

### Diffusion of 3D Knitting: The Fashion Designer and the Digital Divide

Knitwear is a \$200 billion industry making up almost 20% of global apparel sales (Kansara, 2015). Digital fabrication technologies are revolutionizing knitwear production. 3D knitting is a digital fabrication method that uses large flatbed knit machines to create complete, seamless garments in one piece, eliminating all post-production assembly (see Figure 1). Producing 100% seamless apparel has a number of benefits: seam elimination reduces bulk, increases comfort and improves garment integrity, eliminates material waste, and expands possibilities for size inclusivity. Furthermore, this technology may be utilized for production of smart clothing as it allows conductive fibres to be integrated seamlessly throughout the garment, avoiding connectivity issues that often occur at seam intersections in traditional ready to wear clothing.



*Figure 1.* Stoll knit&wear® digital knitting machine. Adapted from ‘knit&wear’ by Stoll, 2019. <https://www.stoll.com/en/machines/knitwear/>. Copyright 2019 by Stoll.

Despite the apparent benefits, the adoption of 3D knitting by North American businesses has been slow. Foster (2017) has identified nine factors that influence the decision of companies in the textile and apparel sector to adopt (or not adopt) these machines. However, while her work looks at purchase-decision factors for companies in a position to acquire their own equipment, purchasing this technology is not viable option for many apparel businesses, and it is not

necessary for designers to own their own equipment to utilize it within their businesses. Design firms that wish to create 3D knit apparel for their own brands and do not have the means or interest in owning their own equipment may work with domestic or offshore contract production facilities to develop and manufacture their products. This is ideal for companies who are interested in including knitwear as one part of a larger range of product offerings and are unable to justify purchasing their own machines. It is also a way for smaller, independent designers that do not have the skills or financial resources to acquire their own equipment to use this technology to develop their designs. Understanding the actual and ideal competencies of independent designers who do not possess their own 3D knit machines is important because it provides insight into a segment of the textile and apparel industry that has not yet been explored. Independent designers bring business to contract production facilities, supporting continued relationships between the production facility and the knit machine manufacturer. Independent designers may also be future investors in the equipment, and thus their ease of access and success in production may influence future purchasing behaviours, which is valuable for knit machine manufacturers. The experience of designers working with contract production facilities is also valuable for other design firms seeking to expand their capabilities to include this technology in their product offerings. Finally, the way designers interact with this technology in the industry is a crucial consideration for higher education institutions seeking to prepare students for careers within an evolving fashion ecosystem.

Within a traditional apparel design approach, the designer controls the development of the garments and has a comprehensive understanding of the production and assembly process; designers possess the authority and confidence to direct the development of their designs even when aspects are delegated to others. With 3D knitting, the designer's capabilities generally do not extend into the technical programming of the knit machines. This limits their control in the

design process and weakens their influence and authority in product development. For those working with external contract production facilities, the knowledge gap between designers and technology users is amplified further compared to internal 3D knit design and development teams that are able to experiment and develop samples on their own equipment. For designers who produce their collections through offsite facilities, the physical distance can further compound the designer's lack of technical skills. These barriers marginalize the role of the designer in the development process because they significantly limit the control that the designer has over the garment properties. This creates a scenario that threatens to eventually remove the designer from the design process, which is problematic because design skills are a key driving force in apparel innovation. While the author's larger research program includes the perspectives of knit programmers and manufacturers, space does not allow for in-depth treatment of these players here. This research presents a critical analysis of existing literature on 3D knitting and operationalizes existing designer-related skills gaps according to key themes identified in qualitative research with 3D knit industry experts.

### **Definitions**

There appears to be no universal consensus regarding the taxonomy for 3D-related knitting operations; this section defines relevant key terms used in this paper. The term 3D knitting refers to garments or products that are created on a flatbed knitting machine in one piece, without seams or additional assembly required. In other literature, the terms seamless knitting, integral knitting, complete seamless knitting are also used. The two major flatbed knitting manufacturers also use their own terminology for this style of knit design and production: Shima Seiki uses the term Wholegarment (Shima Seiki, 2019), and Stoll uses Knit and Wear (Stoll, 2019). Not all flatbed knit products are 3D knit. In addition to 3D knit capabilities, digital flatbed machines can produce knit yardage that designers then cut and

assemble into a garment using a sewing machine; this production method is known as “cut and sew”. These machines are also used to produce shaped knitted pieces that do not require any cutting but must be assembled through sewing or binding to create a garment; this production method is known as “fully fashioned.” The term digital knitting is used in this paper to refer to electrically powered industrial flatbed machines when used for knitting products that are not 3D knit. Creating the design file for the knit machine using the proprietary software is referred to as programming and is conducted by the machine technician, referred to here as the programmer. Finally, the term design refers to the problem-solving process of balancing aesthetic appeal and functional properties to develop products that address the needs of target consumer markets.

### **Literature Review**

This section provides an overview of existing literature on knitting practice in the textile and apparel industry. These results are unpacked and critiqued in more detail with consideration of current research findings in the Discussion section, below.

Some of the most cited literature on machine knitting addresses the design-skills gap that exists between knitwear designers and the programmers operating the knit machines, is from the late 1990s through the mid 2000s. Eckert’s (1997, 1999, & 2001) research on industrial knit practice has shown that designers generally do not have the technical skills to operate the computer software for digitizing designs for industrial knitting machines, creating a communication bottleneck between designers and programmers. Thus, programmers misinterpret designers’ ideas, driving up R & D costs through sample redevelopment and additional time spent programming (Eckert, 1997, 1999 & 2001; Sayer, Wilson & Challis, 2006). Sayer, Wilson & Challis’s work (2006) has built upon and extended Eckert’s research to evaluate knit education in higher education institutions in the UK. Their work has reinforced the existence of a design-skills gap, and also identified that higher education institutions where knit programs were offered

did not provide sufficient training on the necessary skills required to better prepare design students for the realities of working within the 3D knit ecosystem.

Foster's (2017) research investigated the drivers and barriers that influenced a firm's decision to adopt 3D knitting technology, using a case study approach with in-depth interviews to determine the factors that affect technology adoption decisions. While her work addresses the process of technology adoption within a business, it does not investigate the implications of 3D knit technologies on knit product designers – apparel or otherwise.

In the last ten years, multiple scholars have explored the designer's experience using 3D knit technology (Ma 2013; Smith, 2013a & 2013b; Taylor & Townsend, 2014; Taylor, 2015; Underwood, 2009). Underwood (2009) uses a practice-led approach to develop a Shape Lexicon, which is “a visual record of 3D shape knitted preforms” (2009, p. 1) with Shima Seiki technology and created a new methodology to facilitate communication of these shapes. Ma (2013) conceived an integrated model that illustrates the process of developing 3D knit designs and tested it through multiple case study analyses with student designers and then verified with industry experts in the USA. Her work uses Shima Seiki technology exclusively, although she addresses some of Stoll's software and machine functions and capabilities.

Smith (2013a, 2013b) investigated 3D knit from a practice-led approach in New Zealand, exploring creative options and ways of designing knit forms and structures using the technology. Her work addresses the highly technical software required to operate the machines and proposes a “craft community” (2013a) to share the knowledge and expertise on seamless knitting since there are multiple ways of engaging with knit structures and understanding the machine capabilities. She explores seamless knitting as a tool for craft expression and encourages its potential as a craft tool despite its advanced digital interface. Taylor also explored the use of 3D knitting technology as a craft approach with Townsend (2014) and in her own PhD research

(2015). Based in the UK and following a practice-led research approach, her work places a craft methodology at the heart of the 3D knit design process. Acknowledging that a “knitwear technician’s [programmer’s] knowledge is more in-depth than most knitwear designers, ... [and] ... is often naturally biased towards the training received from the machine manufacturer,” Taylor and Townsend ask how the designer can bring more creativity to technical knit production (2014, p. 156) and conclude that designers must gain more access to technical training (2014, p. 171).

As an alternative solution to the noted knit communication challenges, Yang (2010) has recommended the creation of a new hybrid role, the “designer interpreter.” This is a designer who possesses enough programming proficiency to develop the knit file and produce the first prototype of the design without assistance from a programmer. Yang argues that this role would bridge the gap between design language and programming language, allowing the designer interpreter to communicate fluently with both players and mediate the process.

In summary, while previous literature has examined communication bottlenecks in the greater knitwear ecosystem, factors that influence adoption of 3D knitting technology, ways for designers to engage with 3D knitting as a craft tool for creativity, and a possible solution for bridging the communication divide between designers and programmers, it has not thoroughly addressed the implications of this technology on the role of the designer. The present research aims build on the foundations laid by previous literature and examine the experience of designers who do not have access or means to adopt their own 3D knit equipment and assess their changing role in the 3D knit design ecosystem.

### **Methodology**

This qualitative research was conducted through a type of interview called a touchstone tour, taking place in respondents’ work environments to gather rich descriptions of the design

and product development process for 3D knit apparel. Respondents included an independent 3D knit designer (interviewed on June 14, 2018), a 3D knit programmer (interviewed on June 22, 2018), and a managing partner in a production facility that has 3D knit capabilities (interviewed on July 25 and 26, 2018). Touchstone tours are “guided tours...designed as a conversation that uses artifacts and the environment as touchstones for questions and insights” (Martin & Hanington, 2012, p. 184). Guiding questions were prepared in advance to “allow fluid departures based on highlights selected by the tour guide, and attentive observations by the researcher” (Martin & Hanington, 2012, p. 184). Tours were conducted in the participant’s workspace for the programmer and production company. The designer was unable to meet in her workspace as she was in the process of relocating her office. Instead, she recreated her office environment in a meeting room at the local public library by bringing the tools she used for her design tasks, documents from previous design development communications between herself and the production facility, as well as multiple samples of her knit designs. This recreated environment provided touchstone points that became research probes during the interview. Photographs, video recordings, and field notes were also collected during the touchstone tours to triangulate the data.

Purposive sampling via LinkedIn was used to select participants using 3D knit technology to create apparel. Interviews were audio recorded, transcribed using Trint’s artificial intelligence software, and reviewed for accuracy by the researcher. Photographs were collected with permission, and field notes were taken during interviews to highlight key insights. Transcripts were then analyzed with NVivo qualitative data analysis software by identifying and categorizing key themes. Data provided insight into the actual and ideal capabilities of independent designers who do not own their own 3D knit machines.

## **Results**

This section provides a description of participants' roles within the 3D knit ecosystem, followed by results related to designer skills and competencies. Key themes were identified, including communication issues, the importance of yarn knowledge, sampling and production affordability, the impact of programmer capabilities on design and product development, the need for designers to possess technical knowledge of the machine and software capabilities, and barriers to acquiring education and training. Each of these are discussed in turn, below.

### **Participant roles**

This study engaged with a 3D knit designer, programmer, and production facility. Their roles are typically separate and distinct, but together form part of a greater 3D knit ecosystem. The designer respondent (DR) has a background in knit design at a major fashion university in the USA. Her role includes developing ideas and sketches for garments and providing visual and technical detail of her designs to the production facility via the programmer. The programmer respondent (PG) has a background in technical apparel design and knitwear and has programming training and experience on Stoll knitting machines. Her role includes developing digital knit design files using proprietary software (in her case, Stoll's M1Plus software), while being mindful of machine limitations, knit stitch capabilities and designer objectives. The production facility (PF) houses the 3D knitting equipment, and typically employs in-house programmers to work with clients (designers) to develop design files. Key themes that arose from touchstone tours with these respondents are identified below.

### **Communication issues**

Communication issues were the most significant frustration reported by all respondents. When designers do not have access to their own knit machines or related software programs, it is critical to ensure clear and efficient communication is made with the production facility (typically through the programmer). DR shared that tech packs, or spec sheets, are documents

that are provided to the apparel manufacturer by the designer that include all the technical details and specifications required for the manufacturer to produce the design (see Figure 2). This includes fabric type, style information, technical illustrations or flats, key measurements, and colourways. Knitwear designs also include information relevant to the equipment such as knit gauge, needle size, knit stitch count on the garment, and technical yarn information including supplier, fibre, and colour, as well as any other detail the designer wishes to communicate to the programmer or manufacturer. Depending on the complexity of the design, this may be a multi-page document with entire pages dedicated to different aspects of the design, as required. DR explained that this is a critical element for effective communication between the designer and the 3D knit machine users:

“the goal is to make the communication between the designer and the programmer, the designer and the manufacturer as clear as possible. So every little detail that's in the tech pack is really important.”

In creating her tech packs, DR also noted the communication benefit that came with producing through the same production facility over a period of time. She stated, “I just feel like I can talk to them a lot easier. I can call them. It's just an easier for communication.” She felt that her history with the production facility afforded her some liberties in creating the tech packs; she didn't feel the need to write every minor detail or measurement, trusting that the programmer understood her design goals and intentions. This was not the case when working with a new production facility. Without the pre-established trust, she noted that it was important to include this information, especially if there was a language barrier. PF also emphasizes the importance of the designer providing clear communication and sticking with their plan, stating,

“It's just more about having an established set of measurable criteria or deliverables, whatever it is, agreeing to those deliverables whatever they may be, and then not

changing the deliverables mid process or midway or adding something to them that wasn't there to begin with [...] the more simple a product is the more concrete that can be. The more complex [the product], the more difficult that is.”

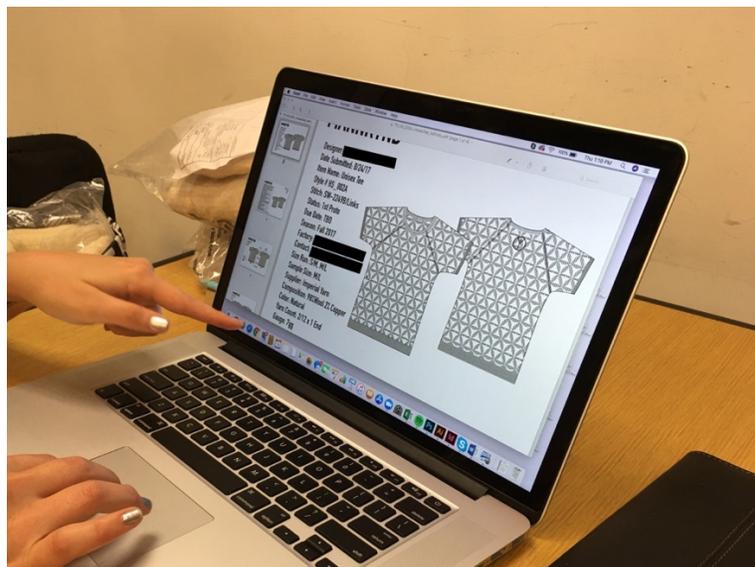
DESCRIPTION / SIZE	1st			Revised Size Spec.	Comments
	Size SPEC.	Measurement	DCNY		
front body length-from hps to hem edge	29	28 1/2			
back body length-from HPS to hem edge	29	28 1/2			
Chest 1" below AH	29	27 1/2			Max
front raglan length	12 1/2	12 3/4			
back raglan length	13 1/2	13 3/4			
Front& Back Raglan Pos Down from HPS	2 1/4	2 1/4			straight down from HPS
bottom sweep-at hem edge	18	18			
hem trim height	1 3/4	7/8			
neck width (seam to seam) @ HPS	8 1/2	8 1/2			Max
front neck drop-hps to edge	4 1/2	3			
back neck drop-hps to edge	11 1/2	11 1/2			
neck trim height	3/4	7/8			
Across Front & Back Raglan 7" Down from HPS	16	15 1/4			
Sleeve Length from HPS	15	15			
Shoulder Slope	1	NA			
Bicip 1" from AH	1 3/4	1			Max
2 x2 Rib start along raglan	1	1			
Sleeve Opening	7	7			

Figure 2. Measurement details from one of DR's tech packs.

For 3D knit, an added complexity for communication that is not encountered in other apparel design approaches is the consideration of how the garment will be assembled (in one piece) on the knitting machine. Access to the proprietary software that programmers use to develop design files to be read by the knitting machine is not easily accessible by independent designers. To compensate for this, DR notes that she develops her technical illustrations, or flats, in Adobe Illustrator to include in her tech pack (see Figure 3). Since the production facility that she works with to manufacture her designs uses Shima Seiki knitting machines, having her own copy of Shima Seiki's SDS-ONE APEX3 software program would speed up the knit development process and enhance clarity of the design because she wouldn't need to rely on the programmer as much, at least for preliminary development. She notes,

“because I don’t have an APEX system myself, that portion of the work I can’t do. If I had access to one I could help a little bit further along... So because I don't, I work with Illustrator and I'll do my sketches.”

Because she is not able to develop a scaled 3D design in the software, measurements become extremely important. To ensure accurate fit, she researches existing garments, whether in retail outlets or from her own closet, to capture measurement details, stitch counts and other technical specifications that she is able to draw from physical samples. This information is provided in the tech pack for the programmer to translate into the knit design file on the computer.



*Figure 3.* DR shares an image of design flats as part of a tech pack.

Once the designer hands the tech pack over to the programmer, the process of unpacking the design for development with the machine software begins. DR notes that programmers “do all the data, they do all the programming, [and] that's a whole other animal.... So there's a lot of back and forth between the designer and the manufacturer.” Experienced programmers know how to assess a design for technical complexity and check in with the designer to confirm they want to proceed. A more complex design means more man-hours on the programming end, that adds development costs for the designer. As PG notes, when a designer presents a design concept

to you, “you have to kind of reflect back to them like, okay I can do that. It's going to be a lot of engineering. Do you want me to spend time engineering?” This upfront communication is important for managing time and budget expectations.

### **Yarn knowledge & availability**

Congruent with previous literature, yarn knowledge was cited as a critical factor for developing any knit product (Eckert, 1999 & 2001; Sayer, Wilson & Challis, 2006; Foster, 2017). In 3D knit design, the yarn is directly connected to the shape and aesthetics of the final garment, so the implications for selecting the correct yarn at the beginning of the process are critical. Respondents across all roles acknowledged the importance of yarn selection in developing 3D knit designs. DR notes that “when you decide on a yarn you want to make sure it runs through the machines, and it doesn’t break the needles or it [the machine] doesn’t break the yarn.” While fibre, yarn, and general textile knowledge is typically provided in higher education fashion programs, the information about highly technical yarn properties and requirements for 3D knit are not provided. DR notes that she gained this technical yarn knowledge through her professional industry experience. PG identified the depth of detail that should be considered during yarn selection, including fibre content, the process that is used to convert yarn to fibre, the different fibre sources and associated costs, and how this can impact the designer’s options based on the desired aesthetics, function, or budget. PF noted the importance of yarn knowledge, stating, “It's very beneficial for anyone that's requesting someone to knit something for them to have some rudimentary knowledge of the yarns. It's absolutely critical. And we find ourselves educating our customers quite frequently.” In this, not all clients – many being designers from small businesses that require production services – are interested in learning these details. He notes, “Some of them just say, deliver this with this, I don't care about your inputs.” This refusal

by some designers to accept any technical decision-making responsibility redirects it back to the production facility, removing some agency from the designer.

Once suitable yarn is selected for production, yarn availability was noted as another key factor for designer consideration. Barriers to accessing yarn can prevent a design from being realized in the manner intended by the designer. These barriers include domestic availability, colour options, and minimum orders. DR shared that she had to order certain wools from Italy rather than her usual domestic source, because the Italian supplier's minimum order size was lower and therefore more manageable for her budget. PF noted that as a domestic facility, they have limited storage capacity for yarn variations, so clients/designers working with them may wish to seek custom yarn sources. However, custom yarns typically come with high minimum order quantities. PF explains,

“you can get any yarn custom made for you in this country no problem if you want to commit to five thousand pounds of it. So, for most items, five thousand pounds would be a lot. That's pretty high-volume production.”

The high-volume minimums required when seeking specific yarns – either domestically or internationally – creates a barrier for smaller businesses and independent designers whose financial capacity may be limited.

### **Sampling and production affordability**

In the development of knit apparel, sample swatches of knit structures are created by the programmer at the production facility and provided to the designer for approval. Once the basic stitch structure is approved by the designer, a full garment prototype is developed. This process requires a great deal of time from the programmer; the more complex the design, the more time the programmer must spend engineering the design pattern in the software. As PG notes, “The programming is slow if you aren't making a basic style”. The work demands a lot of

concentration, which can be strenuous on the programmer. PG explains that “it is not easy and relaxing to program. And there is no templates or modules for this”. And although the knitting machine eliminates post-production labour, the knit sampling process itself can take up a lot of time, tying up the machine and prevents it from being used for other projects. PF emphasizes the bottleneck caused by manufacturing speed of 3D knit designs, as, “It's very slow.” The amount of time spent on developing the knit pattern in the computer and knitting out the samples translates to costs incurred by the designer.

DR notes that “the sampling is probably the most expensive because of the time that it takes from the programmer.” When she first began her 3D knit production she was working directly with a major 3D knit machine manufacturer. They had highly skilled programmers who were capable of developing designs efficiently thanks to their extensive experience working with their own equipment. Samples at this facility averaged DR “about \$400 [USD] each.” However, when the knit machine manufacturer increased their minimum production quantity, DR had to find a new contract production facility to avoid being “locked into the 300-piece minimum. I asked if they could transfer my project to another manufacturer.” The new manufacturer allowed smaller production commitments, but the price per sample became significantly higher. She notes, “I could do as low minimums as I wanted. But they're sampling is much more expensive. So their sweaters were \$1000 [USD] on average.” A new sample is often necessary when any change is made to the design, as it ensures that the machine can accomplish the desired effect, and confirms the final output for the designer. This means that multiple samples may be required to achieve the final desired style, fit, or function of the garment. As PG notes, “going back with more samples can really drive up the R and D and prototyping costs.”

As a designer navigating the 3D knit development process, an understanding, or at least an appreciation of the work that is involved in creating and testing the knit files can help

maintain realistic expectations. From the production facility perspective, PF describes his frustration when designers don't take the high development costs into consideration with the realistic saleability of the fashion item: "the manufacturer doesn't want to have invested weeks in the design of something, because then [if] the customer can't sell it ... Who's going to pay for that?" In addition, he notes that designers do not always understand the need to acquire as much information for the design as possible at the front end of the process due to the complexities and difficulties in making changes at a later stage. He states that "There's a lot of work in the design and development process that has to be done. You can't just flip a switch and all of a sudden, your beige something goes into a beautiful rainbow something. There are a lot of other things that have to happen for that to happen and that might change the price point or it might change the certainly change the cycle time certainly would change the complexities of inventory process."

### **Programmer capabilities**

Because the designer must rely on the programmer for the success of their design, the programmer's skills are crucial to 3D knit production. DR notes there are very few people in the USA who are proficient in knit programming: "Having good programmers ... that's the only way this technology looks good." She explains the frustrating experience she encountered after switching production facilities to take advantage of lower minimums and discovering that the programmers at the new facility were not as skilled as those at the previous manufacturer: "I can't tell you how many prototypes I had to do just for the littlest things ... the framework was there they literally I transferred my data from [the other manufacturer] to them. But the bulk of the work was done so I couldn't understand why these little shifts were [so difficult], they couldn't do them." PF agrees that programming skills will make or break a design, noting that "the roadblock to 3D knitting or using the machines to the maximum of their abilities to

accomplish most of the work at the machine is definitely in the programmer. That is 100 percent.” Designers who are new to the 3D knit process may be unfamiliar with the differences between highly-skilled and less-skilled programmers; this could result in the designer spending more time and money on product development than is necessary.

### **Technical knowledge**

Technical knowledge was noted by all respondents as being helpful for the designer. Accessing the proprietary software directly is one way to gain additional technical knowledge and assist in the development of the garment. DR explains that “you can literally design everything all the way up until the data that gets sent to the machine and knits it out. You can be completely self-sufficient if you can educate yourself in the technology.” But this means that designers must choose between the two main knit machine manufacturers, Shima Seiki and Stoll (because the computer language is not shared between the two), and then pursue formal technical training to learn the software. Without this access and training, designers must rely on their relationship with the production facility/programmer to gain information that will help them navigate the 3D knit design process.

DR notes that through her experience with various production facilities, she has learned about machine capabilities such as needle bed size and knit structure limitations. For example, since 3D knitting creates garments as a series of tubes, the needle bed on the machine, where the yarn is looped in knit structures, must have enough room to create stitches across the entire garment. For a sweater, this means the distance across both sleeves and torso when the garment is laying flat. As PG notes, this may be possible on a smaller size garment, but different machines may physically not be capable of knitting a larger size if their needle bed is too narrow. In addition, the knit structures have limitations that the designer learns about through experience.

For instance, DR explained how there is a maximum depth that a v-shaped neckline can be knitted, simply because the machine cannot knit an angle beyond a certain steep degree angle.

Access to technical knowledge also informs the amount of work that needs to be done. The designer should know when to step in and push for further development, or to stop the programmer if they are satisfied with the development. PG shared an experience of working with a client who was happy with the knit structure development even though PG felt more could be done to create a better garment: “You know if it was for me I'd want to make some changes but I'm not the one to make that call.” But further development would have incurred further sampling costs, and this ongoing development may not be an option for every design that is created, depending on the designer's budget. Likewise, if a programmer without much experience in the technology is resisting any approach to development, the designer benefits from technical knowledge by being able to push back and assert her ideas. DR shared a frustrating experience working with a less-skilled programmer who did not have the experience to produce her design in the manner she knew was possible from her own previous experience. In cut and sew production, it is common for manufacturers to reduce production time by taking various shortcuts, or pushing back against certain production methods if they are more time consuming or expensive. Because knitwear is much more technical than cut and sew production, it is even more important for the designer to know when they can stand their ground and when they have exhausted all options.

### **Barriers to education and training**

Apparel design students in higher education institutions commonly learn the basics of creating tech packs to work with production facilities in the industry. This is beneficial for working within a larger company or as an independent designer, because the tech pack is the standard form of communication between designer and production facility. However, the level of

detail and the amount of practice that students receive in school is not always sufficient. DR explains that while she learned about tech packs in her design program at university, “we didn’t learn them efficiently and not certainly not how to get really good at them. So I got that education in my first year [working in industry].” Learning programming skills is also difficult due to limited facilities that offer the training. Learners must choose between the two major knit manufacturers since their respective programming languages are not transferrable. Yet if this training was more accessible to designers it would enhance their technical knowledge, cutting down programmer involvement in sampling and development and subsequently reducing time needed the production facility. DR notes, “I think it would be extremely beneficial if a designer learned programming because then they save a lot of time and money.” She elaborates that learning programming as a designer is empowering, because “you can literally design everything all the way up until the data that gets sent to the machine and knits it out you can be completely self-sufficient if you can educate yourself in the technology.” However, even when training can be acquired, it takes time to achieve proficiency, as noted in DRs accounts of working with more and less skilled programmers.

PG notes that for her programming training, she traveled to Germany to learn machine operations and Stoll’s M1Plus software program, but “then came home to spin my wheels on the flat part of the learning curve for a couple of years because I was on my own.” She explained that a majority of her education came from trial and error, which required access to a machine and software. PF emphasizes the time required to become skilled at programming, and that access to the software alone is not enough. “it is a long study to get to a level where you’re truly able to utilize the machine in a way that you need to for 3D knitting because this software is not the important thing. The software is a method a means for you to tell the machine what you want it to do.”

In summary, the designer's role in the 3D knit apparel ecosystem is impacted by communication issues due to knowledge gaps relating to yarn and machine capabilities. This lack of knowledge drives up costs for sampling and prototyping, with designers relying heavily on programmers' technical knowledge to develop knit products. While these challenges may be mitigated with more training, there are geographic and financial barriers to education in this sector. These results discussed in relation to the greater 3D knit ecosystem, below.

### **Discussion**

The results of this investigation support and update previous research into knitting capabilities and provide a closer analysis of both the actual and ideal capabilities of the designer in the greater 3D knit design ecosystem. This section discusses the current research findings in relation to previous literature and suggests recommendations for 3D knit designers.

Communication issues were a key design development problem reported by respondents in this study. The results of the data collected here show that Eckert's (1997, 1999, 2001) research into the designer/programmer relationship in the knitting industry, while now over twenty years old and not specific for 3D knitting, is still relevant for the current 3D knit ecosystem. One of Eckert's proposed solutions to the communication bottleneck between designers and programmers was for knit manufacturers to develop an AI enhanced computer system to translate designers' concepts into "complete and correct" data for the programmer (1997, p. 157).

Today, almost twenty years later, despite her suggestions for improved communication, only one of the two leading flatbed knitting machine manufacturers has made any significant advancement in their software user interface. Shima Seiki's proprietary SDS-ONE APEX3 software allows designers to select knit stitch patterns from a vast library of swatches, provides 3D digital rendering of apparel prototypes, converts illustrations and photos to stitches according

to gauge, allows the user to scan yarns into the system to render designs using accurate materials, and more. In contrast, while Stoll's M1Plus programming software does include stitch libraries and some stitch visualization capabilities, the user interface is still highly technical and a significant barrier for designers looking to advance their knowledge in programming capabilities.

It also appears that educational programs do not fully prepare students to perform optimally in the industry since on-the-job training for important design and communication tools like tech packs is still necessary. This finding mirrors the results of Alvanon's 2018 report on the State of Skills in the Apparel Industry, which identified a significant skills gap among fashion designers, with technical design and product development topping the list of greatest training needs by area (p. 16). In addition to tech pack knowledge gaps identified by the designer, all respondents indicated that it would be beneficial for the designer to possess technical knowledge of 3D knitting prior to developing and producing their designs. However, when it comes to gaining machine-specific knowledge, there are limited training facilities and higher education programs can provide designers with technical skills to improve communication and design success. This leaves designers to build their education through interactions with programmers and production facilities. 3D knitting is a more complex programming process that requires additional training and experience beyond standard flatbed knit programming. Unlike a traditional cut and sew apparel production process, where the lead designer directs development until the point of mass production, the 3D knit development process demands most design and fabrication considerations be resolved before a first prototype is even produced. And because the designer generally does not possess the technical skill needed to operate the knit software and machinery, let alone using it for 3D knit design, much of this development happens at the hands of the programmer.

Over the last ten years, research on the use of 3D knit technology as a design tool has presupposed that designers wishing to incorporate this technology into their designs already have access to the machines and the related proprietary software (Ma 2013; Smith, 2013a & 2013b; Taylor & Townsend, 2014; Taylor, 2015; Underwood, 2009). Taylor & Townsend (2014) assert that machine and software access will increase confidence and competence in designers' programming capabilities, leading to greater autonomy and creativity in the 3D knit design process (2014, p. 171). However, until 3D knit software becomes more widely accessible through a more user-friendly interface or affordable open-source software options, many emerging designers and smaller design firms will not be able to access these tools to achieve this technical competence; an interim solution is required.

Yang (2010) has taken a different approach, arguing for the creation of a hybrid position within the textile and apparel ecosystem that bridges the knowledge gap between the designer and the programmer. Considering the current state of the industry, this "designer interpreter" role is an idealistic and unrealistic solution. It has already been established in this research that limited training facilities and programs exist. Where they are available, the associated costs are significant: Shima Seiki provides training at their Japan-based headquarters to clients who purchase machines. This means the upfront investment in the multi-thousand dollar 3D knit equipment (and up to \$200k+ USD depending on machine model<sup>1</sup>) as well as the cost of a round-trip flight to Japan (as reported by DR, Shima Seiki covers training and accommodation expenses once learners have arrived in Japan). This is not an option for small operations who do not have the capital to invest in their own machinery.

A handful of college and university programs offer a course or two on the basics of Shima Seiki or Stoll software programming, but users generally must be registered as an

---

<sup>1</sup> Estimate provided by Shima Seiki to the researcher via email

undergraduate student in a multi-year program to gain access to these classes<sup>2</sup>. Stoll offers programming courses at their headquarters in Germany in two-week installments for a fee<sup>3</sup>, but for North Americans, paying for an overseas flight, accommodation and tuition is still a large financial investment considering multiple two-week courses would be required to gain minimal proficiency in the technology. Currently there are only two facilities known to the researcher that offer a fee-based training class knit machine software to the public, and both are for Stoll's M1Plus program. One is within a production facility in North Carolina, which offers a one-week programming class each month, and another is with production facility in California, where they have recently started offering two-day short courses four times a year.

Programmers were cited by all respondents as being critical to the success of 3D knit production. Programmers do not write new computer code for the knit machine to read; they use proprietary knit software to develop a unique design, just as a writer might use a word processing software to create a document. The key difference in this example lies in the relationship between the software interface and the output mechanism. With a word processing software, a writer programs a document to create any combination of letters, line spacing, etc., and the printer will obey the command to print the file. The writer does not need to know where the ink cartridge is located or other technical printer details to produce a successful print. In contrast, with knit software, the programmer can input any design, but the knitting machine will not produce it unless the programmer obeys the machine operation criteria. The possibilities for the design are therefore constrained by the capabilities of the machine, which are mediated by programmers who understand how to translate designs into files that obey machine parameters. Based on the results presented here, it appears that knit software and machine capabilities have not evolved encourage more direct designer involvement because knit manufacturers still

---

<sup>2</sup> See program offerings at North Carolina State University, Kent State University

<sup>3</sup> Course offerings provided by Stoll to the research via email

perceive 3D knit technology (and digital knit technology, in general) as a tool for production, rather than a tool for design.

Without machine or software access, designers can still conceive of designs for 3D knit garments and work with contract production facilities to develop these concepts into physical products. However, this raises the question of whether the designer is still “designing” if their agency and authority is marginalized by heavy reliance on programmers. Smith (2013b) raises this question when referring to designers engaging directly with the machine but using the related software’s pre-developed modular knit components. For designers without access to the technology itself, this question becomes even more important. Sayer, Wilson and Challis observed in 2006 that for 3D knitting, “The role of the designer must also change; an ability to understand 3D design concepts and the machine parameters is required to complement traditional skills” (p. 43). The present research shows that 3D knit competencies have not yet been integrated into the fashion design skillset, and this may be simultaneously hindering the diffusion of advanced fabrication 3D knit technology in the textile and apparel industry. Education has been cited by all respondents as being a key factor in the success of 3D knit designs, whether through the production facility educating designers on yarn properties, the programmer educating designers on machine capabilities, or the designer needing to learn through trial and error about communication requirements for 3D knit design development. The lack of knowledge and the barriers to gaining knowledge appear to be the biggest factors in prohibiting greater diffusion of 3D knit technology.

Previous literature has encouraged designers to delve more deeply into programming software to take ownership and enhance creativity in design (Ma, 2013; Smith, 2013a & 2013b; Taylor & Townsend, 2014; Taylor, 2015; Underwood, 2009). However, based on the examples provided by respondents, some of the 3D knit challenges could be mitigated without the multi-

year dedicated work required to gain proficient programming skills. For instance, designers could benefit from access to directed educational opportunities, such as in-person or online short courses on knit tech pack development, online modules with close-up demonstrations of knit machine capabilities and basic functions, and digital or print resources on yarn requirements and ideal yarn uses within 3D knit applications. For higher education institutions that do offer knit training, this could be extended to a wider audience through interdisciplinary class projects or specialized courses that pair designers with programmers-in-training to solve design challenges collaboratively. Geographic and cost barriers can potentially be overcome with creative thinking and diverse modes of instruction to increase designer's skills and capabilities for 3D knit design.

### **Conclusion**

This research explored the skills required for apparel designers to develop 3D knit garments, with particular consideration of designers who do not have access to their own 3D knit equipment. This is a perspective that has not been fully explored in previous literature but makes up an important segment of the apparel industry. The role of these designers was examined through the perspectives of three key players in the 3D knit ecosystem: the designer, the programmer, and the production facility. Key themes related to design practice for 3D knitwear arose, including ongoing communication issues, knowledge gaps relating to yarn and machine capabilities, affordability of sample-making and production, designers' reliance on programmer capabilities, and barriers to acquiring education and training.

Results indicate that there are still significant communication issues between designers, programmers, and production facilities. Although designers are generally provided with some training in school to develop tech packs for communicating with manufacturers, often for cut and sew operations, this training does not appear to be sufficient for industry practice and does not include any direction for working in the area of 3D knit. General yarn knowledge is typically

gained in fabric and textiles courses in fashion design programs, but the depth of knowledge about yarn properties required for 3D knitting is not provided in school; designers are only able to gain this information when they begin experimenting with different yarns in the development and sampling of their designs at the industry level. However, development and sampling are expensive, and increasing designer access to preliminary knit structure development opportunities – either through publicly accessible short courses or increased interdisciplinary training in higher education institutions, – may mitigate the financial impact in the apparel development process.

Results also indicate that programmer capabilities greatly influence the success of a given design. Although all respondents agreed that designers would benefit from increased knowledge about 3D knitting machine and software capabilities, education opportunities that provide training for designers seeking to expand their understanding in 3D knitwear are not easily accessible due to geographic and financial barriers. The reliance on trained programmers to operate the knit machinery signals that 3D knit technology (and digital knitting in general) is still considered by knit machine manufacturers as a tool for production rather than a tool for design.

Online courses that provide introductory training customized for designers' needs may facilitate better technical knowledge in 3D knit production for more fluent communication with programmers. The results of this research suggest that the main factor necessary to increase agency in apparel designers engaging with 3D knitting is greater access to education using multiple modes of delivery to reach wider audiences with directed content. Despite recent research and industry interest, the full capabilities of 3D knitting have yet to be realized. Bridging access to this technology through new educational channels could facilitate a positive disruptive force in future textile and apparel innovation.

### References

- Alvanon. (2018). *The state of skills in the apparel industry 2018 report*. Alvanon & Motif
- Eckert, C. (1997). *Intelligent support for knitwear design*. (Unpublished doctoral dissertation) The Open University, UK.
- Eckert, C. (1999). Managing effective communication in knitwear design. *The Design Journal*, 2(3), 29–42. <https://doi.org/10.2752/146069299790225306>
- Eckert, C. (2001). The communication bottleneck in knitwear design: Analysis and computing solutions. *Computer Supported Cooperative Work (CSCW)*, 10(1), 29–74. <https://doi.org/10.1023/A:1011280018570>
- Foster, K. R. (2017). *Factors influencing the adoption of 3D knitting technologies by U.S. companies: A case-study analysis* (Unpublished doctoral dissertation). North Carolina State University, Raleigh, NC.
- Kansara, V. A. (2015, June 18). Knyttan aims to disrupt \$200 billion knitwear market. *Business of Fashion*. Retrieved from <https://www.businessoffashion.com/articles/fashion-tech/knyttan-raises-seed-round-aims-to-disrupt-200-billion-knitwear-market>
- Ma, Y. (2013). *An Integrated Model for Shaped Knit Garment Design and Development* (Unpublished doctoral dissertation). North Carolina State University, Raleigh, NC.
- Martin, B., & Hanington, B. M. (2012). *Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions*. Beverly, MA: Rockport Publishers.
- Sayer, K., Wilson, J., & Challis, S. (2006). Seamless knitwear - the design skills gap. *The Design Journal*, 9(2), 39–51. <https://doi.org/10.2752/146069206789377113>
- Shima Seiki (2019). WHOLEGARMENT® Knitting Machines. Retrieved from <http://www.shimaseiki.com/product/knit/>

- Smith, A. E. (2013a). *Seamless knitwear: Singularities in design* (Unpublished doctoral dissertation), Auckland University of Technology, Auckland, NZ.
- Smith, A. (2013b). *Seamless knitting is it/can it be used as a digital crafting tool?* Making Futures (4). 1-6. <http://makingfutures.plymouthart.ac.uk/media/51137/amanda-smith.pdf>
- Stoll (2019). knit&wear®. Retrieved from <https://www.stoll.com/en/machines/knitwear/>
- Taylor, J. (2015). *The technical designer: A new craft approach for creating seamless knitwear* (Unpublished doctoral dissertation). Nottingham Trent University, UK.
- Taylor, J. & Townsend, K. (2014). Reprogramming the hand: Bridging the craft skills gap in 3D/digital fashion knitwear design. *Craft Research*, 5(2), 155–174.  
[https://doi.org/10.1386/crre.5.2.155\\_1](https://doi.org/10.1386/crre.5.2.155_1)
- Underwood, J. (2009). *The design of 3D shape knitted preforms*. (Unpublished doctoral dissertation). RMIT, Melbourne, Australia.
- Yang, S. (2013). *A creative journey developing an integrated high-fashion knitwear development process using computerised seamless V-bed knitting systems*. (Unpublished doctoral dissertation). Curtin University, Perth, Australia.