interview data and codes separately, and proceeded to re-code the data. Over the course of several weeks, and meetings, the entire research team iterated upon the interviews and codes, ultimately agreeing upon the themes described below (similar to [14]). These findings later served as a guide to the design of Brookdale.

4.3 Findings

In total, the 17 designers created 19 fashion-tech garment concepts using different forms of input and output technologies for expression (see Table 1 and Figure 3). We frame our findings in the context of our process described earlier, and discuss themes and patterns that occurred. While we illustrate individual examples, we stress these themes were common amongst all designers.

T1 — Cultural Reflections, Personal Lenses. Given the theme of the show and the history of the Herero women, many of the designers used some of our initial interviews and discussions to reflect on difficult topics (e.g. genocide) before creating concepts. As one designer (D1) noted *"...I really felt the tears of the women, the more I learned. I'll somehow incorporate this into my design concepts."* Some designers even drew upon the fabrics they used or had saved. One designer (D1) used a fabric they had kept for several years, stating *"this strange fabric is very special to me, as I found it while I was travelling....I kept it for all these years and felt now is the time to use it to express the important theme of the show."*

Interestingly, many of the designers also viewed using technology as an expressive lens to (D6) *"travel between the past and the future, and explore what the Herero from the past, would look like and the statement they would make in the 21st century."* Another designer (D7) also used the difficult topic as a source of pride *"...given my background and heritage, I actually want to send a hopeful and bold message on the runway for the Herero women, and I'll use my models' walk to do so."* Ultimately, all 17 designers used the show theme as a lens to express their own deeply personal stories.

T2 — Designing With (and Without) Technology. One of the main challenges designers faced when iterating on their design concepts was their lack of access and unfamiliarity with technology such as sensors, or how to approach challenges like making a garment move, as part of their design and ideation processes. One designer even mentioned (D3) *"I use a lot of patterns for how I design, and I modify them or I mix and match them...I have no clue at all if things you've shown me or I've found have patterns with tech or not."* Another noted that (D4) *"...even when I look at a lot of these electronics, they don't visually tell me what they do and there's so many different sizes and shapes of things, I don't know what is best to use (without help)."*

Although we did introduce designers to many different concepts and technologies as part of our interviews and discussions, one challenge they needed to overcome for several weeks before making progress on their design concepts, was incorporating more technology abstraction in their design processes. This is best described by D11 who stated *"I really go into fabric stores, feel out my fabrics,*

Figure 3: Some of the concepts created by designers. (a) Using a proximity trigger to hide emotions on the face of the wearer, with light output serving as a visual output of the emotion; (b) Using motors to move parts of a shoulder, to represent strength and unity; (c) Using capacitive materials to trigger lighting, representing agriculture of the Herero; (d) Using color from a visual projection onto fabric, to display images and video, as well as light output.

and can visualize how things work when I'm in the moment...but the tech side has made me think about this much differently as I can't really touch it, and it doesn't work for me that way yet." All 17 designers elucidated this specific challenge between designing with and without technology.

T3 — Balancing Design Freedom with Choice (and Constraint). Following the introduction of different technical concepts (e.g. 3D printing) to designers, it became apparent that some were overwhelmed with the amount of choices available, as well as technical constraints, with one designer (D9) mentioning *"I get it with fashion, but what I potentially could do with technology feels like I need to learn an alien language."*

Despite eventually overcoming the breadth of expressive technical choices, the fashion designers were also concerned that making technical choices would later significantly impact the freedom for their concepts. This is because many were used to having their designs or expressive concepts change continuously or evolve, sometimes moments before appearing on a runway. For example, one designer (D16) noted *"I'm a bit scared of choosing something for tech now because what if I want to change it later or I feel like something doesn't work? It's easy unsewing or adjusting things or changing a design on the fashion side...but I don't know if can really work that way with the tech side."* Freedom also meant the ability to fix things, and given that the fashion designers did not have technical experience, they were also considering how to ensure their garments could be fixed easily. One designer commented (D8) *"I'm not even really sure how we go about fixing something technical if it doesn't work...it's not really like fashion."*

One key aspect that continually occurred was the fashion designers were continuously concerned about feasibility of their designs, with one (D7) noting *"I have some crazy ideas around wings flapping or the shoulders transforming the dress, but I'm not sure if I can actually do this myself"*. We did not impose any technical limitations in their iterative processes for their concepts. In total, 14 of the 17 designers synthesized this theme throughout their interviews.

T4 — The Fear of Programming. Towards the final weeks of our interviews and discussions, we also introduced some of the programming languages and concepts that could be required – such as sample Arduino code to make a garment move using servo motors – and all 17 designers were apprehensive about programming their concepts, despite some knowing their designs and forms of expression were complicated (e.g. incorporating both precise garment movement alongside touch input). One designer (D7) noted *"I don't mind learning programming....I probably should since everything is tech now, but doing it now will take away from what I'm good at, and I don't want to do that right now."*

For nearly two weeks, designers felt intimidated knowing that programming might be necessary to complete a fashion-tech garment. We alleviated these concerns by showing them other approaches for how a garment could be programmed for expressive output (e.g. block-based programming) which helped in overcoming these concerns. One designer noted (D17) *"I think my tech is pretty simple...I use a tattoo to trigger a pattern [of lights], and having all this code for something that I think is simple doesn't make sense. If it was much more visual, it would be easier for us to experiment with things."*

5 DESIGN GOALS

Building on our prior experiences with avant-garde fashion-tech runways as well as relevant prior work [22, 38, 63, 67], we used the themes derived from our participatory design process described earlier to synthesize the following key design goals for Brookdale.

- G1 ***Easy to Use*** – Our system for novice fashion-tech designers needs to be easy to use in several disparate areas, which includes: ease of physical design, construction and integration, simplicity of configuration and programming, ease of operation, and even availability of components used (T2, T3, T4).
- G2 ***Flexible and Extensible*** – Given the large number of possible options for expression using input and output, Brookdale needs to be flexible in how it enables a wide variety of different effects and aesthetics, while also making it easier to add more mechanisms as needed as a design changes (T1,T2,T3).

G3 ***Robust and Resilient*** – During prototyping and experimentation, it is important to have a system that doesn't break down due to issues such as loose wiring, and most importantly, can handle the conditions of the runway environment (T2, T3).

G4 ***Supporting Invisibility*** – It's important to design our system (especially hardware components) in a manner that doesn't dominate or overwhelm the concepts of designers. As a result, the implementation details should blend into the background (e.g. be sewn) so components like wires and batteries can be suitably discreet alongside our hardware (T2).

G5 ***Physical Commonality*** – It is important to provide a system and components that feel like they fit in a designer's toolbox. This means that much like scissors, threads, mannequins and other physical tools for fashion designers, our system (especially physically) needs to visually describe function, while also not requiring extensive knowledge to understand or remember what it does (T2).

6 THE BROOKDALE WEARABLES SYSTEM

Following the interviews and discussions of phase one, we embedded ourselves as technologists with the fashion designers for a total of 14 weeks, to assist with the technical aspects of avant-garde garment construction, and provide guidance as needed. We used this role, along with our previously described design goals, as a means of iterating upon different system concepts, hardware designs, component choices, and interfaces before creating Brookdale. This also enabled us to uniquely design Brookdale for the range of activities that fashion designers undertake when creating avant-garde fashion-tech garments, as well as for runway environments [67].

As a result, we developed a system for prototyping wearables – called *Brookdale* – that consists of a combination of custom, plug-and-play, modular hardware that can be programmed in a web-based, drag-and-drop programming environment. It enables designers to quickly experiment and iterate upon different expressive fashion-tech concepts using several forms of input and output (e.g. smart tattoos, light, environment, actuators). Ultimately, it allows them to create simple, yet powerful demonstrations of fashion-tech. As the space of technologies for creative expression is large, we did not focus on implementing every possible form of sensors or technologies. Instead, we implemented those we derived from the design stories in Phase One (see Table 2) and focused on the overall experience for the fashion designers using the system. This means that we interacted with the fashion designers frequently throughout the development of both the hardware and the software for Brookdale . First, we describe how the Brookdale system works, and the specific design and technical choices that were made as part of our participatory design process over a 4 week period, before we later describe the 10 week deployment process.

6.1 Brookdale Hardware

The hardware for the Brookdale system consists of custom boards that provide input and output capabilities (called *Beads*), as well as a custom board for controlling input and output (called a *Brain*). Table 2 provides a summary of all the hardware used in the Brookdale project, along with the frequency of use by designers in their final garments.

For the Beads, we iterated on a number of different shapes with our fashion designers (e.g. circular, rectangular, rounded), but eventually chose a standard rectangular shape for all Beads. This was based on input from the fashion designers and how they envisaged placing electronics on a garment (after being shown several different methods), as well as common functional apparel design patterns and the abstracted cylindrical shapes that comprise the human body ([32, 78, 80]). We also made the Beads as small as possible (40.50mm x 15.70mm x 6mm) so fashion designers could hide them in the seams and hems of garments, and color-coded them to make it simpler to identify functionality (G1, G4, G5).

In total, we created six input Beads with capabilities like light, proximity, colour, touch and environmental sensing (those previously described in Table 1). For output, we created a *Motor* bead with a PCA9632 PWM driver that can drive up to four servo motors at a time. We also modified existing LED WS2812B light strips for use with the Brookdale hardware. Each input sensor is connected to an ATSAMD21G18 processor over I2C, with output controllers driven directly by GPIO. All beads also have a 3.5mm jack connector for use with a single-wire wire protocol called JACDAC [1, 21]. JACDAC is used for all communication between Beads and Brain. Due to our standardized PCB design with the ATSAMD21G18, it is also possible to add additional I2C sensors as needed (G2).

For uniformity, the Brain also uses an ATSAMD21G18 microcontroller, but unlike the Beads, it is circular in shape (radius 22.50mm x 6mm height). The Brain also features seven 3.5mm jack connectors, six of which are used as dedicated light output connectors for the specially modified LED strips. Only one (middle) is used for communication between the Beads and the Brain via JACDAC. Its circular shape and multi-connector design makes it easy to remember that the Brain serves as a connector hub, similar to the already circular multi-way headphone splitters. Sticking to wired communication, as opposed to wireless, was a conscious decision, as prior research conducted in an avant-garde runway setting suggest runway environments are especially noisy, making wireless communication extremely unreliable [67].

The Beads and Brain can be connected to each other via standard 3.5mm audio cables, either directly or through commonly found

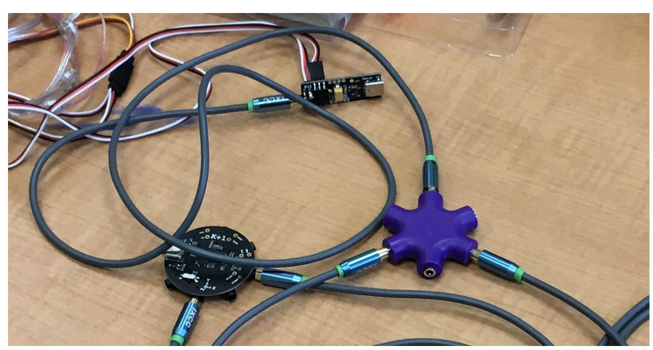


Figure 4: A Brain connected to a Motor Bead through a standard multi-way headphone splitter and audio cables.

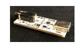
Bead Name	Description	Frequency of use	Image
Brain	6 x 3.5mm jack connectors for light output 1 x JACDAC 3.5mm jack connector	17	
Tattoo	6 x capacitive touch pins 1 x JACDAC 3.5mm jack connector	5	
Light	1 x TLS2591 light sensor 1 x JACDAC 3.5mm jack connector	1	
Color	1 x TCS34725 RGB color sensor 1 x JACDAC 3.5mm jack connector	1	
Environment	1 x BMP280 environmental sensor 1 x JACDAC 3.5mm jack connector	0	
Motion	1 x LIS3DH accelerometer 1 x JACDAC 3.5mm jack connector	8	
Proximity	1 x VL53L0X time-of-flight distance sensor 1 x JACDAC 3.5mm jack connector	1	
Motor	1 x PCA9632 PWM driver 1 x JACDAC 3.5mm jack connector	2	

Table 2: A summary of the Brookdale hardware along with the frequency of which each piece of hardware was used by designers.

audio hubs (Figure 4). While we iterated on a number of possible types of connectors with the fashion designers, and even discussed soldering of electronics and using wiring instead, we eventually settled on the audio cable for a number of reasons. First, audio cables are considerably more rugged and reliable (G3) and may be more appropriate for runway environments. Second, fashion designers are able to find and purchase them in many locations, preventing issues of component availability (G1). Third, audio cables are reversible and familiar making them easier to use (G1). Lastly, using extenders and different audio cables lengths, designers can reliably size them according to the garment requirements, as well as sew them to hide them effectively (G4).

Often when we iterated on design concepts with the fashion designers in Phase One, electrical power was the most complex part of a garment to explain, as it requires knowledge and experience to properly ensure power is delivered safely and reliably. Many of our designers did not fully understand the issues related to power. To minimize this challenge, not only can Brookdale boards be individually powered using a USB-C connector, they can also be powered from the audio-jack connector (G1, G3, G4). This means that power can be injected and consumed by any connected board as long as power supply meets demand. The ability to inject power through any board is especially useful for more power hungry scenarios where servos and motors move or actuate a garment. All Brookdale boards also feature a power indicator to allow for the quick diagnosis of power delivery issues (G1).

As designers wanted to incorporate capacitive materials and smart tattoos into some of their designs, we ensured our Tattoo Bead worked with the gold leaf material from [36]. We also provided designers the option to use a second capacitive material, which was a customized silver ADP-5015T4 aluminum adhesive from Nitto [4], that was able to stick onto fabrics and skin better while also being responsive to capacitive input during our informal tests. We provided similar functionality as [36] for both conductive tattoo materials with our Tattoo bead, but also enable more expressive scenarios as the Tattoo Bead connects to other Beads for input/output (G2).

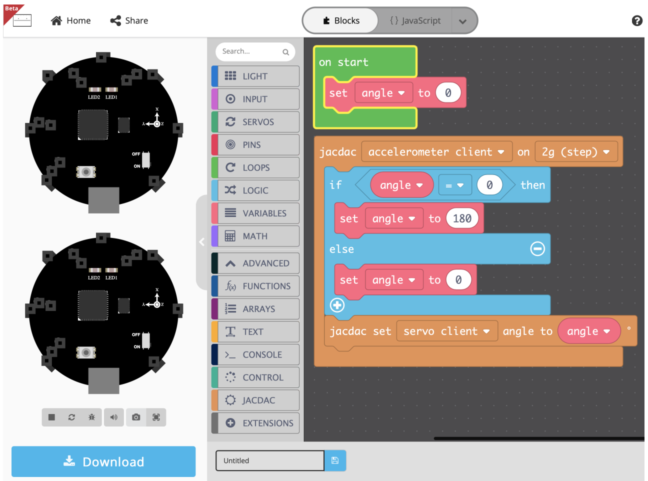


Figure 5: The customised MakeCode programming environment for Brookdale. A program that changes the rotation of a Motor Bead when a step is detected by a Motion Bead.

6.2 Brookdale Software

To complement our custom hardware, we provided an easy to use programming environment built upon Microsoft MakeCode [22] (G1). MakeCode uses the Web browser common to many modern devices to facilitate the creation, simulation, and compilation of programs. Once a program is compiled in MakeCode, it can be transferred to a micro-controller using drag-and-drop file transfer over USB. Rather than require a user to learn the low-level syntax of languages like C/C++, MakeCode instead provides a drag-and-drop visual programming language based on Blockly [25]. Similar to Scratch [61], MakeCode also promotes a reactive programming paradigm where code is more expressive and takes the form of *on <x> do <y>*. This programming paradigm is more intuitive than synchronous approaches where a user has to detect events manually using *if <x> then <y>* (G1) [40].

Similar to our iterative approach with the fashion designers and the hardware components of Brookdale , we also iterated with them on what visual components (or blocks) should be added to the MakeCode environment to enable them to program their components in an easy manner. Early in our design process for the programming environment, we described how the hardware components worked functionally and translated their conceptual language for blocks.

Figure 5 shows an example application, constructed in our custom MakeCode environment, that causes a servo to rotate every time a step is detected. With this approach, a usually complex application is distilled into a relatively simple to create 8 block program (G1). Next, the blocks used do not specify devices to communicate with, but rather resources the application requires (G2). Lastly, the blocks for inter-device communications are reactive and event-driven making it easier for inexperienced users to understand (G1). Ultimately, this translates to a really dynamic composition experience where any device offering the required resource (i.e. an accelerometer) becomes part of the application.

To support the dynamic plug-and-play aspect between the Brain and Beads, we utilized a new protocol called JACDAC [1, 21]. All JACDAC-based devices (such as the Beads and Brain) are peers and communicate free-form packets with one another across a shared bus, unlike existing protocols such as I2C and SPI [41, 66]. JACDAC devices host services, similar to the REST-services [24] of the Internet, that provide access to resources other devices may not have access to otherwise. Hosted services and device information can be automatically discovered through packets that are regularly broadcast on the bus. From the ground up, JACDAC is designed to be robust in dynamic situations allowing recovery from irrecoverable scenarios that plague other protocols (G3). As shown in Figure 5, JACDAC allows devices running similar services to act as drop in replacements, giving flexibility to a user when prototyping and built in redundancy if hardware fails (G2, G3). If an application requires use of more than one of the same service, a user can easily refer to specific devices by name.

In Brookdale, JACDAC is critical to enabling asynchronous communications between all Beads and Brains through the 3.5mm audio jack connector, allowing resources to be shared regardless of the position of boards on a model or mannequin. We do this through custom firmware for each Bead that reads the I2C sensor and transmits it via JACDAC. For input Beads, different data is transmitted depending on the Bead (e.g. a step event for the Motion Bead or a range value for the Proximity Bead). For output Beads, data around commands are transmitted (e.g. set an angle for Motor Bead or set a light pattern for the Brain). All communication between the Brain and beads used JACDAC . Combined, JACDAC and MakeCode provide an easy-to-use, drag-and-drop, event-driven visual programming environment for those with minimal technological experience.

7 PHASE II: DEPLOYING BROOKDALE

To gain insights into *how* novice fashioner designers would use Brookdale as part of their final design and construction processes for their garments, as well as observe its performance in an avant-garde fashion-tech runway environment, we conducted a 10-week deployment study, following Phase One (see Figure 2).

7.1 Method and Procedure

Continuing our participatory design process, we worked with the 17 fashion designers as embedded technologists over a 10-week period to deploy Brookdale. Over this period, we held multiple workshops every week (both virtually and live) to provide technical assistance and guidance for Brookdale. However, we did not assist the fashion designers with construction of their garments.

With the aim of allowing fashion designers to work with a set of known components, we gave each designer five brains and five of each Beads. We also provided them with different types of WS2812B-based LED lights (e.g. single strips, string-based), servo motors, various audio cable lengths (and connectors), audio splitters, smart tattoo materials, as well as USB power banks (3000mah, 0.35"x2.1"x3.3") to power the Beads, Brain and other components.

7.2 Data and Analysis

We used a mixed methods approach to analyze the progression of the Brookdale system from the garment construction processes to the final avant-garde runway show. We captured and transcribed

Figure 6: Some completed avant-garde fashion-tech garments created by the fashion designers using Brookdale and shown on the runway. Garments a - d are completed versions of those described in Figure 3. Garment e uses a capacitive material to trigger lighting.

data from our semi-structured, in-situ interviews, as well as discussions during workshops and the show. Similar to phase one, we used a thematic analysis approach to analyze this data. We also supplemented the themes from our analysis with our observations as embedded technologists.

7.3 Findings

The fashion designers constructed 19 different avant-garde fashion-tech garments for the runway show (Figure 6). We frame our findings in the context of the processes we observed while being embedded as technologists: *ideation*, *construction* and *the runway*, similar to those described in [67].

Ideation with Brookdale. One of our more interesting observations was how the Beads were frequently used by the fashion designers in a tangible manner before starting to construct their garments. For example, they would often combine their physical or digital sketches (i.e. on their phone) with the Beads by placing them physically near locations on their sketch where they felt it would integrate into their pattern or perform most optimally (e.g. placing a motion Bead near a hip or leg) for their chosen expressive output (Figure 7a). As one designer (D6) commented *"I like that these are small enough that we can plan out things pretty easily without me having anything yet...it's also really helping me understand how things need to work together."*

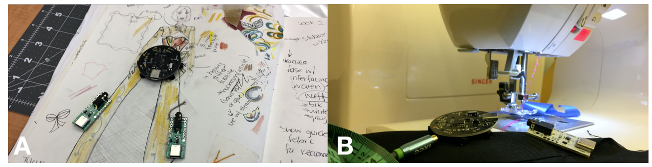


Figure 7: Brookdale in the wild. (a) A technical concept being laid out and planned physically on a sketch. (b) A designer sewing a Bead and Brain into their fabric during construction.

We also observed several designers change their garment concepts towards the end of their ideation phases before constructing. For example, one designer (D14) added smart tattoo interactions because *"...actually, I like the tattoo a lot more now because I can use it to make it look cooler and make the tech sort of subtle."* While we designed seven beads, not all ended up being used due to the design changes (specifically environment and light). Ultimately, the designers having the Beads and understanding their functionality meant they iterated on concepts very quickly (G1,G2,G4,G5).

Construction with Brookdale. The approaches that fashion designers used to integrate many of the Beads varied. Some decided to sew them in directly (Figure 7b), while others sewed in cables, splitter hubs, and LED strips first and left the Brookdale components "free" to move around in the garment. This was because they wanted to be able to have easier access to the Brookdale components, as well as be able to remove the electronics before a garment was steamed. We did observe some fashion designers even physically apply steam to the Brookdale components, and noticed no negative effects (G3).

Designers often hid components into seams, hemlines, and wrist areas, indicating that the size of the Beads was sufficient for many of the designs. Other strategies that we observed fashion designers used for integration included:

- Hiding USB power banks either in the back area of a garment, or having them strapped to a hip or leg, hidden by the garment on top of it.
- Sewing pockets or using velcro for the USB power banks.
- Hand stitching lighting strips or instead using a casing around a light strip as a strategy to have both diffusion (i.e. balance out the light across a certain length) while also making it easy to sew using a sewing machine or hand stitch.
- Thick cardboard for mounting a motor, either on the shoulders underneath fabric or stability when using motors
- Using pins to keep the audio cables from being extremely loose in the garment.
- Loosely stitching a sensor inside the garment. For example, a motion sensor would be stitched loosely near the knee so that it could distinctly move, regardless of how a model walked with the garment).

In many cases, LED strips followed a similar pattern, making it easy for designers to remove or fix their garments as needed (G1, G3-G4). This indicated that the design patterns of garments can provide natural guidance for how technology such as Brookdale can be integrated into non-avant-garde fashion-tech garments. Lastly, while we did have drag-and-drop software readily available many fashion-designers were unable to properly attempt programming due to not having laptops, having busy schedules, and continually modifying the visual looks of their designs – even until moments before the runway. Despite this challenge, we co-created the programs needed to make their garments function (e.g. rotate a motor 30 degrees). As the designers were already familiar with the syntax and blocks from being involved in the design process, co-creation involved describing what event the Beads should trigger upon, and what the output should be. From this process, we did observe that several had conceptual models of patterns for LED lighting that were generally difficult to translate into a block-based coding method. For example, *"...can you make the blue more wavey, and move quicker in the middle when it pops up."* Additionally, the designers who utilized multiple inputs for an output (e.g. using a Tattoo Bead and a Motion Bead to trigger lights) faced challenges in conceptually understanding the flow of logic of nested blocks (as per the syntax) with respect to how they worked on their garments. This informed us on the need for a potentially simplified programming model involving multiple sensors and correlating them to a visual map of the body. However, all designers expressed a strong interest in the ability to program their garments with the Brookdale software for future runway shows.

For the garments constructed that used the Motor Bead, there were several challenges designers faced, because of the unfamiliarity of materials (e.g. using fishing line to pull the garment up or down) or the servo motors not designed to be properly mounted on fabric areas (e.g. around the shoulders). For the Tattoo bead, we provided a desktop laser cutter to allow designers to make custom patterns, but most designers instead chose to draw their own patterns and cut them out. The color patterning of the Beads and Brain also helped the fashion designers when they wanted to change functionality. For example, a designer did change their concept one day before the show (using a smart tattoo instead of motion as a trigger), and swapping out a sensor did not require any assistance (G1). Overall, due to the familiarity of many of the physical components, many of the fashion designers were able to independently construct their garments physically, with only needing assistance for programming, especially with garments that used multiple input triggers.

Brookdale on the Runway. The backstage runway environment was a challenge in the deployment of Brookdale, where we observed a number of issues. Firstly, the backstage environment of a runway is extremely hectic with a large number of people involved in the production. Often, models were trying on garments backstage multiple times, meaning that a significant amount of wear and tear occurred before they appeared on the runway. For the fashion-tech garments, this meant that we were needed to debug several garments that initially appeared to stop working. What we discovered was that the technology was operating correctly (G3), but the designer had connected JACDAC components into the incompatible light ports of the Brain, and vice versa. This was no fault of the designers who had forgotten that LED strips had to be connected to ports in a specific order (similar to how most systems are designed), which was at odds with the plug-and-play ecosystem of Beads and Brains. This taught us an important lesson: it was a mistake to require novices to understand and remember networking concepts, especially under pressure. We realised that JACDAC should be used for all components, including lighting. That is, we didn't completely follow plug-and-play everywhere in the system (G1).

We also observed that the poorly ventilated runway environment meant garments and people were overheating. For Beads such as the Tattoo bead, sweat meant capacitive materials occasionally became unreliable, as the calibration we performed prior to the show was no longer the same while the garment was being worn. Moreover, models would wear the fashion-tech garments for a long period of time as they awaited their turn to appear on the runway (sometimes for over 45 minutes). This further contributed to the heat issue, caused battery drains and brown-outs for lighting effects, as well as infrequent triggers for outputs that involved combinations of the Motion Bead.

Although the Brookdale software is web-based, the Brain is programmed through a USB cable. In the runway environment, a laptop with a USB cable is not a functional device for either debugging or reprogramming hardware, particularly when design changes (or even code such as lighting patterns) are made moments before a garment appears on the runway. Ultimately, we partially achieved G1, but there is an opportunity for providing even more accessibility for fashion designers to program their garments, by using other technologies such as Bluetooth or WiFi.

Lastly, the runway environment also affected some of the visual input and output capabilities of garments – not the Beads or Brain (G3) – causing last minute design changes. For example, one garment that used a Color Bead and a Light bead, was to have a projector mounted in the hat display different colored images, but because of the environmental lighting conditions being uncontrolled (and random) for the Light bead (which also controlled the effects of the LED when nothing was projected), the Light bead was dropped entirely. Also, as the Color Bead was not able to pick up the colors of the projector from its distance, and thus change the light patterns on the front of the garment accordingly, the designer instead used a second model as a dancer, who used the projector in their hands to directly project onto the Color bead at different distances, triggering the light effect. After the show, the designer commented (D5) *"This actually worked out better than what we had planned before...it became more of a performance which made me different from the other designers."* Despite these issues, many fashion designers overall felt the system was appropriate and expressive for the context, with one (D3) stating *"everything worked, and I was a bit nervous before...but the audience loved it!"*. When comparing Table 1 and Table 2, there were several instances of designs changing last minute and beads not being utilized specifically because of the dynamism of runway conditions (e.g. lights, or environment).

8 PHASE III: FURTHER REFLECTIONS

After the 24-week participatory design process (see Figure 2), we then conducted follow-up interviews with the fashion designers to see how the experience of being introduced to different technologies through Brookdale affected their aspirations, as well as their current and future plans in the fashion industry. We also allowed the fashion designers to keep the Brookdale components after the runway show, as we wanted to see how and if they would incorporate them into their own processes and garments without the need of an avant-garde fashion-tech runway show.

8.1 Method and Procedure

We recruited 5 of the 17 fashion designers over a period of 3 days, 16-weeks after the conclusion of the avant-garde runway show, for semi-structured interviews. Interview sessions lasted no longer than 30 minutes, where we asked about their experiences during the 24-week process, if and how they'd used Brookdale since the conclusion of the runway show, and if and how their aspirations and directions had changed.

8.2 Analysis and Findings

We captured and transcribed the data from these interviews, and again used thematic analysis to generate our findings.

Continued Tinkering. Of the five fashion designers we interviewed, two still continued to tinker and learn fashion-tech concepts with Brookdale. One was interested in learning how to combine an EEG headset into their garment, while the other had begun learning more about how to use the other Beads that they did not incorporate into their garment. As they stated (D9) *"overall the experience was amazing, and other than the crazy finish, I wanted to learn more about where to put things for the future, so I am."*

All designers noted that while they felt that their designs and expectations were ambitious at the start, they felt they were mostly met and that the tech (for the most part) became a part of the fashion process. This was described by one designer (D12) as "the thing is, you never really finish things properly for a runway, everyone makes tons of changes, so it just goes on the runway with whatever you got. So in that sense, the tech was kind of like that too. I did what I needed with it to tell the story that I wanted."

All designers also commented that our participatory design process where we worked alongside them directly to develop Brookdale and assist them with their garments, encouraged them to learn some of the more "difficult" areas in fashion-tech. For example, one designer (D8) commented *"I'm going to learn some programming now, because it doesn't seem difficult after watching you all work with us. I really want to do more cooler [light] patterns with the tattoos the next time."* Interestingly, all fashion designers also wanted to do more technically complicated garments with the Beads for their next avant-garde fashion-tech show. For example, one (D1) stated *"The 3D printed stuff you guys showed at the beginning looks really cool, I want to combine that with my tattoo stuff and the projector tech that DJ used at the show."*

Beyond Technology. One of the biggest impacts the entire experience provided for the fashion designers, was how it introduced uniqueness into their own garment portfolios when compared to peers in their community who were not able to participate in the fashion academy's program. Several made comments such as (D9) *"I have a pretty unique portfolio now that I've incorporated tech, and I know doing more unique things with it will set me apart and lead to better opportunities"* and (D8) *"I kinda felt like because I went through this crazy process, it actually showcased what I could do far more than if I did the regular avant-garde or couture stuff in New York."* One designer (D1) even began seeking out small job opportunities involving technology, stating *"I actually started looking for small jobs where I could make custom clothing with sensors and lights because I kinda got the hang of it."*

Becoming Ambassadors. One major theme mentioned by all the fashion designers we interviewed, was the notion of them becoming fashion-tech ambassadors in their respective communities and groups in the Brooklyn area. One designer (D12) noted that *"...because of my dress, a lot of people constantly ask me how I did it and want to know more. I've kind of copied what you guys taught for the basics and use that, so I'm an expert now [laugh]."* Others commented that the show even impacted their social media feeds amongst their friends and other designers, such as (D9) *"I get tagged on a lot of posts related to wearables or tech fashion things, and I share a lot of cool things in that space now...trying to build my brand."*

9 DISCUSSION

We discuss key lessons learned when designing tools like Brookdale within the broader space of wearables, as well identifying the avant-garde runway as a strong area for research.

'Where' is the wear. Certainly, a significant number of toolkits have been created for wearables and fashion-tech (e.g. [37, 38, 51, 59]). As we demonstrated throughout this work, there are still large gaps in the research space when exploring technologies in the context of avant-garde runways. It is an extreme environment in many ways, so understanding the issues that fashion designers face when incorporating electronics was a challenge we continually faced throughout our participatory design process for Brookdale. For example, there is still a technical language barrier with respect to programming, as well as the question of what programming should even look like in such environments where computers are not ideal devices for dynamically adjusting garment functionality. Prior work in programming languages for novices (such as [46, 62]) have demonstrated value for one aspect of the runway processes we've described in this work (customizing functionality), but there is an opportunity to reconsider these approaches when considering the entire runway process and those of fashion designers. We made specific design choices because we considered where the garments (and technology) would be worn (e.g. using audio cables to mitigate constant movement and breaking while backstage) or how the software and firmware layers worked between the Brain and Beads (e.g. using a protocol designed for plug-and-play for the Beads, rather than I^2C). Ultimately, we strongly believe that using the runway and its processes is a valuable lens for conducting research for fashion-tech and wearables, and this work is an important step in incorporating the entirety of the runway process and designs to build a wearables system.

Moving Beyond Research. One area that we found particularly valuable in our participatory design process with fashion designers, was our early discussions describing the state of fashion-tech and wearables. It helped to both inform the fashion designers of the space of possibilities, while also enabling us to consider a system design that was significantly more flexible and adaptable to the space as it grows. The main challenge we faced in our introductions to fashion-tech, was that many fashion designers weren't able to find learning materials on their own, due to a huge focus on tools for makers and education, similar to [67]. This means that in order to grow the community of fashion-tech and other creative communities, we also need to consider a more inclusive means of presenting tools and technologies. For Brookdale, we overcame these issues by being embedded with our audience (the fashion designers) and demonstrating how it could be used in-situ, with sketches from the fashion designers as well as physical demonstrations on mannequins and garments. Another unique challenge we faced, was designing and manufacturing the Brookdale hardware in-situ with designers as they worked through their concepts. In our process, we leveraged non-populated PCB boards as "low-fidelity" physical prototypes for designers to overcome this, as the PCBs helped facilitate conversations around design concepts, sensor placement, and ultimately what the final technology could do.

From System to Community. A valuable and interesting side effect of our participatory design process, was that we ultimately created our own unique and small community for fashion-tech in New York. This is interesting because, similar to [17], we can now observe a longer term impact that transitions from Brookdale being a wearables system, to one that is a community platform, creating fashion designers who are skilled enough to adapt many different concepts and technologies on their own, and have more pragmatic explorations (i.e. not runway ready but consumer ready). We also view this approach as a means of overcoming some of the observed inspiration challenges, also mentioned in prior research [67]. As we reflected on our own role as the creators of Brookdale after the show, we realized that we also became ambassadors in the community, alongside the designers. Though not all members of the team are fashion designers or have fashion backgrounds, we also began to contribute to our respective communities for wearables through meetups and workshops, based on our experiences throughout the Brookdale process. Ultimately, a system and community are intertwined, as are the system creators and designers.

10 LIMITATIONS AND FUTURE WORK

We recognize that our design process focused on a single group of fashion designers and is not representative of the general population as a whole. We also recognize that despite having a modular, easy-to-program system, fashion designers did not have enough time in their schedules, nor the tools (i.e. laptops) required to program their garments. This limited us in evaluating the effectiveness of the programming aspect of Brookdale for novice fashion designers. For future work, we would like to perform a complete usability study of Brookdale, where we specifically evaluate the programming effort required by both novices and experienced fashion-tech designers.

We also acknowledge that we do not provide quantitative analysis of the fundamental technologies used by Brookdale, JACDAC and MakeCode. Detailed analysis of these technologies is beyond the scope of this paper, but we plan to perform such analysis as future work.

We would also like to revise the Beads in the future, aiming to reduce the form factor further and potentially use flexible PCB materials to ease the integration with garments. While we used standard USB power banks, we'd also like to explore using smaller dedicated battery modules that could be plugged into the Brookdale system, similar to the beads. Moreover, we would also like to give fashion designers more ways to express their ideas with more Beads for sensing and output. But most importantly, we believe that while the initial focus of Brookdale was the avant-garde runway, it could be applied in other areas including smart jewellery [7] and prosthetics. Lastly, we intend to release a version of Brookdale for the public, and aim to study some of the interesting aspects around the fashion and avant garde community that we discussed, similar to how Lilypad [17] proliferated in the maker and wearable communities.

11 CONCLUSION

We introduced Brookdale, a modular, plug and play prototyping tool for fashion-tech garments that used the avant-garde runway environment as its context. Brookdale is designed to address the challenges that novice fashion-tech designers face when they first begin designing, experimenting, and constructing fashion-tech garments, by providing a number of custom, modular, plug and play hardware components along with customized drag and drop software. To create Brookdale, we used a 24-week long participatory design process with 17 fashion designers that involved semi-structured interviews, system design, and finally a deployment for a large runway show in New York. We followed this with a set of interviews 16-weeks after the show to track the progress of some of the designers. Our results provide insight into how the avant-garde process could be incorporated into existing wearables research, and inform the design of future wearable technologies.

ACKNOWLEDGMENTS

Project Brookdale was a large project with a number of moving components and a tight timeline for execution. There are several people to thank who helped realize the vision for this research work. First, we'd like to thank the Brooklyn Public Library, its staff, and all those whom who played a part in creating, producing and realizing the BKLYN Fashion Academy show.

Next, we'd like to thank the Brooklyn Fashion Academy organizers, especially Lynnsie Augustin and Winnie Siclait for hosting us and allowing us to embed ourselves into their program. We'd also like to thank each of the Fashion Designers for their insight, expertise, conversations and allowing us to join their different Brooklyn fashion communities.

We'd also like to thank many of our colleagues at Microsoft Research. Evelina Barhudarian for valuable (and early) help, advice and insights into Fashion, as well as navigating the team through IRB processes. Ani Babian for helping to organize different parts of the Brookdale deployment. The Microsoft Research Hardware Lab, especially Sokunthea Neang (SK), Todd Jurgensen, Teresa LaScala, Lex Story, for help and advice in designing and creating the early hardware prototypes of Brookdale. Tara Grumm, Tricia Mayer, Lisa Clawson, and the Video Team of Microsoft Research Outreach, for helping us with documentation and creating so many valuable materials for the paper.

Lastly, we'd like to thank all of our anonymous reviewers for their feedback in helping improve this work.

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