Fold, Stand and Drape: Unweaving Physical vs Digital Textile Design Considerations

Author(s)
Kuijpers, Alexandra A.M.; Goveia Da Rocha, Bruna; Van Bommel, Maarten R.; Nachtigall, Troy

DOI
10.1145/3623509.3633351

Publication date
2024

Document Version
Final published version

Published in
TEI '24: Proceedings of the Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction

Fold, Stand, and Drape: Unweaving Physical vs Digital Textile Design Considerations

Alexandra A. M. Kuijpers
University of Amsterdam, a.a.m.kuijpers@uva.nl. Amsterdam University of Applied Sciences, The Netherlands
a.a.m.kuijpers@hva.nl

Bruna Goveia da Rocha
Amsterdam University of Applied Sciences, The Netherlands
b.goveia.da.rocha@hva.nl

Maarten R. Van Bommel
University of Amsterdam, Faculty of Humanities and Faculty of Science, The Netherlands
m.r.vanbommel@uva.nl

Troy Nachtigall
Amsterdam University of Applied Science, t.r.nachtigall@hva.nl. Eindhoven University of Technology, The Netherlands

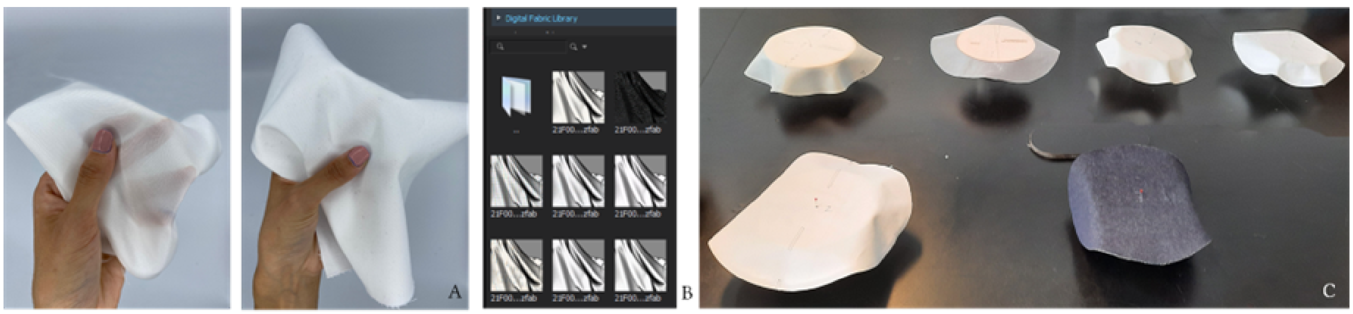


Figure 1: Soft textile materials: (A) Physical engagement with textiles; (B) Own digitized textile material files in CLO3D [10]; (C) Textiles draped on a disc.

ABSTRACT

Fashion design has rapidly become a digital process where textiles are simulated as soft, conformable materials on a digital body. The embodied experience and physical interaction with the textile have been replaced by screen-based media, resulting in a gap in understanding between physical and digital textile material. Consequently, understanding digitized textile properties and characteristics has become challenging for practitioners. This research investigates fashion designers' implicit understanding when selecting textiles, specifically how interactions with physical textiles influence design considerations. Twenty digital fashion designers interacted with ten physical textile materials via tangible and scientific drape measurements, reflecting upon their design considerations. In digital environments, a tangible understanding of material properties is vital, and scientific drape measurements add significant understanding to digital design. The research advances our understanding of integrating digital tools in textile and soft material practices, where a postphenomenological approach is employed to help formulate the design considerations in selecting materials.

TEI '24, February 11–14, 2024, Cork, Ireland

ACM ISBN 979-8-4007-0402-4/24/02.
https://doi.org/10.1145/3623509.3633351

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI)**; • **Interaction design**; • **Interaction design process and methods**;

KEYWORDS

Design Considerations, Fashion, Textile Tangibility, Digital Textiles, Digital-Physical Relationships

ACM Reference Format:
Alexandra A. M. Kuijpers, Bruna Goveia da Rocha, Maarten R. Van Bommel, and Troy Nachtigall. 2024. Fold, Stand, and Drape: Unweaving Physical vs Digital Textile Design Considerations. In *Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '24), February 11–14, 2024, Cork, Ireland*. ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3623509.3633351

1 A TECHNOLOGICAL SHIFT IN TEXTILE PRACTICE

Fashion design (and other textile design) practices have recently undergone a paradigm shift to digital fashion. The technological shift was pushed by COVID-19 and motivated by socio-technical factors of digitalization and a need to transition towards sustainable practices. Before the technological shift, designers commonly considered and selected textile material properties through physical engagement with the materials (Fig. 1A), enabling an implicit evaluation of the textile properties and characteristics. In the ongoing transformation to digital design, designers consider textiles on a computer screen (Fig. 1B), often disconnected from tangible interaction. The wide range of textiles, with their large variety of properties, makes them tunable for an extensive range of purposes, including clothing, architecture, automotive, and medical applications. Textiles are the fundamental materials in fashion and clothing, available in endless variety, each with its unique visual and tactile experience. Textiles play a significant role in our daily lives by affecting our movement depending on how they bend, fold, stretch, and drape along with our body movement. Drape here refers to the technical term that describes how the textile falls, folds, or flows thanks to gravity and other forces, as seen in (Fig. 1C).

Fashion designers negotiate functional and aesthetic design considerations when creating an embodied garment. These design negotiations are phenomenological (e.g., is it warm enough for the intended climate) and postphenomenological (e.g., does this style help express the wearers' worldview). Fashion Designs' digital paradigm shift allows software to visualize tens of options but has isolated the designer's involvement with the material "human-artifact relations" [66]. The lack of a physical textile requires a new digital understanding of physical-digital textile relationships that we see emerging in conversations with digital fashion designers [17]. Postphenomenological approaches to understanding textile material-aesthetics [19] have shown touching the fabric "fabric hand" and textile drape play a key role in moving past screen-based "dis-embodiment" [53]. We speculate that digital fashion software struggles to respect the subtle yet unique differences between phenomenological and postphenomenological design considerations in textiles. Previous design research has shown that fashion and textile designers are particularly specialized in dealing with the subtleties of textile "aesthetics, comfort or functionality" as a discipline [69], which is implicit and difficult to communicate outside the field [34]. This leads us to wonder how tangible and drape interactions with textiles relate to the design considerations of fashion designers, so we do not lose the specialized textile understanding moving forward.

Software like CLO3D [10], Browzwear [7], and Lectra/Gerber [24] enable fashion designers to design, fit, and simulate fashion [4, 17, 30]. Creating new textile definitions is difficult due to the prohibitive cost of equipment and specialized expertise required for accurately measuring textile properties and drape [45]. Most fashion software uses digital textile materials based on objective measured textile properties, e.g., bending, tensile elongation, shear, and friction, as seen in Fig. 2 [45, 47, 58]. We find most designers use the included digital textile examples. This is challenging because often there is little understanding of the digital relationship with the physical textile. The software allows users to add physical properties to generate [60] and visualize (as drape) digital textiles, allowing for a comparison between the physical and digital drape of the textile [42], but few designers do this. Fashion designers often approach textiles through bodily interaction, drawing upon their tacit and implicit knowledge to inform their experience. In contrast, textile science relies on objective measurements to consider textile properties [56]. Instead of looking directly at the software, we look at the bodily interactions of the designers to better understand what is happening when choosing a textile.

Where we would have once looked to digital software to see what changed, we now wonder how digital fashion designers negotiate the design considerations of physical textiles. To explore how digital designers confront physical textiles in practice, we devised the Fold, Stand, Drape bodily design study. We asked twenty digital fashion designers to experience ten textiles typically used in fashion design with a description of how the digital and physical design processes typically work. The digital fashion designers documented their design considerations while handling and observing the physical properties of textiles, reflecting on how that changed their textile decisions when designing. We were deeply interested in what happens when interacting with physical textiles as we find something is missing when the designers work only with digital textiles at the beginning of the design process.

The research contributes to the understanding of design considerations for textiles in design: 1) digital fashion designers continue to build design considerations upon tangible understanding, which reinforces the already found importance of the tangible for an implicit understanding of textile properties for designing in a digital environment; 2) fashion designers' textile material understanding is deepened by examining drape, which emphasizes the importance of observing the physical textile in reality when making design considerations; 3) fashion designers value both phenomenological and postphenomenological experiences to develop design considerations for textile materials. Combining tangible interaction and drape observation with the same physical textiles provides new insights into closely related physical experiences with textiles. The findings give valuable input for research to create physical-digital textile relationships, making them more understandable and accessible. The research intends to inform researchers and practitioners engaging in embodied textile research and the fields of fashion, textiles, and developing software for clothing, gaming, and immersive reality.

2 CURRENT PRACTICES OF CONSIDERING SOFT TEXTILE MATERIALS

A challenge with textiles is how different communities consider the properties and characteristics of textiles in practice. Fashion design tends to use implicit textile material knowledge focusing on aesthetics, comfort, and functionality [52, 56, 69]. Textile science uses objective mechanical and physical properties and develops measurement systems to define (or predict) textile drape, touch, and quality by relating the properties [5, 12, 36]. Design researchers prefer exploring, understanding, integrating, and defining textiles (and other soft materials) through embodied interaction and user-centered perspectives [18, 55, 65]. Berglin et al. [3] suggested looking at approaches used in interaction design, stressing the importance of methods "for working, throughout the design process, with a broad perspective on fashion aesthetics where the expressiveness of acts of use is systematically linked to the expressiveness of textile materials and clothing form" [3].

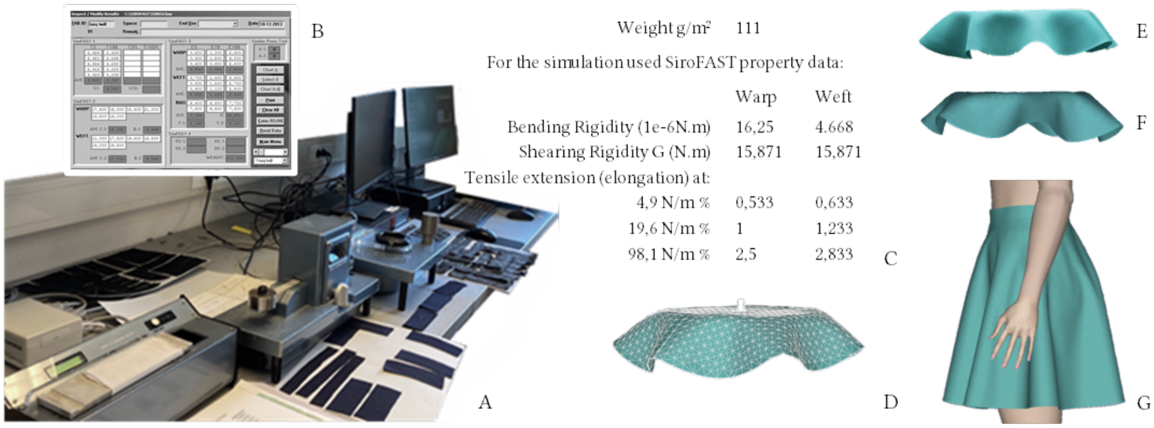


Figure 2: Textile Material lab with physical textile drape and simulations in Lectra [24] based on the textile measurements: (A) SiroFAST [5] system for objective measurement of textile; (B) SiroFAST [5] menu with measured textile properties; (C) SiroFAST [5] property data; (D) simulated textile drape; (E) physical textile drape; (F) simulated or digital textile drape; (G) simulated skirt.

Although approaches differ, there is a shared interest among design researchers, textile material and computer science researchers, and fashion designers in understanding textile properties like tensile elongation (stretch), bending, flexibility, and drape [1, 42, 47]. Cooperation between perspectives brings specific domain knowledge of fashion design when creating the properties and characteristics of garments that satisfy aesthetics and functionality [20]. We elaborate on approaches in fashion design (2.1), textile materials science (2.2), and design research practices (2.3) to see how they can inform each other in the shift to digital design.

2.1 How fashion and textile designers approach soft textile materials

Traditionally, fashion designers start with a sketch and then use two methods to create garment designs. One method is draping a soft textile material around a dress form (or mannequin: a generalized physical representation of the body) to define cut textile panels. A 2D pattern is traced from the draped panels [37, 48]. Another standard method is pattern drafting, where a two-dimensional (2D) pattern is drafted often from a basic block (a flattened 2D representation of the body), which is then physically prototyped (referred to as "sampled"). Both methods require a highly iterative process of prototypes in multiple sizes (fit samples) depending on the quality and complexity of the designed garment [59]. "The garment design process is highly specialised, requiring a combination of design creativity and technical pattern making skills, as well as a thorough knowledge of fabric performance" [30]. The move to digital design contributes to reducing textile materials and the required time [17, 43, 48].

The software digitalization of fashion began in the late 1990s, but widespread use accelerated significantly during the COVID-19 pandemic, resulting in fast technological changes in textile material practice [17, 37]. In current practice, digital fashion design software has translated the traditional process to digital iterations, see Fig. 3. Virtual garments allow design practice to digitally simulate prototypes and explore possibilities rapidly [4, 17, 60], see Fig. 3E. Yet, the screen-based nature of digital design has created a gap with the tangible interaction of the physical textile. As a result, designers face new challenges when incorporating digital tools and designing using digital textiles, see Fig. 3D, instead of physical textiles. There needs to be a better relationship between physical and digital textiles that the designer needs to address. Fashion designer Ruben Baker stated it best, "My biggest concern in my business is that what I'm doing in 3D, can I trust it or can I not trust it?" [17]. Designers often need to adjust the sliders of the textile properties artistically, see Fig. 3B and 3D, to make the digital textile appear more like the physical textile [22].

3D clothing design software addresses time-consuming complexity and creativity that has evolved between 2D patterns and 3D design on the screen-based abstraction of a body [4, 8, 50, 60]. The software helps understand the complexity of textile structures when draped on the body, stemming from the expert knowledge of fiber and yarn properties [8, 9, 14, 69]. Commonly, the mentioned skills require multiple years to master this knowledge [57]. The digital representation enables designers to develop and communicate early in the design process, encouraging greater collaboration [50]. The designer can now consider the complete manufactured textile, making it easier to communicate the direct interaction between the design and the textile with stakeholders across fields and disciplines. Is a physical interaction still needed with the textile to understand how the resulting textile garment interacts with the body? We experience as experts that the digital textile libraries that present the digital textile as a flat textured image see Fig. 3D or, at best, on a proportionless sphere (or disc), make it challenging to understand the digital textile in relation to the physical textile.

There is a rich variety in physical textiles, each with a unique visual and tactile experience based on the fiber composition (e.g., cotton, wool, polyester), yarn construction, or structure (knit, woven, and non-woven) [21, 37, 68]. From objective measured textile properties, 3D fashion design software calculates and simulates fiber

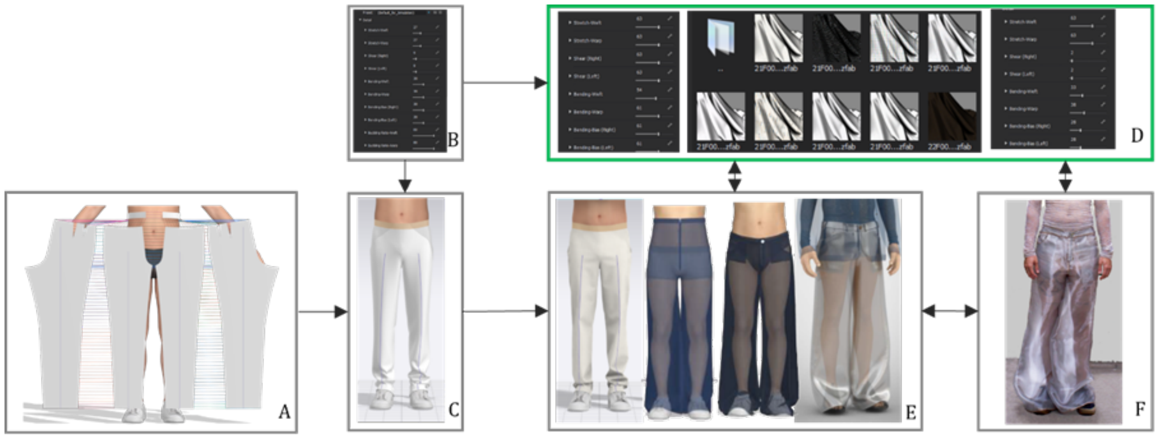


Figure 3: Digital fashion design process in CLO3D [10]: (A) archetypical concept block placed on design fit avatar; (B) sliders of the default CLO3D simulation material; (C) garment in default CLO3D simulation material; (D) digital textile material files in CLO3D created with the measured properties of the physical textiles used at the university; (E) iterative design process; (F) a photograph of the final physical design (by fashion design student).

and structure, which can be complex [42]. Moreover, in fashion and textiles, design practice varies based on location and interactions with a complex system of stakeholders. The difference between handmade Parisian Haute Couture, high-end designer, contemporary, high-street, and mass-market clothing is enormous [28, 37] yet the software is the same. 3D fashion design software is now used in design practices [17], and those engaging with digital-only fashion design [4, 60], personalized digital knitting [4], garment-shape through textile manipulation [8, 50], shape-changing textiles interfaces [9], and sustainable approaches like zero waste cutting [49]. These involve direct interaction with the textile process and call for an explicit understanding of design considerations to be translated into fashion design software.

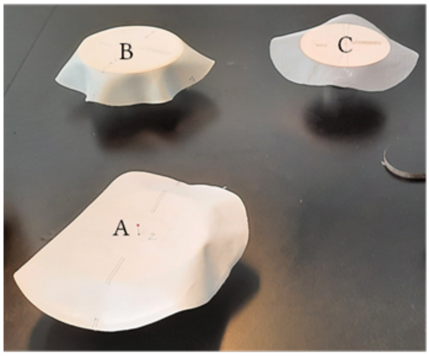
2.2 How material science and computer science approach soft textile materials

The digitalization of textiles for garments is urgent, as expressed by the European Textile Strategy [11] which stresses the importance of the designer in the decision process to select and use durable, quality materials as part of the strategy to reduce the extreme amounts of waste textile practices are causing [23]. The urgency of sustainability in clothing and textiles requires changes in all parts of fashion practice, affecting the textile practice particularly: "Fabric decisions are best made before designing a specific silhouette" [37] to avoid errors in prototypes. Incorporating a sustainable attitude in an aesthetic design process and finding new ways [50] also applies to creating digital prototypes, considering soft textile materials used for garments with their large diversity and very subtle differences in characteristics between similar textiles with different material properties [8]. Understanding the technical challenges in measuring and simulating intricate textile properties requires input from textile material science [45] and computer science [6].

Textile material and computer science use elaborate measuring systems to determine objective mechanical and physical properties. Systems like the Kawabata Evaluation System (KES) and Fabric Analyses by Simple Testing (FAST) measure and connect bending, shear, extensibility (elongation), and compression properties to performance and touch [5, 36]. Objective-measured properties and textile weight simulate textile [6], enabling digital garment fitting and connecting physical and digital textiles [47, 58]. Fit, in this sense, is an interaction between the digital 3D human, digital textile, and digital 2D pattern [42]. Textile properties of bending, elongation (stretch), shear (diagonal stretch), and friction play a crucial role. Tensile measurement devices are commonly used to test according to multiple standards; the elongation standard is advised as a starting point to obtain elongation and shear for 3D fashion design software [16, 43, 45, 62].

This is not to say that these are standards everyone uses; many of the mentioned software companies have their textile testing kits that are incompatible with each other due to different methods, incomparable units, and a lack of accuracy, with most believing that textile manufacturers should provide these objective measurements [16, 43, 45, 62]. Objective material characterization is often seen as a black box of physical properties, e.g., Fig. 4, requiring material and computer scientists to spend enormous effort creating relationships between each software's physical and digital textiles. Working with multiple software packages is common in practice [17] causing efforts towards interoperability between systems [62]. The accuracy of measurement affects the accuracy of the simulation [45, 47, 58] resulting in time and material investment as each textile is measured multiple times to obtain software-specific properties, adding to the need for more standardization [16, 45, 47, 62].

From the material science perspective, the static textile drape is how the material flows or stands, influenced by gravity [13]. Drape is often measured by laying a 30 cm (about 11.81 in) diameter textile centered on an 18 cm (about 7.09 in) disc. In the Cusick drape test method, the fixed proportions and circular shape result in an even overhang of the drape [12, 13, 63]. Drape is understood as the interaction between the textile's bending and shear properties (see Fig. 4), where the internal forces (related to, e.g., fiber, yarn, weave,



SiroFAST			Cotton Twill 21F00020		Silk ponge 21F0015		Silk Organza 21F00013	
Property	Symbol	Unit	Warp	Weft	Warp	Weft	Warp	Weft
Weight	W	G/m2	360		32		23	
Extension	E5	%	0.3	0.3	0.6	0.4	0.3	0.3
	E20	%	0.4	0.4	0.9	0.6	0.5	0.5
	E100	%	1.6	1.6	2.7	1.5	1.2	1.2
	EB5	%	0.2		7.3		13.3	
Bending length	C	mm	39.5	34.9	24	20.3	33.2	32.2
Bending Rigidity	B	µN.m	217.7	150.4	4.4	2.7	8.1	7.4
Shear rigidity	G	N/m	566.8		16,9		9.3	
Thickness	T2	mm	2.144		2.15		2.208	
	T100	mm	2.058	A	2.077	B	2.069	C
Surface Thickness	ST	mm	0.086		0.073		0.139	

Figure 4: Draped textiles and their SiroFAST [5] measurements showing the differences in bending, shear, extensibility (elongation) properties, and weight of: (A) cotton twill; (B) silk Pongé; (C) silk organza.

finish) intersect with the textile's weight and gravity, determining how the textile folds, stands, and drapes. Bending and shear properties are highly correlated to textile drape. The interaction between bending and shear causes unique, subtle, and significant differences in a textile drape and behavior [13, 42]. Subjective comparisons by expert users between the digital and the physical textile drape have shown high correlations, making the drape helpful for comparing and verifying physical and digital drape [42].

2.3 How design researchers approach soft textile materials

Novel approaches are needed to understand the digital-physical relationships of these materials [17, 43], which has been a focus of recent TEI and related communities as a form of hybrid embodied knowledge [61] or first-person embodied textile experience [52]. Design research has been interested in tangible soft textile materials, showing the importance of documenting the process [26], sharing tangible swatches [55], new textile design processes [70], and bridging between different disciplines [69]. Design researchers have also shown soft textiles play a key role in embodied interaction with wind [54], electrostimulation [41], conductive biomaterials [2], and shape-change [40, 65]. Recent research like SKOBY has measured the flexibility (elongation) of microbial textiles [1], drape motion using Machine Learning [29], and the importance of fit and stretch to capture motion sensing [46]. Additionally, design researchers have recognized the challenges and opportunities in exploring the potential of tuning textile and yarn properties for understanding the relationships between fabrication processes, material properties, and interactive possibilities [9, 14].

Embodiment is an important concept for garments, given the constant, direct, and intimate contact with the body requires. Elements of embodied interaction show how "relevant behaviours to tactile experiences with textiles that we have not accessed with previous methods, and no previous descriptions were encountered in the fashion design and textile literature, or more generally in relation to materials experience" [56]. Design research into materials [18, 41, 46, 54, 64] has begun to address understanding soft materials. Yet, the challenge of defining the design considerations surrounding textile materials remains [9, 14, 45, 50, 57, 69]. But we remain hopeful as there are many approaches in more complex materials like the "Material Experiences Framework" [25, 35], the "Materials in Product Selection Tool" [38], and the "Material Lens" [67]. Postphenomenological framing in Research through Design increases a deeper and more dimensional understanding of human-technology relations [31]. The importance of tangible interaction often lost in current digital practice, is addressed [32, 33, 53], asking for new physical and digital soft materials relationships to be addressed. Moreover, exploration of the definition "hybrid" and the digital-physical relation in "co-production" [15] and more than human approaches [39] show.

In design research, it is generally understood that a phenomenological understanding of materials requires tangible interaction. A material-aesthetic-driven interaction design perspective considers how material shapes the design and interacts with the wearer's body, how the wearer interacts with the garment [18] and how technical and aesthetic materials interact. In "Solar Garments" [19], textile material and solar cells (both selected for their tactility) lead the researcher to see technology as a material from a postphenomenological perspective [19]. A valuable approach for other HCI researchers [27], postphenomenology seeks to overcome technology's purely functional and instrumental roles [19] by embracing material aesthetics to consider how the technology artifact mediates between humans and the world. In this role, technology can "coshape" [66] new relationships or reinforce or decrease interpretations between humans and their worlds. Subjectivity and objectivity are shaped by the mediation of our behavior and perception through technology. Suppose aesthetics includes the bodily interaction or sensory level. In that case, the practical handling of "things" and the materiality of "things" becomes relevant again beyond just a visual perception of beauty and style [66].

3 METHODOLOGY

We recruited 20 digital 3D fashion designers in an upper-level 3D fashion design course for a three-part workshop. Participants agreed to an informed consent form where collected data was anonymized. The workshop was described as a research project and not part of their educational program; three male and seventeen female students ranging from twenty to twenty-seven years

Table 1: Textiles

Identifier	Category Code[a]	End-use category	Description	Weight in g/m^2
21F00013	A1	Sheer/special occasion	Silk Organza	21
21F00015	A2	Sheer /special occasion	Silk Pongé	36
21F00012	B1	Shirts/blouses/dresses	Cotton Satin-unbleached	112
21F00018	B2	Shirts/blouses/dresses	Poplin / Organic	120
21F00035	C1	Sweaters/jumpers	Winter sweat	295
21F00036	C2	Sweaters/jumpers	Inlay or loopback weft knit [21]	280
22F00001	D1	Suiting/coats	Slightly felted wool	279
22F00002	D2	Suiting/coats	Wool (CK)	198
21F00020	E1	Casual wear/jeans	Heavy Twill/White denim	381
22F00000	E2	Casual wear/jeans	Raw Denim	470

[a] From Table 1 only the category code was given to the participants

old participated. The workshop took place in a European context, but the international nature of the course brought students from worldwide. Participants were enrolled in a digital 3D fashion design course with specific classes on working with digital textiles. Participants had 3D fashion design firmly embedded in their curriculum, with at least two years of previous experience with the 3D design software, including adjusting avatars and designing cutting patterns. Many participants had previous experience with physical fashion design. They were prompted to work in a hybrid way and to consider the interaction between digital and physical designs with physical samples. In order to inform designers, design researchers, and software developers, of the digital physical textile experience, we concentrated on opening an understanding of how design practitioners consider physical textiles instead of the software-based digital textiles they are used to.

Participants engaged in a high-paced, four-hour-long workshop that followed the typical time frame of fashion practice. The workshop was divided into three phases: Tangible, Drape, and Reflection. To ensure that the design considerations remained unbiased during the Tangible phase, the participants were kept unaware of the content of the next phase. Additionally, the Drape phase was conducted in a separate room. Ten textiles were selected, see Table 1, with both similar and distinctive characteristics inspired by previous research [42]. The ten textiles, publicly accessible at our university library, were divided into five end-use categories familiar to fashion designers. While the end-use possibilities are extensive and depend on the designer, brand, and fashion [37, 68], we included the most common textiles in our test set in Table 1. Fashion typically describes fabrics by their assumed end use, e.g., suitings are textiles used to make a suit. We organized the textiles by weight of each end-use category see Table 1. We did not share the textile information with the participants during the workshop.

The textiles were cut into square samples measuring 30x30 cm (see Fig. 5A) for the Tangible phase and circular samples 30 cm in diameter (see Fig. 5B) for the Drape phase. For the Drape phase, a semi-scientific drape setup with the circular samples were placed on a laser-cut disc of 18 cm (see Fig. 5B and C) based on previous research [42, 44]. A questionnaire with structured open questions for each phase was given. Participants were instructed to: 1) touch with the textiles similarly, 2) thoroughly consider each textile, and 3) fill in the questionnaire.

The first phase, Tangible, started with a presentation (appendix 1) in which the participants were introduced to examples of how other material researcher approaches materiality, including examples from Giacardi and Karana [25], Wiberg [67], and Kesteren et al. [38]. Inspired by "Interaction Design Methods in Fashion Design Teaching" [3], we asked participants to consider methods in contrast to fashion design practices to approach textiles from a fresh perspective. Participants touched and interacted with all ten textiles (see Fig. 6), noting their design considerations based on the structured questions see Table 2.

The second phase, Drape, consisted of an introduction to scientific drape measuring methods, including a presentation on drape analysis methods. During the workshops, the participants worked with physical textiles. To link with the digital environment, a digital library with the ten textiles draped on a digital drape meter according to the standard dimensions [42] was presented (see Fig. 7) with examples of how the library functions practically in CLO3D. This scientific drape method for generating digital textile definitions was a novel workflow for the participants. Participants were asked to consider the physical draped textile (see Fig. 8) and to record their insight on each sample's design considerations. Semi-structured interview questions about the drape phase (Table 3) considering the Drape observations of the textile followed.

The third phase, Reflection, asked participants to reflect on how the information from the drape phase changed their design considerations from the Tangible phase for each textile, see Table 4. Textiles from Tangible interaction and Drape observation were available for the reflecting participants.

4 RESULTS

Responses to the Tangible, Drape, and Reflection phase questions in Tables 2, 3, and 4 were organized into a spreadsheet (appendix 2), sorted by responses per participant and textile type (see Table 1). Open interview questions enriched the participant data and reflections. The input from the participants was tagged to enable selection based on characteristics (e.g., soft, rough, stiff, etc.) while the context of their answers was preserved. During the study, we

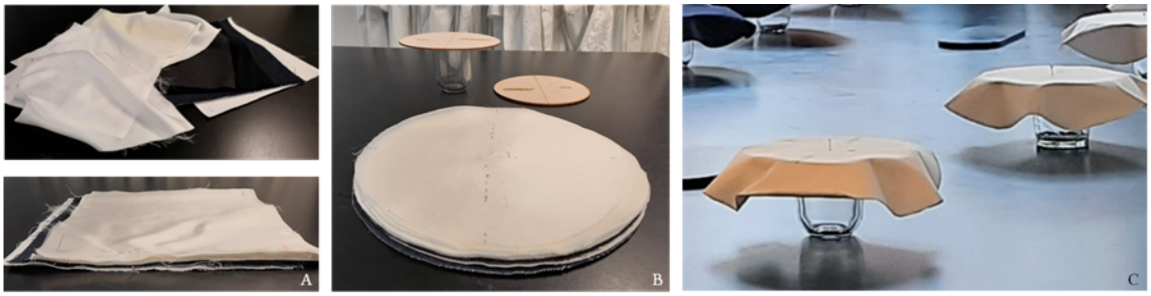


Figure 5: Workshop preparation: (A) Tangible samples of the ten textiles; (B) Drape samples of the ten textiles, with laser-cut support disc and stand; (C) the circular samples draped on the support disc.

Table 2: Questions *Tangible* interaction

	Questions	Purpose
T1	What do you feel when you touch the fabric?	To generate insight and implicit understanding into the process when designers consider textiles for a design.
T2	What could you use this fabric for, and for what not? Why?	
T3	What is the comfort of the fabric? How does it feel on your skin, inside and outside?	
T4	What are you considering when you select this fabric for designing?	

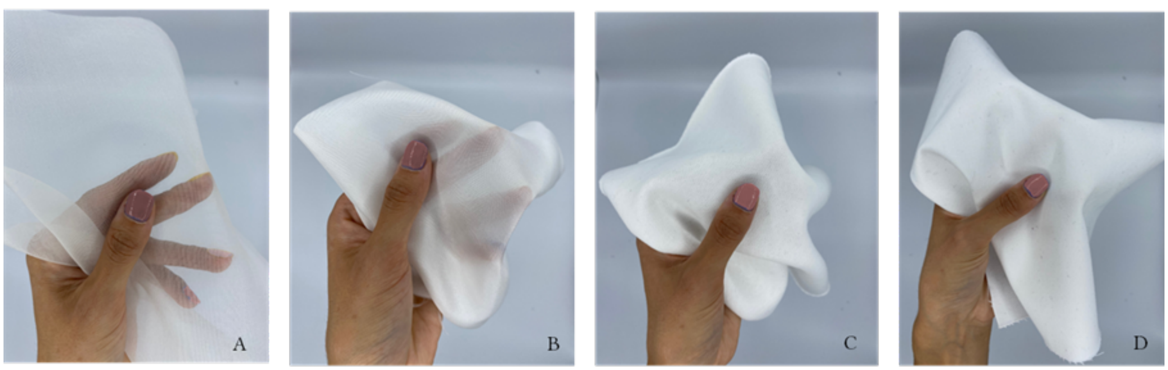


Figure 6: In the Tangible phase of the workshop, participants felt and expressed design considerations: (A) Textile A1; (B) Textile A2; (C) Textile C2; (D) Textile E1.

Table 3: Questions *Drape* observation

	Questions	Purpose
D1	What textile properties and characteristics can you observe?	Questions to get insight into the participants' design considerations (observations from the top and front of the drape)
D2	What else can you observe about this fabric?	
D3	What could you use this fabric for and what not in your opinion? Why?	
Du1	How many waves or nodes can you count?	Drape Understanding (Du). Ensure thorough observation and analyses, in a similar way, increase understanding (observations from the top of the drape)
Du2	The amount of drape (ten point scale: no drape - a lot of drape)	
Du3	The stiffness of the drape (ten point scale: limp-stiff)	
Dg1	What did you learn from the drape analyses?	Drape general questions (Dg) (Not textile specific). Get insight based on the presentation and drape methods.
Dg2	How does the information from the drape analyses effects your design practice?	

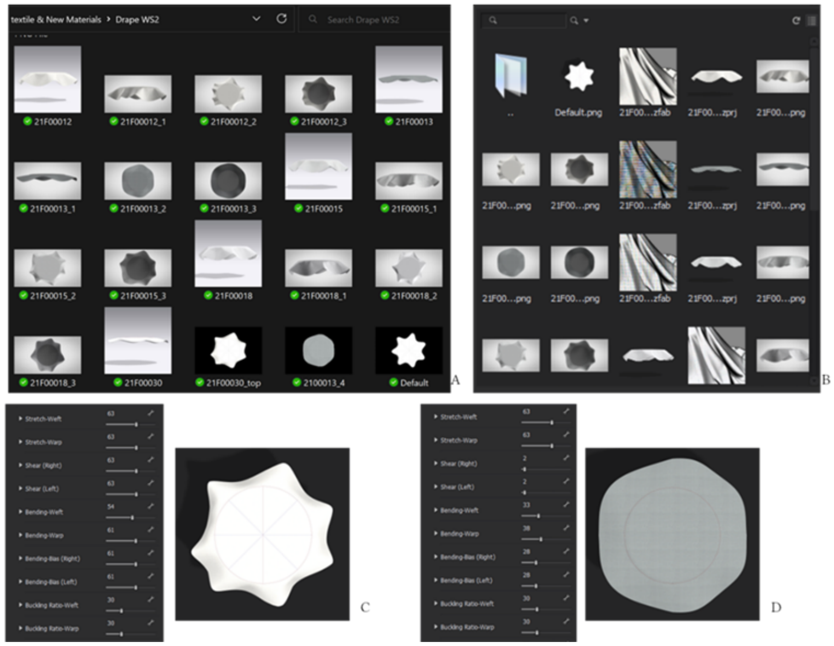


Figure 7: Configuration of the digital textile library, simulated in CLO3D [10] based on textile measurement of physical textiles from Table 1 (A) The library in Microsoft SharePoint [51]; (B) The library is connected in CLO3D [10]; (C) and (D) directly accessible and usable digital textiles with different properties – samples 30 cm diameter draped on an 18 cm disc, and sliders with converted textile properties.

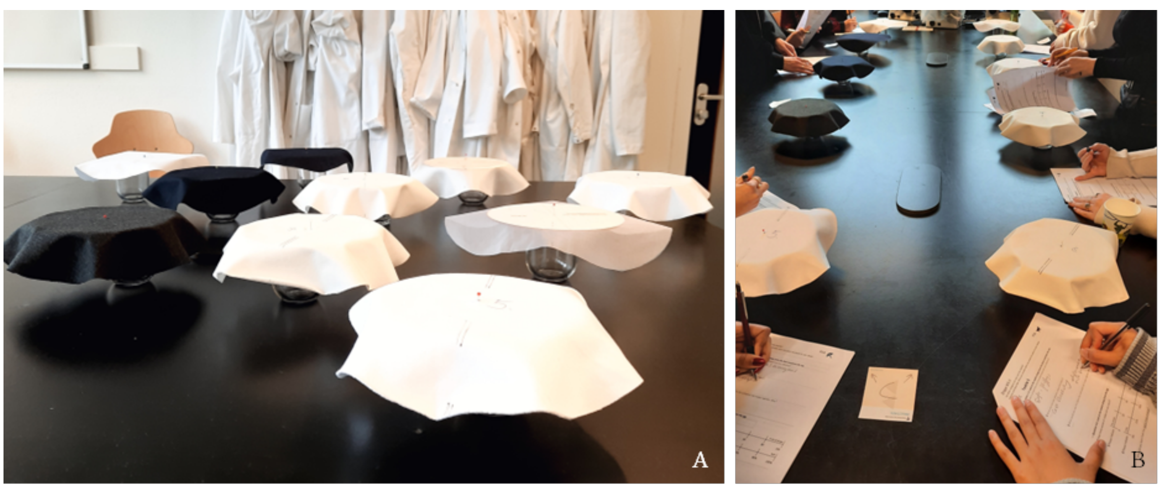


Figure 8: Drape phase of the workshop (A) and (B) where participants observed drape and made design considerations.

Table 4: Questions *Reflection*

	Questions	Purpose
R1	How does the information from the drape view and drape analyses change your design consideration for this textile? How does it: Inform you? Confirm you? Challenge you?	- To give the participants guidance for the reflection on the drape analyses. - To measure how the drape observation influenced their design considerations.
R2	When you look back at your considerations you wrote down during *Tangible*, what can you alter based on the insights from *Drape*?	

analyzed the data on each textile to determine how their characteristics relate to measurable properties and how design considerations evolved throughout the workshop. Additionally, we examined the data based on the intended end-use for each textile.

4.1 Design considerations across workshop phases

In Table 5, exemplary observations of the participants summarize the main findings. The observations are organized in three categories: Section 1) The importance of tangible interaction for the interpretation of the textile material; Section 2) Increased understanding resulting in a changed attitude towards the textile material through drape observations; Section 3) The design considerations based on tangible interaction changed after observing the textile's drape. The textiles are indicated with the category code given in Table 1. Participants were assigned anonymous individual numbers (e.g., P1, P2, etc.). Full results are provided in the appendix, and findings are presented in section 5.

5 FINDINGS

The workshop caused a shift in the participants' design considerations. Tangible interaction was a crucial element for their design considerations, as shown in Table 5. The observation of the drape contributed to material understanding and design considerations. The participants' comprehension of the material and attitude towards it improved during the drape phase.

5.1 Importance of a *Tangible* reference

The results from the *Reflection* phase showed the importance of *Tangible* interaction to the participants with physical textiles for interpreting the material. P17, as an example, when reflecting on textile-B2 stated that it was challenging "to look at the properties without touching it because the observation was a bit different. It looks stiff, but it isn't; it's quite soft" when reflecting upon the *Tangible* considerations. Similarly, P7 preferred *Tangible* interaction to understand the textile: "When feeling the fabric, I can say more about it than when I look at it." P7 and P17 illustrate well the importance of *Tangible* interaction and the challenges of the digital transition of textiles. The *Tangible* phase includes different layers of understanding, implicit knowledge, experience, and skills previously gained through making, interpreting, and relating. Through this method of interaction, design considerations are made based on the textile properties and characteristics in relation to bodily perspective, use, wear, situation, application, making, finishing, performance, quality, durability, and aesthetics. The findings and statements of the participants emphasize that *Tangible* interaction is an important way of working with soft materials. The *Tangible* interaction is increasingly missing when designers work in digital 3D design programs and select their materials on a screen.

We observed that participants' bodily interaction in the *Tangible* phase with the textile interactions elicited participants to consider the samples from both first and second-person perspectives, often in combination with each other. From a first-person perspective, for example, P20 considered "the structure" of textile-A1 from a designerly perspective to "create transparent volume" and "straight designs with a transparent look." When considering the second-person perspective, for example, P13 for textile-C1, considered the body of the wearer, mentioning their comfort, and protection against cold in combination with the first-person perspective, for example, "a thick fabric, maybe not the best for draping". Additionally, participants related the distinct characteristics of each textile, explored during the *Tangible* phase, to a possible use. P13, for example, related the "super stretch, solid, flexible, soft and warm" characteristics of textile-C2 to "feels comforting" connecting this to a "sweater" as a suitable garment. For the textile-B2, P4 considered "elegant pants," and questioned if a lining was needed related to the "silky, smooth, thin, slippery, no stretch, nice on the skin" characteristics.

In some cases, the requirements, and challenges for working with the textiles (make and finish) were considered, like P18 related "hard to work with sewing-wise" to the "fragile" characteristics of textile-A2. Or P18 considered that the design possibilities to drape or structure the textile-B2 could be used to create "a sheer top or dress that has to be very flowy and lightweight." Furthermore, characteristics were often considered in relation to a degree of luxury or durability. P4, for example, related the characteristics of textile-B2 to "elegant pants" and simultaneously considered "Can I decrease how much it creases? Will it stain easily?" The durability and quality considerations of the participants fit the requirements of the European Textile Strategy

The results showed that most of the participants understood the textiles quite well: They identified textile characteristics (e.g., soft, smooth, silky, slippery, rough, structured, flexible, stiff, stretchy, thick, thin, fragile, breathable, warm, scratchy, insulating, creases, wrinkles), drape characteristics (stiff, flowy), optical characteristics (see-through, shine), and the weight for the lighter or heavier textiles. The proposed end-use largely supports the common end-use of the selected qualities described in Table 1.

5.2 Contribution of *Drape* observation to material understanding and the design considerations

The *Reflections* of participants enabled us to identify ways that *Drape* observation contributed to a more nuanced understanding of the textiles considered in *Tangible*. While in some cases, *Drape* (somewhat) confirmed the design considerations, we also see a change in the attitude of many participants towards the materials by relating the *Drape* observation to the *Tangible* interaction. Some participants used *Tangible* interaction to examine the drape and based their design considerations on the drape properties of the textile, but their considerations changed after the *Drape* phase. P18, for example, stated they would like to use textile-A2 "for a sheer top or dress that has to be flowy and lightweight." Through observing the *Drape*, understanding, and attitude changed towards the textile: "It's more fragile than I thought. It is shiny and soft. The drape is beautiful. The fabric is challenging sewing-wise because it is so fragile. Not as see-through as I thought, nice shine as well".

In some cases, the change in attitude during *Drape* observation also highly impacted participants' thoughts on the suitability of the materials for certain kinds of designs. During *Tangible* P17 considered that textile-A2 could be used for "Curtains for privacy"

Table 5: Examples of the process across the different workshop phases on the design considerations

Phase 1 *Tangible* interaction Properties and end-use	Design considerations	**Phase 2** ***Drape* observations**	**Phase 3** ***Reflection***
Section 1) The importance of tangible interaction for the interpretation of the textile material			
Textile-B2 - P7: "Thin light weighted fabric, but a little stiff. It feels nice on the skin, but it does not fold very nicely. The outside is more structured & the inside is more smooth. Maybe a structured top or structured dress, but it is see-through, so then I'll have to line it."	"I think I would use it for samples."	"Stiff, crisp. Lightweight, but sturdy."	"When feeling the fabric I can say more about it than when I look at it." Changes: "Nothing."
Textile-B2 - P17: "The fabric feels quite soft and smooth. It feels soft on the skin and breathable, like a cotton weave. The fabric can be used for casual summer wear. It is not suitable for outer or winterwear."	"I am considering the fact that it is a white simple weave that can be used for a lot basic designs."	"It looks stiff and like it wrinkles easily. It's woven and white." Use: "Shirt."	"It wrinkles easily. It can be used for casual wear." Challenging: "To look at the properties without touching it, because the observation was a bit different. It looks stiff, but it isn't its actually quite soft."
Section 2) Increased understanding resulting in a changed attitude towards the textile material through drape observations			
Textile-C2 - P13: "Super stretch – solid – flexible -Soft. Soft and warm would feel comforting." Use: "Top/sweaters."	"Tiny bit see-through – but a lot is possible with the stretch."	"Thick – solid - a lot of drape ⟶ flexible. Soft – not see-through." Use: "Sweaters."	"There is more drape than when I thought while feeling the fabric. Even though the fabric is solid, it is super flexible"
Textile-A2 - P18: "Very soft but fragile, light weighted, makes a sand, is see-through and fringes easily. It feels comfortable and soft on the skin. Also breathable yet sweaty in summer? I would use it for a sheer top or dress that has to be very flowy and lightweight."	"If I want my garment to be see-through and this fragile, it is also hard to work with sewing-wise."	"Looks soft, shiny, comfortable on the skin and drapes nicely. Shiny surface." Use for: "Sheer tops, summer collections, flowy garments."	"It's more fragile than I thought. It is shiny and soft, the drape is beautiful. The fabric is challenging sewing-wise because it is so fragile. Not as see-through as I thought, nice shine as well."
Textile-D2 - P11: "Minimal stretch. Soft . Thin size twill. Both sides smooth and soft. Yes: Pants, shirts. No: Hoodie, sock, jogger.	"Thickness/thinness, color, feel, twill, consistency, smell."	"Soft. Felted look. Drapy. For: Jacket, shirt, pants."	"Felted soft look. Drapyness. Digital vs reality look on this. How does the digital effect this in reality?"
Textile-A1 - P1: "Slightly rough. Scratchy. See through. Uncomfortable Inside/outside (same). Tule underskirt (for volume). Ability to build structure. Not for Jumper: Lack of comfort, insulation and weight.	"It's transparency, lack of stretch & ability to build volume with."	"See-through. Stiff. Frays at edges. Netting for skirts to build volume. Not: T-shirts, due to lack of comfort/opacity."	"Informs that there would be little drape. The fabric was stiffer than I expected. Challenge: "How little drape there was. It would create a stiffer more voluminous underskirt from what I originally thought."
Section 3) The design considerations based on tangible interaction changed after observing the textile's drape			
Textile-B2 - P4: "Silky smooth, thin, slippery, no stretch. ... nice on the skin, . . . rather breathable ... Creases quite easily. Blouses, dresses. Elegant pants (lining ?)."	"Can I decrease how much it creases? Will it stain easily?"	"A bit stiff, lightweight? Matte, smooth." Use: "dress/blouse – formal and informal."	"The fabric was /seemed way stiffer during drape than during tangible, I suggested a wider range of garments than during drape."
Textile-A2 - P17: "The fabric is very comfortable, soft on the skin, both sides and almost weightless. ... Curtains for privacy . . . not really suitable for garments because it is so see-through."	"I'm considering the fact that it is lightweight, see-through and that it doesn't wrinkle easily."	"It is shiny, and a bit see-through. It looks smooth and lightweight. Its white and woven". Use: "Curtains, sleepwear, or lingerie."	"It could be used for a garment. It is weightless and therefore drapes easily." Challenging: "To look at ways how to use the fabric." Changes: "That it would be pretty as a sleepwear. I first said it wouldn't be suitable for a fashion garment."
Textile-A1 - P20: "A bit rough and crunchy. It's thin and breathable but not too soft. For creating transparent volume, for straight designs with a transparent look."	"The structure."	"Thin but stiff. Very light, so light it doesn't have a lot of drape. To create shape + texture."	"That it is stiffer. I already thought it was very stiff. Even stiffer than I expected." Challenge: "Play further to know the structure."
Textile-C1 - P13: "Inside super soft, no stretch super solid, strong. Comforting, warm would be something people could wear every day. Tops and sweaters. Especially with sweater people love a super soft inside."	"Kind of a thick fabric, maybe not the best for crazy Draping."	"Thick - not symmetrical draping. Solid – soft". Use: "Sweaters."	"Seeing it as drape, it was more than when I only felt the fabric. You can indeed drape crazy with it".

as it was "not really suitable for garments because it is so see-through." After the *Drape* observation, their design considerations changed by finding that the textile "is weightless and therefore drapes easily. It would be pretty as sleepwear." During *Tangible*, P4 considered textile-B2 for: "Blouses, dresses. Elegant pants." Through the observed *Drape*, on the other hand, they visualized that: "The fabric was /seemed way stiffer during *Drape* than during *Tangible*, I suggested a wider range of garments than during *Drape*."

Regardless of how *Drape* confirmed or changed the considerations made through *Tangible*, we observed that the combination of methods supported participants in gaining a deeper material understanding. In turn, this deeper understanding helped participants consider the possible implications of using the textiles for specific applications. P1, for example, considered the "Ability to build volume with" textile-A1 during *Tangible* interaction. The reflection of P1 on the *Drape* observation indicates an increased understanding and better insight into the end effect of textile-A1 on the garment they envisioned before: "The fabric was stiffer than I expected" so "it would create a stiffer, more voluminous underskirt from what I originally thought." P13 had a similar experience after observing the *Drape* of textile-C2: "There is more drape than when I thought while feeling the fabric. Even though the fabric is solid, it is super flexible".

More than a tool for visualizing measurement input in digital design, these reflections indicate that the introduction of *Drape* observation to textile consideration can support designers to increase their understanding of materials. *Drape* observation equips designers with new tools to consider the characteristics of physical materials for their designs. Combined with *Tangible*, *Drape* observation can also equip designers to better understand digital textile materials when designing in digital environments.

6 DISCUSSING AND REFLECTING UPON THE CHALLENGES AND IMPLICATIONS OF DESIGNING WITH DIGITAL SOFT TEXTILES

There is a challenge when dealing with the physical-digital difference in textiles in fashion design. We find that design considerations are not only enhanced when considering textile hand and drape, but that the design considerations benefit in both phenomenological and postphenomenological ways.

6.1 Challenges of digital vs physical textile materials

There is a physical-digital difference between the design considerations perceived through physical engagement and designing from the (tunable) properties in the digital environment that come from textile and computer science. Physical design considerations are often understood through the hand and often become implicit. Digital design considerations miss the embodied interaction with its implicit understanding. Physical and digital textile materials are based on the slight differences in objective measured bending and shear properties. But as we see in the digital designer reflections, the design considerations in textiles, clothing, leather, and fashion go beyond sliders to adjust the stiffness or flowyness of the soft textile material. Physical-digital textile transformation for fashion design practice requires a combination of phenomenological and postphenomenological approaches to represent what designers are considering. There is value in increasing designers' understanding of scientific properties, but developing a nuanced understanding of the designers' considerations when creating a digital material is equally important.

The phenomenological argument that more science is needed to accurately simulate textiles is previously understood. Developing an understanding of scientifically measured textile properties required to simulate textiles in garments is important to designers, design researchers, and obviously, material or computer scientists [1, 2, 29, 41, 46, 54], as discussed in 2.3. The shared interest in accurately digitalizing textiles [9] helps facilitate digital design processes that simplify the complexity of fashion design. However, this only works when accurate [45], which remains important to fashion technology related research [8, 9]. The phenomenological properties remain vital not only to the physical artifact but vital to the digital textile as well. The shared interest from design, science, and design research needs greater knowledge transfer [26, 61] and new processes [40, 70], which are valuable to incorporate for textile and fashion.

We find that great opportunities are in the postphenomenological approaches to textile and fashion as the design considerations of the designer (and most likely the wearer) "coshape" the meaning of physical textile materials [66] and in research of screen-based "dis-embodiment" [53]. In digital fashion design, a postphenomenological lens is valuable to understand the different layers that occur in the initial phases of the design process when a textile is considered for a design. Embodied interaction with the textile enabled designers to translate implicit knowledge into design considerations for the textile materials. They are resulting in a phenomenological understanding of textiles developed through tangibly interacting with the soft textile material.

Only having a tangible interaction with the textile created a more postphenomenological understanding of the design considerations. Observing the textile draped resulted in phenomenological interpretations of the material. A combination of both tangible and drape resulted in a postphenomenological vocabulary within the reflections that demonstrates the participant understands the entanglements between both phases as they consider what each means to the wearer's everyday life. Phenomenological understanding allows the designers to make postphenomenological design considerations for subsequent phases of design, fabrication, and use where ideas of style, social interaction, and personal expression become important. Design considerations based on a deeper textile material understanding consider the wearer's comfort, durability, aesthetics, style, and more, as discussed in 5.1. Then materiality of "things" becomes relevant again beyond just a visual perception of beauty and style [66]. Understanding the relationship of digital-physical textiles requires holding often explicit phenomenological and often implicit postphenomenological ideas in the mind simultaneously. More research into the software of digital fashion design is required.

6.2 Drape

In the drape phase, we found that the drape method changed the perception of the soft material, co-shaping the relationship between the designer and the soft material, uncovering limitations and new possibilities for their use. In our study, the drape method informed, confirmed, or challenged the participant designers. At the same time, it supported them to consider the differences and similarities between the material properties related to the drape of the textiles evaluated. This method allows designers to visualize how textiles could flow around or stand from the body.

The general reflection of the workshop participants on the drape observation provides insights into what they learned during the workshop and how they think it affects their design practice. The reflections showed the potential of drape tools to increase participant knowledge and understanding of the textile from a post-phenomenological view [66]. How Verbeek placed the role of the sewing machine for designers' "involvement and human artifact relations" [66], this artifact role plays the drape in a digital environment. However, participants also expressed concerns about only considering a textile based on the drape observation. The contrasting experiences fit a postphenomenological view where personal emotional interpretations are reinforced or diminished as new relations "coshape" [66]. Moreover, the participants understood that skills are needed to understand the drape observation, which reflects their involvement in understanding the 'context of the artifacts' and what these artifacts 'make available' [66]. The general reflection of the participants on the drape method confirms the textile-specific design considerations across workshop phases. In this case, the scientific drape measurement method functions as an artifact that mediates experience. The technology mediated the perception of the textile's drape and shaped subjectivity and objectivity [66].

In the discussed examples, the textile in drape is mainly approached from a personal perspective, while the tangible phase tends to consider the wearer as well. At the same time, the draped textile places the material in a new perspective, inviting to "Play further" or to review the design considerations, adding the value of a combination of tangible interaction and observing the drape of the textile. Through the drape observation, they better understood the possibilities of the textile. The drape visualized a more nuanced view of the stiffness or flowyness of the textile than only tangible interaction. In other words, by experiencing both tangible and drape, the drape method can mediate the overall interpretation of the soft material when approached from postphenomenological design considerations. The visual drape, on its own, misses the "sensorial conception of aesthetic" [66] which is required to relate the material properties and characteristics to relevant design considerations. At the same time, the visual drape contributes to the material understanding. However, without a tangible understanding of textiles, fashion designers seem to lose the specialized implicit textile understanding related to the design considerations.

6.3 Tangible

In the tangible phase, the participating designers used tangible interactions to consider textile properties and characteristics. While these findings are not new, they confirm the importance of tangible interaction in digital fashion design. Through a first-person embodied process, participants engaged their implicit understanding and knowledge of textiles to translate their experience into design considerations. The participants associated the textile properties and characteristics with requirements for making and finishing garments from the textiles, considering their quality using durability, performance, and aesthetics. Participants considered the user or wearer from bodily perspectives that were often situated and aesthetic. As seen in the findings, the tangible interaction with the textile enabled the participants to translate the phenomenological understanding into postphenomenological design considerations. The tangible interaction was similar to the embodied techniques interaction designers apply to their processes, which HCI design students have been trained to use. The knowledge and understanding expressed by the participants but also their consideration showed overlap with the design considerations of design researchers working with wearables and garments. Moreover, the results relate to how other designers interact with and explore textile materials that we see in similar research [2, 19, 26, 52, 56].

TEI researchers combine physical, digital, and hybrid tools [61] that acknowledge the importance of tangible interaction [52, 70]. Combining tangible interaction with drape observation creates a hybrid way of working. Designing in a digital environment for the physical world requires a designer to create a digital soft material definition. To create a digital soft material definition, a designer must understand and be skilled in tangible interaction with textiles and how their characteristics translate into design considerations. Designers need to integrate scientific tools into their artistic work process in a digital environment. The ten textiles provided a reference tool to interact with textiles in a digital environment. To facilitate 3D digital textile transformation, a tactile reference and a reflective process enabled designers to understand the design considerations more profoundly.

7 FUTURE PERSPECTIVES

There remain opportunities for research and practice in textile design where the disciplines of fashion, textile, material science, computer science for textile simulation, and tangible design research use significantly different approaches to describe soft textiles. While we see design researchers bringing many of these approaches together, there still needs to be a disciplinary difference. The examples in 2.1 and 2.3 show a similar interest and need for understanding the expertise of drape and properties like bending, extensibility, and shear of the textile material we discussed in 2.2. What is emerging is a new understanding of soft textile materials that spans disciplines and requires a translation between the systems of working with these materials is made possible. The possibilities are embodied, phenomenological, and postphenomenological.

The ten textiles we selected and divided into five basic textile categories familiar to fashion designers resulted in rich data. Still, ten is the minimum number needed to create enough differences and similarities between the textiles for the designers to make informed comparisons. Considering the ten textiles in each of the workshop phases made the workshop long and intense, which might have caused the input decline, which we saw during the Reflection phase, where only thirteen participants completed all the questions. For a future workshop, a more extensive group reflection may yield better if time is a constraint to let each participant consider from each category one textile, this would require twice the number of participants. Another consideration might be to omit the knitted textiles C1 and C2.

The present results are based on the process of going through the tangible interaction, while the participants still needed to be made aware of the content of the next phase. The tangible phase consisted of intense interaction with the textiles. As a result, during the drape observation and analyses, the participants were already familiar with the textiles, we wonder if this knowledge influenced their considerations during drape observation. Observing the semi-scientific drape to consider the drape of the soft material was a new method for most participants. To provoke an even deeper understanding of the design considerations based on the soft material textile drape, the first two phases of the workshop could be flipped. A future study could split participants into two groups following the workshop in alternating order, like drape-tangible and tangible-drape.

While this study provided valuable insights into the perspectives of fashion designers with physical and digital backgrounds, it is important to acknowledge that the sample was limited to this specific group. Therefore, future studies could broaden the scope by including designers from outside the fashion industry who work with physical and digital materials. This could provide a more comprehensive understanding of the topic and uncover new perspectives and insights.

In this study, we found postphenomenological approaches allowed us to gain a deeper understanding of the material aesthetics of textiles in screen-based visualizations. Our findings revealed that the drape is a promising method for translating measured properties and bridging the gap between physical and digital textiles in the practice of design. Future investigations could continue to explore the contributions of postphenomenology as designers help others relate to the embodied nature of textiles as garments. Additionally, our focus was on static presentations of textiles. Still, there is a large body of work on animated and dynamic representations that could be incorporated into future research to expand our understanding of this topic further.

More research is needed to understand the design considerations of textiles that depend upon combining physical textile tangible and drape considerations into design practice in the digital space. In this, the way of combining the tools discussed in this paper should be further developed with explorations of how to make them easily accessible in physical and digital design spaces. Within the limitations of the different 3D software programs, the simulated textile based on the measured textile properties enables researchers to create tools to support integration between the understanding of the physical and digital drape of the materials.

We invite others to explore the possibilities between the physical and digital textile needs for further research involving cooperation between disciplines, including standardization of textile measurement to overcome the hurdles for accurately simulating textiles. Moreover, decreasing the gap between the embodied tangible interaction with the physical material and the drape observation will help others make design considerations that are postphenomenological in practice. We see opportunities not only for textile and fashion design but also in architecture, interior, game design, HCI, TEI and software engineering, where textiles and similar soft materials are increasingly part of the design process.

8 CONCLUSION

We find that tangible interaction with soft textile materials is essential for digital designers to gain a phenomenological understanding of soft textile materials, this strengthens the already-known importance of tangible interaction. The phenomenological understanding allows designers to make postphenomenological design considerations. Even more interesting is that the drape observation can offer rich insight into materials design considerations that reach deep into the situated everyday practice of the wearer, often reinforcing the implicit postphenomenological ideas. Design considerations for textiles and likely other flexible materials are informed by the decisions made when the designer interacts with the materials. tangible and drape experiences, as a fold, stand, and drape approach, helped designers confront the understanding needed to create design considerations for digital material definition in digital design. Moreover, the research indicates a potential complementary relationship between tangible interaction and drape observation for new methods for considering textile materials.

ACKNOWLEDGMENTS

Thanks to Lindsay Azzopardi, Veronique Benoy, Joep Berkers, Ana Cristina Codreanu, MichałKalinowski, Lorenzo Massini, Rowan Snippe, and Tanya Yeromina for their precision, accuracy, and dedication during participation in the research activities. We value their contribution to assisting with measuring, capturing, digitizing textiles, organizing, and archiving the physical and digital textiles.

REFERENCES

[1] Bell, F., Chow, D., Choi, H. and Alistar, M. 2023. Scoby Breastplate: Slowly Growing A Microbial Interface. *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2023), 1–15.

[2] Bell, F., Chow, D., Lazaro Vasquez, E.S., Devendorf, L. and Alistar, M. 2023. Designing Interactions with Kombucha SCOBY. *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2023), 1–5.

[3] Berglin, L., Cederwall, S.L., Hallnäs, L., Jönsson, B., Kvaal, A.K., Lundstedt, L., Nordström, M., Peterson, B. and Thornquist, C. 2007. Interaction Design Methods in Fashion Design Teaching. *The Nordic Textile Journal 2006-07, p. 26-51.* 27, (2007).

[4] Black, S. 2019. Sustainability and Digitalization. *The End of Fashion: Clothing and Dress in the Age of Globalization.* A. Geczy and V. Karaminas, eds. Bloomsbury Visual Arts. 113–132.

[5] De Boos, A.G. and Tester, D.H. 1994. SiroFAST: Fabric Assurance By Simple Testing: a system for fabric objective measurement and its application in fabric and garment manufacture.

[6] Breen, D.E., House, D.H. and Wozny, M.J. 1994. A Particle-Based Model for Simulating the Draping Behavior of Woven Cloth. *Textile Research Journal.* 64, 11 (1994), 663–685. DOI:https://doi.org/10.1177/004051759406401106.

[7] Browzwear: Welcome | 3D Fashion Design Software: https://browzwear.com/. Accessed: 2023-02-13.

[8] [Buso, A., McQuillan, H., Jansen, K. and Karana, K. 2022. The unfolding of textileness in animated textiles: An exploration of woven textile-forms. *DRS2022: Bilbao, 25 June - 3 July, Bilbao, Spain.* (Bilbao, Jun. 2022).

[9] Castro, J.F.M., Buso, A., Wu, J. and Karana, E. 2022. TEX(alive): A Toolkit to Explore Temporal Expressions in Shape-Changing Textile Interfaces. *Designing Interactive Systems Conference* (New York, NY, USA, 2022), 1162–1172.

[10] CLO | 3D Fashion Design Software: https://www.clo3d.com/en/. Accessed: 2023-02-13.

[11] Coscieme, L., Manshoven, S., Gillabel, J., Grossi, F. and Mortensen, L.F. 2022. A framework of circular business models for fashion and textiles: the role of business-model, technical, and social innovation. https://doi.org/10.1080/15487733.2022.2083792. 18, 1 (2022), 451–462. DOI:https://doi.org/10.1080/15487733.2022.2083792.

[12] Cusick, G.E. 1968. 21—The Measurement of Fabric Drape. *Journal of the Textile Institute.* 59, 6 (1968), 253–260. DOI:https://doi.org/10.1080/00405006808659985.

[13] Cusick, G.E. 1965. 46—The dependence of fabric drape on bending and shear stiffness. *Journal of the Textile Institute Transactions.* 56, 11 (Nov. 1965), T596–T606.

DOI:https://doi.org/10.1080/19447026508662319.
[14] Devendorf, L., De Koninck, S. and Sandry, E. 2022. An Introduction to Weave Structure for HCI: A How-to and Reflection on Modes of Exchange. *DIS 2022 - Proceedings of the 2022 ACM Designing Interactive Systems Conference: Digital Wellbeing* (Jun. 2022), 629–642.
[15] Devendorf, L. and Rosner, D.K. 2017. Beyond Hybrids: Metaphors and Margins in Design. *DIS 2017 - Proceedings of the 2017 ACM Conference on Designing Interactive Systems* (2017), 995–1000.
[16] Digital Fabric Physics Interoperability: 2020. http://3drc.pi.tv/2020/12/02/digital-fabric-physics-interoperability/. Accessed: 2023-09-01.
[17] Digital Product Creation: Fashion's Big Supply Chain Opportunity - YouTube: 2023. https://www.youtube.com/watch?v$=$aCncIdevyxo. Accessed: 2023-07-10.
[18] van Dongen, P. 2019. *A Designer's Material-Aesthetics Reflections on Fashion and Technology*. ArtEZ Press.
[19] van Dongen, P., Wakkary, R., Tomico, O. and Wensveen, S. 2019. Towards a Post-phenomenological Approach to Wearable Technology through Design Journeys. *Textile Intersections* (London, 2019).
[20] Dunne, L.E., Ashdown, S.P. and Smyth, B. 2005. Expanding garment functionality through embedded electronic technology. *Journal of Textile and Apparel, Technology and Management* . 4, 3 (2005), 1–11.
[21] Eberle, H., Hermeling, H., Hornberger, M., Menzer, D. and Ring, W. 2002. *Clothing technology: ... from fibre to fashion*. Verlag Europa-Lehrmittel.
[22] elastic fabric – How can we help you? 2023. https://support.clo3d.com/hc/en-us/community/posts/360043191194-elastic-fabric. Accessed: 2023-07-12.
[23] EU Strategy for Sustainable and Circular Textiles_EUR-Lex - 52022DC0141 - EN - EUR-Lex: 2022. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri$=$CELEX%3A52022DC0141. Accessed: 2023-11-23.
[24] Fashion at a turning point: Rebuilding the industry's future together | Lectra: https://www.lectra.com/en/events-webinars/fashion-at-a-turning-point-EN. Accessed: 2023-02-13.
[25] Giaccardi, E. and Karana, E. 2015. Foundations of materials experience: An approach for HCI. *Conference on Human Factors in Computing Systems - Proceedings* (Apr. 2015), 2447–2456.
[26] Goveia da Rocha, B., Spork, J. and Andersen, K. 2022. Making Matters: Samples and Documentation in Digital Craftsmanship. *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2022), 1–10.
[27] Goveia Da Rocha, B., Tomico, O., Markopoulos, P. and Tetteroo, D. 2020. Crafting research products through digital machine embroidery. *DIS 2020 - Proceedings of the 2020 ACM Designing Interactive Systems Conference* (Jul. 2020), 341–350.
[28] Goworek, H. 2010. An investigation into product development processes for UK fashion retailers: A multiple case study. *Journal of Fashion Marketing and Management*. 14, 4 (2010), 648–662. DOI:https://doi.org/10.1108/13612021011081805.
[29] Greinke, B., Petri, G., Vierne, P., Biessmann, P., Börner, A., Schleiser, K., Baccelli, E., Krause, C., Verworner, C. and Biessmann, F. 2021. An Interactive Garment for Orchestra Conducting: IoT-enabled Textile & Machine Learning to Direct Musical Performance. *TEI 2021 - Proceedings of the 15th International Conference on Tangible, Embedded, and Embodied Interaction* (Feb. 2021).
[30] Hardaker, C.H.M. and Fozzard, G.J.W. 1998. Towards the virtual garment: Three-dimensional computer environments for garment design. *International Journal of Clothing Science and Technology*. 10, 2 (1998), 114–127. DOI:https://doi.org/10.1108/09556229810213827/FULL/XML.
[31] Hauser, S., Oogjes, D., Wakkary, R. and Verbeek, P.P. 2018. An annotated portfolio on doing postphenomenology through research products. *DIS 2018 - Proceedings of the 2018 Designing Interactive Systems Conference* (Jun. 2018), 459–472.
[32] Höök, K. *et al.* 2018. Embracing First-Person Perspectives in Soma-Based Design. *Informatics*. 5, 1 (Feb. 2018), 8. DOI:https://doi.org/10.3390/informatics5010008.
[33] Höök, K. 2010. Transferring qualities from horseback riding to design. *NordiCHI 2010: Extending Boundaries - Proceedings of the 6th Nordic Conference on Human-Computer Interaction* (2010), 226–235.
[34] Igoe, E. 2010. The tacit-turn: textile design in design research. *Duck Journal for Research in Textiles and Textile Design*. (2010).
[35] Karana, E., Pedgley, O. and Rognoli, V. 2015. On materials experience. *Design Issues*. 31, 3 (Jul. 2015), 16–27. DOI:https://doi.org/10.1162/DESI_a_00335.
[36] Kawabata, S. 1980. *The Standardization and Analysis of Hand Evaluation*. Textile Machinery Society of Japan.
[37] Keiser, S., Vandermar, D. and Garner, M. 2022. *Beyond Design: The Synergy of Apparel Product Development*. Bloomsbury Publishing.
[38] van Kesteren, I.E.H., Stappers, P.J. and de Bruijn, J.C.M. 2007. Materials in Products Selection: Tools for Including User-Interaction in Materials Selection. *International Journal of Design*. 1, 3 (2007), 41–55.
[39] Keune, S. 2021. Designing and Living with Organisms Weaving Entangled Worlds as Doing Multispecies Philosophy. *Journal of Textile Design Research and Practice*. 9, 1 (Jan. 2021), 9–30. DOI:https://doi.org/10.1080/20511787.2021.1912897.
[40] Kim, H., Coutrix, C. and Roudaut, A. 2018. Morphees+: Studying Everyday Reconfigurable Objects for the Design and Taxonomy of Reconfigurable UIs. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, Apr. 2018), 1–14.
[41] Knibbe, J., Freire, R., Koelle, M. and Strohmeier, P. 2021. Skill-Sleeves: Designing Electrode Garments for Wearability. *TEI 2021 - Proceedings of the 15th International Conference on Tangible, Embedded, and Embodied Interaction* (Feb. 2021).
[42] Kuijpers, A.A.M. 2017. *Evaluation of physical and virtual fabric drape created from objective fabric properties*. The University of Manchester .
[43] Kuijpers, A.A.M., Geelhoed, M.W. and Crietee, M. 2021. *The Future of Fabrics: Digital Fabric Roadmap*.
[44] Kuijpers, A.A.M. and Gong, R.H. 2017. Defining Fabric Drape. Breaking the Rules: Fashion Disruptive Technology Conference proceedings International Foundation of Fashion Technology Institutes IFFTI-2017-Amsterdam (Amsterdam, 2017), 156–172.
[45] Kuijpers, A.A.M., Luible-Bär, C. and Gong, R.H. 2020. *The Measurement of Fabric Properties for Virtual Simulation - A Critical Review*. IEEE.
[46] Liang, A., Stewart, R., Freire, R. and Bryan-Kinns, N. 2021. Knit Stretch Sensor Placement for Body Movement Sensing. *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2021), 1–7.
[47] Luible, C. and Magnenat-Thalmann, N. 2007. Suitability of standard fabric characterisation experiments for the use in virtual simulations. *In Proceedings of World Textile Conference AUTEX* (2007), 1–5.
[48] McQuillan, H. 2020. Digital 3D design as a tool for augmenting zero-waste fashion design practice. *International Journal of Fashion Design, Technology and Education*. 13, 1 (Jan. 2020), 89–100. DOI:https://doi.org/10.1080/17543266.2020.1737248.
[49] McQuillan, H., Archer-Martin, J., Menzies, G., Bailey, J., Kane, K. and Fox Derwin, E. 2018. Make/Use: A System for Open Source, User-Modifiable, Zero Waste Fashion Practice. *Fashion Practice*. 10, 1 (Jan. 2018), 7–33. DOI:https://doi.org/10.1080/17569370.2017.1400320.
[50] McQuillan, H., Walters, K. and Peterson, K. 2021. Critical Textile Topologies X Planet City: the intersection of design practice and research. *Research in Arts and Education*. 2021, 1 (Feb. 2021), 241–268. DOI:https://doi.org/10.54916/rae.119326.
[51] Microsoft SharePoint Online - Samenwerkingssoftware | Microsoft 365: https://www.microsoft.com/nl-nl/microsoft-365/sharepoint/collaboration. Accessed: 2023-11-22.
[52] Ojala, A. 2023. I Feel You: Exploring possibilities to create touch-responsive woven textiles imitating living beings. *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2023), 1–3.
[53] Ornati, M. 2023. A Conceptual Model of Dress Embodiment and Technological Mediation in Digital Fashion. *Fashion Communication in the Digital Age* (Aug. 2023), 57–67.
[54] Ossevoort, S. and Bruns, M. 2023. Embodying Wind through Flare: How Natural Phenomena Can Contribute to Enriching the Design of Interactive Systems. *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2023), 1–11.
[55] Perner-Wilson, H. and Posch, I. 2022. How Tangible is TEI? Exploring Swatches as a New Academic Publication Format. *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Feb. 2022).
[56] Petreca, B., Baurley, S. and Bianchi-Berthouze, N. 2015. How do designers feel textiles? *2015 International Conference on Affective Computing and Intelligent Interaction (ACII)* (Sep. 2015), 982–987.
[57] Pouta, E. and Mikkonen, J.V. 2022. Woven eTextiles in HCI — a Literature Review. *Designing Interactive Systems Conference* (New York, NY, USA, Jun. 2022), 1099–1118.
[58] Power, J. 2013. Fabric objective measurements for commercial 3D virtual garment simulation. *International Journal of Clothing Science and Technology*. 25, 6 (Nov. 2013), 423–439. DOI:https://doi.org/10.1108/IJCST-12-2012-0080.
[59] Ruppert-Stroescu, M. and Hawley, J.M. 2014. A Typology of Creativity in Fashion Design and Development. *Fashion Practice*. 6, 1 (May 2014), 9–35. DOI:https://doi.org/10.2752/175693814X13916967094759.
[60] Särmäkari, N. 2023. Digital 3D Fashion Designers: Cases of Atacac and The Fabricant. *Fashion Theory*. 27, 1 (Jan. 2023), 85–114. DOI:https://doi.org/10.1080/1362704X.2021.1981657.
[61] Smit, D., Hengeveld, B., Murer, M. and Tscheligi, M. 2022. Hybrid Design Tools for Participatory, Embodied Sensemaking: An Applied Framework. *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2022), 1–10.
[62] Standard Operating Procedures for Digital Fabric Physics Interoperability: 2021. http://3drc.pi.tv/2023/07/20/3drc-materials-sop/. Accessed: 2021-12-11.
[63] Technical Committee ISO/TC 38 2008. ISO 9073-9:2008 - Textiles — Test methods for nonwovens — Part 9: Determination of drapability including drape coefficient. International Organization for Standardization.
[64] Tomico, O. and Wilde, D. 2016. Soft, embodied, situated & connected: enriching interactions with soft wearables. *mUX: The Journal of Mobile User Experience*. 5, 1 (Dec. 2016), 3. DOI:https://doi.org/10.1186/s13678-016-0006-z.
[65] Vahid, D.G., Jones, L., Girouard, A. and Frankel, L. 2021. Shape Changing Fabric Samples for Interactive Fashion Design. *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2021), 1–7.

[66] Verbeek, P.-P. 2005. *What things do: philosophical reflections on technology, agency, and design*. Pennsylvania State University Press.

[67] Wiberg, M. 2014. Methodology for materiality: interaction design research through a material lens. *Personal and Ubiquitous Computing*. 18, 3 (Mar. 2014), 625–636. DOI:https://doi.org/10.1007/s00779-013-0686-7.

[68] Wilson, J. 2010. *Classic & Modern Fabrics*. Thames and Hudson.

[69] Zhang, M., Stewart, R. and Bryan-Kinns, N. 2022. Integrating Interactive Technology Concepts With Material Expertise in Textile Design Disciplines. *Designing Interactive Systems Conference* (New York, NY, USA, Jun. 2022), 1277–1287.

[70] van Zilt, J., Winters, A., Carlotta Kelbel, H. and Bruns, M. 2022. The design process of a multi-disciplinary tool for developing interactive textiles. *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, Feb. 2022), 1–16.