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A Systematic Literature Review on Computational Fashion Wearables

Shiva Jabari, Asif Shaikh, Çağlar Genç, Oğuz Buruk, Johanna Virkki, and Juho Hamari

Faculty of Information Technology and Communication Sciences, Tampere University, Tampere, Finland

ABSTRACT
Computational wearables are redefining our presence in the world and transforming our lifestyles by engendering a seamless connection between the wearer and the worn. Despite numerous original studies on the development as well as the current advances of wearables, a systematic review from the standpoint of fashion seems to be lacking. Thus, this systematic review aimed to explore the current state of research on computational fashion in wearables' literature in terms of the key domains, theoretical models, materials, interaction modalities, and existing gaps. To this aim, the authors built a search string based on the keywords in related topics and conducted the research using Scopus databases. As a result, a total of 4777 papers between January 1990 to August 2021 were screened and 82 research study papers finally passed the inclusion-exclusion criteria for the purpose of the review. The results display: first, computational wearables' studies are becoming more inclined towards the aesthetic aspects of fashion wearables; second, although the functional aspects of the design processes received more attention, embodiment was the most discussed theory in the included studies; third, the extensive application of fabric implied the need for new fabrics with both smart quality and flexibility to afford aesthetic aspects; fourth, ambient data as input modalities received extensive attention in fashion wearables; fifth, kinetic output modalities as novel modes of fashion expression are becoming as prevalent as visual modalities. Finally, our findings provide a detailed overview of distinct facets of studies on computational fashion and a future research agenda for researchers and designers working on fashion and wearables.

KEYWORDS
Computational fashion; wearables; fashion design; interaction design; embodied interaction

1. Introduction

Wearables with computational fashionable expressions are progressively blending in diverse aspects of our lives through various forms of clothing, jewelry and other accessories with different manifestations of interactions, communications and expressions (Tamminen & Holmgren, 2016; Mackey et al., 2017; Dagan et al., 2019; Jarusriboonchai et al., 2019; Olsson et al., 2020; Epp et al., 2020). Adorning our bodies with these diverse types of bodily technologies makes them an integral part of our clothing and a means of our self-expression, and thus creates a space where fashion and interactive technologies come together. The increasing ubiquitousness of wearables and the introduction of aesthetic notions into the field of computational wearables open new venues of inquiry and research for the wearables field, shifting focus from functionality (technology) to context (garment) (Galbraith, 2003). Human-computer interaction has traditionally laid emphasis on functionality, usability and efficiency of designs (Dunne, 2010); however, the development of computational wearables and their exposure to public eyes raise the need in this field to incorporate more aesthetic aspects and take fashionability concerns into account.

Computational clothing refers to apparel with the capability to process, store, retrieve, and transfer data (Barfield et al., 2001). These wearables provide their wearers with the functionality of modern computational devices while at the same time they act as interfaces whose designs convey the wearers' individual and communal tendencies (Barnard, 2020). Computational wearables similar to conventional clothing and accessories are interfaces between people and society, thereby aesthetics properties and expressiveness are of critical importance (Tomico et al., 2017). They establish an identity for the wearer by communicating the wearer's self-image and their membership in a social group (Aspers & Godart, 2013). As such, designers of wearables need to find stylistic languages recognized by both the wearer and the spectator (Tomico et al., 2017). This requires wearables to be favorable, attractive, and aesthetically pleasing to the eye of the public to receive social acceptance (Kelly & Gilbert, 2016).

The focus of wearable technology so far has been more on functionality; however, nowadays the call for fashion and aesthetic considerations have been progressively on the rise (Ouverson et al., 2017; Page, 2015). For the computational clothing to be recognized as an accepted component of the user and as an everyday apparel, it is imperative that it will feel and look like actual clothing. The area of computational fashion wearables requires the convergence of multidisciplinary practices, and integrating various disciplines seems to be vital to develop wearables that are not only functional, but

CONTACT Shiva Jabari shiva.jabari@tuni.fi Faculty of Information Technology and Communication Sciences, Tampere University, Tampere, Finland

they are also comfortable and support 'aesthetically enriched interactions' (Paredes et al., 2021, p. 2). To this end, the designers involved need to be informed about diverse areas including fabric or textiles, networking, power sources, microelectronics, human interface design, and cultural fashion trends (Barfield et al., 2001). On account of that, more systematic knowledge examining the relation between those diverse aspects for providing information and directions to designers and researchers of computational fashion wearables needs to be produced.

Although it is possible to point out singular studies (Cho et al., 2009; Dunne, 2010; Jeong et al., 2017; Dagan et al., 2019; Buruk et al., 2021), a comprehensive overview of the field that would lead to holistic knowledge and reveal future research direction about the fashion aspects of wearables is missing. To the best of our knowledge, this is the first systematic review on wearables, which studies them via the fashion lens. Several previous systematic reviews looked into other aspects connected to wearables. For instance, Ometov et al. (2021) had a comprehensive review on the history of wearables and their market and provided an extensive classification of wearables. Niknejad et al. (2020) and Kalantari (2017) conducted a systematic review on the studies which focused on the issues and challenges related to the adoption of smart wearables. Ferreira et al. (2021) carried out a systematic review on the wearable technology and consumer interaction. They identified the prevailing trends and themes in the literature of wearables technology. Suranga Seneviratne et al. (2017) had a comprehensive survey of the commercially available products and research prototypes and classified them according to their functionalities and wearing modes. The findings of their survey indicated that communication security, energy efficiency, and wearable computing are the most studied topics in the literature. McCallum et al. (2018) explored studies which evaluated wearables in terms of research designs, user engagement, acceptability and effectiveness.

However, in this systematic review, we aim to contribute to the field by providing the designers and other stakeholders a comprehensive overview on the diverse aspects of computational fashion wearables. In this study, computational fashion wearables (CFWs) are defined as body-worn artifacts, such as jewelry, accessories or elements of clothing, designed to be worn on the body and enhanced both 'technologically and aesthetically'. In other words, they are wearables with embedded technologies, which are dynamic and interactive; moreover, aesthetic considerations were also attended to in their construction to be visually attractive and appealing. The novelty of the present survey resides in the uniqueness of braking a new ground by reviewing smart wearables from a fashion perspective, an approach which, to our knowledge, was not previously put forth. By doing this, it reveals how fashion-oriented theories and practices are considered in smart wearable studies. Furthermore, it uncovers challenges and sets the stage for future research on integrating fashion into smart wearable theories, design, and practice. Accordingly, this research study systematically reviews the literature on CFWs to give an overview of the academic studies done in this area and to specifically answer following questions:

1. What are the key domains in computational fashion wearables research?
2. What are the theories or theoretical frameworks applied in the computational fashion wearables research?
3. What are the main materials used in the design of computational fashion wearables?
4. What interaction modalities have been adopted in computational fashion wearables research?
5. What are the gaps in current computational fashion wearables research, which need further investigation?

This systematic literature review (SLR) intended to consolidate the existing research and classify the relevant information to identify and categorize the concepts in CFWs for further studies. It also aims to raise awareness regarding challenges the designers and scholars might face in this domain. The present SLR has two main contributions to both interaction and fashion designers who are interested in the field of computational fashion wearables.

- The analysis and overview of 82 fashion-oriented wearable research studies that provide the relevant audience with better understanding and broad knowledge about the concept of computational fashion wearables.
- Theoretical, practical and design-oriented agendas for future design solutions and directions to support the future research studies in computational fashion wearables.

2. Background

2.1. Theory of fashion

According to Sproles, the fashion phenomenon, in the broadest sense as a generalized behavioral concept, is defined as 'a culturally endorsed form of expression' and in clothing, fashion is 'a culturally endorsed style of aesthetic expression' (cited in Eckman & Wagner, 1995, p. 464) in a society at a particular time. Fashion is generally conceptualized in two dimensions: the fashion object such as a specific stylistic material product or a non-material social product like any behavioral practice; and the fashion process is a dynamic mechanism through which a product receives acceptance or rejection in a social system. Fashion objects symbolize the 'collective tastes' of the members of a society at a particular time, and in order to receive acceptance, they need to possess some qualities including novelty, aesthetics, styling, social acceptability, status symbolism, ego gratification and other psycho-social qualities like high social-visibility and high ego-involvement (Eckman & Wagner, 1995).

Fashion is considered as a system or systems which can be studied linguistically, semiotically, culturally, and economically (Barthes, 1983; Borthwick et al., 2015). Fashion system is a dynamic whole and, in this system's perspective, the involvement of multiple actors is very significant

(Thornquist, 2018). Fashion culturally and socially portrays the zeitgeist of the time (Wilson, 2020), and it is cultural history through its manifestation in culture, social norms, and diversity. As such, it can be studied in connection with a number of concepts such as fashion and identity, fashion and aesthetics, fashion as communication and fashion and consumption. This situation makes fashion as a source for various theories and highlights it's interdisciplinary nature (Barnard, 2020).

Furthermore, fashion is also conceptualized as the lived experiences of wearing practices around the body. Entwistle and Wilson (2001) assert that sufficient recognition has not been given to how dress is a 'fleshy practice involving the body' (p.4), and that disembodies fashion and neglects 'the place and significance of the body' in fashion (p. 4). Entwistle indicates that the body is a 'fashioned body' (Entwistle 2000, p. 1) and argues that the fashion system takes the perspective of the lived and experienced body, or "a situated bodily practice" (Entwistle 2000, p. 344), which shifts the position of fashion as an object to fashion as the activity of wearing. Fashion can also produce new cultural meanings and categories (Thornquist, 2018), giving rise to changes in individuals and society. Wearing, from the interactive perspective, can be explained as a constant negotiation between self and inward experience established in the process of trying, changing, and experiencing the body/self through different ways of wearing (Thornquist, 2018). Accordingly, fashion is seen as a kind of expression generated by body and wear in a wearing that evokes an interactive embodiment (Shusterman, 1999; Kozel, 2008). It's important to understand cultural, societal and embodied framings of fashion to be able attain the goal of fashionability while designing wearables.

2.2. Theory of computational fashion wearables

Computational wearables deal with the whole body, challenging the designers in the areas of technology, society, and aesthetics. For wearables to be recognized by society, a stylistic language seems to be needed (Neidlinger et al., 2017). Computational Fashion Wearables is an interdisciplinary field, which can draw from both human-computer interaction (HCI) and fashion theories and principles. However, the normative semiotic fashion theories are inadequate for designing soft wearable technologies (Joseph et al., 2017), and on the other hand, most HCI theories underlining the functions, functionality, technical issues and usability of software and hardware also fall short in providing design knowledge for soft wearable technologies (Ryan, 2014). Conventionally, HCI is research-oriented and mostly seeks for objective solutions, while fashion is subjective and motivated by creativity (Pan & Stolterman, 2015).

Smelik et al. (2016) maintain that the two main factors of materiality and embodiment should be taken into consideration both in the design and in the theoretical reflection on wearable technology. Materiality refers to recognizing matter as active and living element in making the world (Pink et al., 2016). Materials possess agency beyond their mere look and feel (Smelik et al., 2016). Tomico and Wilde (2015) suggest that the design process should focus on the relation between the body performance and material properties. For instance, the structure, the weight and the stretching qualities of the materials used in design are in constant dialogue with the body with regard to comfort, positioning, and expressiveness. This continuous dialogue between the body and the artefact permits a constant reshaping of the material properties, and the body movement and contributes to the design process. Material explorations on the body, during a design process, equips the designer to with the necessary awareness and information to move from designing an item to be used, to an item to be worn (Tomico & Wilde, 2015).

For technology to be wearable, the design needs to become 'embodied' because wearable technology is worn on the body (Dunne et al., 2014). Embodied interaction involves creating, manipulating, and sharing meanings via engaged interaction with objects. Focusing on the phenomenon of experience, embodied interaction detects that computing is getting both more tangible and more social (Dourish, 2001). Van Rompay and Hekkert (2001) first introduced the term 'embodied design', situating it within a phenomenological approach. They found empirical evidence 'that people understand the world largely based on bodily experiences' (2001, p. 39). Later they argued that human's understanding of objects is based on the interaction with the world around them and their bodily experiences (Van Rompay et al., 2005). In the same line, Hummels and Lévy (2013), arguing for an 'aesthetics of interaction' (p. 46), firmly suggest prioritizing taking a first-person perspective over a third-person perspective in designing. Smelik et al. (2016) believe that to allow the user to become intimately connected with fashion technology on an emotional and personal level, it is essential that wearables are designed so as to be aesthetically appealing but at the same time comfortable for wearing.

Theories can provide the researcher with a systematic view of the phenomenon under study and helps them to make predictions about it (Kerlinger, 1986); accordingly, it is a noteworthy effort to understand how the existing computational fashion wearables studies with fashionability and aesthetics orientation deal with the main theoretical or conceptual approaches, and the current theoretical influences in their works. In this direction, the present SLR also examined the included studies in terms of general concepts and theoretical perspectives they discussed or mentioned that they grounded their studies on.

3. Review method

This systematic review has been conducted according to the systematic research criteria and protocol suggested by the Preferred Reporting Items for Systematic reviews and MetaAnalyses Protocols (PRISMA-P) (Shamseer et al., 2015; Page et al., 2021). PRISMA statement is a reporting guideline which assists authors and scholars to report a transparent and accurate account of their systematic reviews and meta-analyses.

3.1. Search strategy

Initially inclusion-exclusion criteria were defined according to the keywords in the area of fashion-tech wearables or computational fashion. Attempts were made to include the relevant terms to reach the optimum results in terms of the related articles in this interdisciplinary area. After some initial trial search on Scopus, we decided to include all the literature, written in English, on 'computational fashion' and 'fashion and technology' in our systematic review. The focused target was original and peer reviewed research papers published in journals, books or proceedings. In other words, the studies concerned with fashion design, human computer interaction, wearables-fashion, interactive fashion design, interactive fabric and/or clothing interface were decided to be included in this systematic review. Next, a search string was developed based on the defined criteria including main keywords, and the operators such as 'AND' and 'OR' were also applied to connect the related keywords.

Since fashion-tech is an interdisciplinary area including fashion design, human-computer interaction design, wearable-fashion, interactive fashion design, interactive fabric and clothing interface, several words and terms from these fields were tried out according to the inclusion-exclusion criteria. The focus of the search was on peer-reviewed published papers between 1990 and 2021 in order to cover as many papers as possible in wearables related to fashion. As so terms such as fashion, haute couture, smart and interactive were the keywords in the search string. Accessibility of the articles in libraries, Google Scholar and Scopus meta-databases (although the search was done only in SCOPUS, Google Scholar were used for downloading papers), the originality of the studies (the study or artefacts were created by authors and not was based on previous studies e.g., literature reviews) and being peer reviewed were also included in the criteria. After some trials, the final search string was selected: 'TITLE-ABS-KEY ((smart* OR interactiv*) AND (fashion* OR coutur* OR haut*)) AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch"))' and was used for the automatic search in Scopus databases. Scopus was selected since this database gives access to a vast extent of peer-reviewed content from high-quality journals (Kulkarni, et al., 2009). In the string, "cp" means conference proceedings, "ar" means journal articles and "ch" means book chapters.

3.2. Study selection

3.2.1. Screening

The above-mentioned search string resulted in 4777 papers. Eleven papers were initially removed due to being duplicates. To assess and ensure the relevance of the popped-up articles, a thorough scanning of the titles and abstracts was done based on the inclusion-exclusion criteria. The inclusion-exclusion criteria consisted of seven items: (1) Time period (1990–2021), (2) Language (in English), (3) Population (literature including fashion and technology), (4) Target studies (Research studies concerned with fashion design; human computer interaction; wearables-fashion; interactive fashion design; interactive fabric and/or clothing interface). We must mention here that all the studies included in this SLR had indicated that fashion or aesthetics was one of their design concerns. Thus, studies that developed wearable prototypes with purely utilitarian purposes without fashion-related concerns were not included. (5) Study type (Original and peer reviewed research papers published in journals, books or proceedings), (6) Accessibility (full text accessible in Google scholar, Scopus databases, or libraries), and (7) Duplication. Accordingly, 4432 papers were excluded. A second screening was done by full text examination of the papers, and totally 267 papers were excluded (9 papers were not in English; 60 papers were not research studies, 28 papers were not accessible; and 170 papers were not in scope). As a result, 67 papers were considered for the purpose of the systematic review.

3.2.2. Reference searching

Not to miss out on any related paper, the researchers conducted backward citation searching. A manual search was done by examining the reference lists of the included papers and searching the citation of publications on the Google scholar. This step added 15 more papers to the outcome of the automatic search (67), and the total included paper increased to 82 papers. The complete process of paper selection is displayed in Figure 1.

3.3. Coding papers

Two essential aspects of any systematic review are data abstraction and data extraction. Data abstraction means selecting data items from each included paper, and it will be subject to the aims of the systematic review (Bown and Sutton, 2010). The researchers intended to examine the current state of fashion wearables by academia and to find answers to their already posed questions. Accordingly, the coding scheme of the present systematic review was deductive and it was based on the key categories from the questions set out to be answered including the key domains, theoretical frameworks, interaction modalities, materials in current CFWs research. Thus, the researchers applied these items as the coding themes and extracted the data, which were relevant to these themes. It is worth mentioning that to increase the assessment quality, two reviewers (one fashion-oriented and the other computing interaction-oriented) worked independently throughout the coding step and finally compared and discussed their findings. To answer the research questions, the reviewers thoroughly read each study paper to spot the relevant sections for the required data. For instance, to find a domain of a wearable, the reviewers attended to the purpose and the application that wearable was intended for by the authors of the study paper. This information could be found throughout the

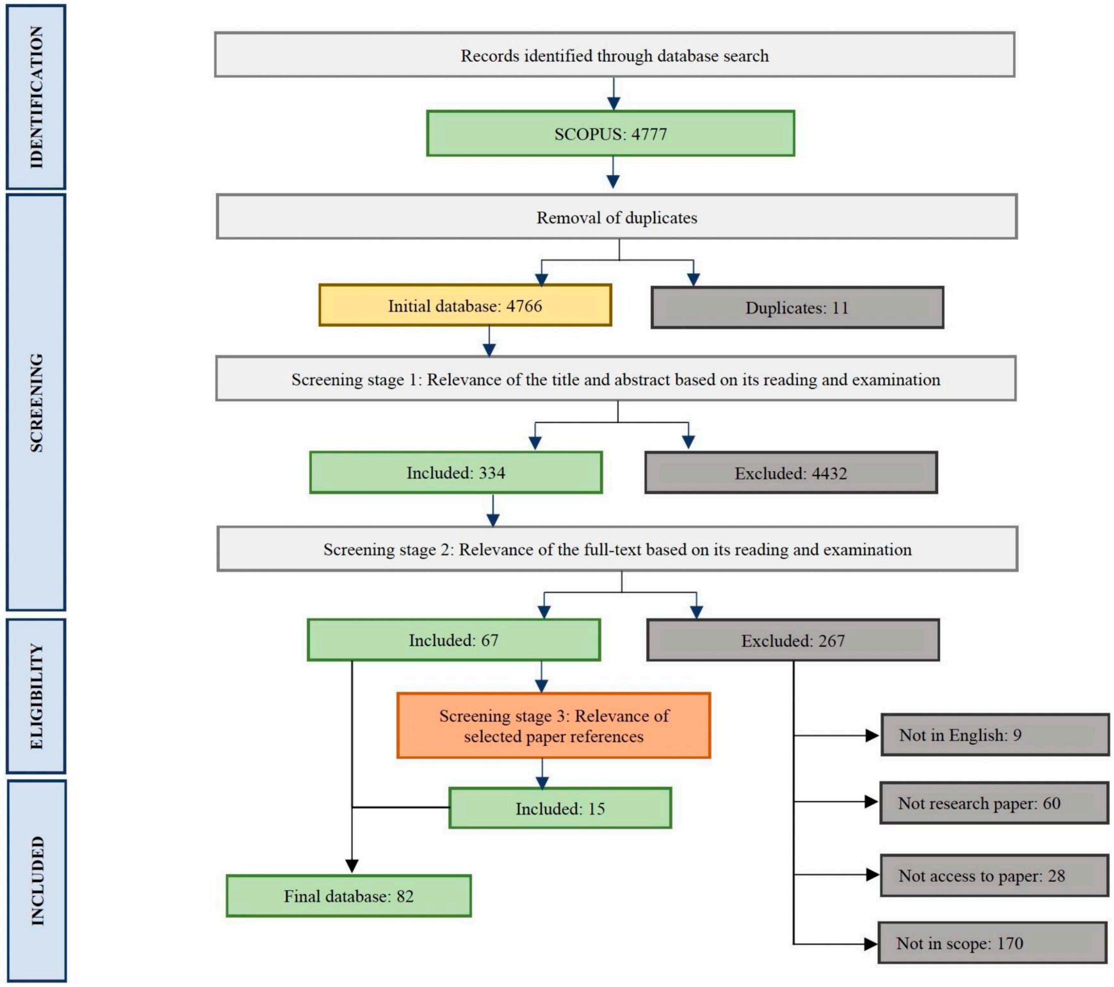

Figure 1. Paper selection process.

paper, especially in the title, abstract and introduction and conclusion. The theoretical framings, if mentioned, was usually spotted in the background or in the design section. In some cases, the researchers had to search the keywords in the "search" section of PDF document to look through the whole writing piece and crosscheck the data.

4. Results

In this section, the data extracted from the included papers are presented with their descriptive analysis through figures and tables. All the original studies were thoroughly reviewed, and the data related to the research questions and the objectives of this systematic review were derived and tabulated in Microsoft excel sheet including: title; author(s); year; domain; theories/theoretical framework; materials; and interaction modalities.

4.1. The timeline of the publications

Figure 2 displays the distribution of 82 original papers published on CFWs from 1990 up to August 2021. According to Figure 2, the number of the studies done on CFWs was the highest in 2018. It also reveals there were not many studies before 2015 on fashion wearables. It is worth mentioning that the present SRL includes only the first half of year 2021, so there might be more studies in 2021, which were not examined in this review.

According to the above chart, 82 CFW studies were detected in total, most of which included fashion wearable prototypes. Some interesting facts came out of the data: six out of these 13 research studies were initiated from interaction designers including (Marti, Iacono et al., 2018; Genç et al., 2018; Wang et al., 2018; Honauer, 2018; Kleinberger & Panjwani, 2018; Pan et al., 2018). Three studies (Lee, 2018; Mihaleva & Pataranutaporn, 2018; McMillan, 2018) were originated from fashion designers, 2 studies (Koon et al., 2018; Pan & Pan, 2018) form mechanical engineers, and 2 studies (Kuusk et al., 2018; Du et al., 2018) from textile and material designers. It is worth mentioning that ACM was the most publishing or presenting venue for these studies with 6 papers (Lee, 2018; Koon et al., 2018; Mihaleva & Pataranutaporn, 2018; Honauer, 2018; Kuusk et al., 2018; McMillan 2018). Marti, Iacono et al. (2018), Marti, Tittarelli, et al. (2018), and Pan and Pan (2018) were published in Springer, Du et al. (2018) and Kleinberger and Panjwani (2018) in TEI (Embedded and Embodied Interactions),

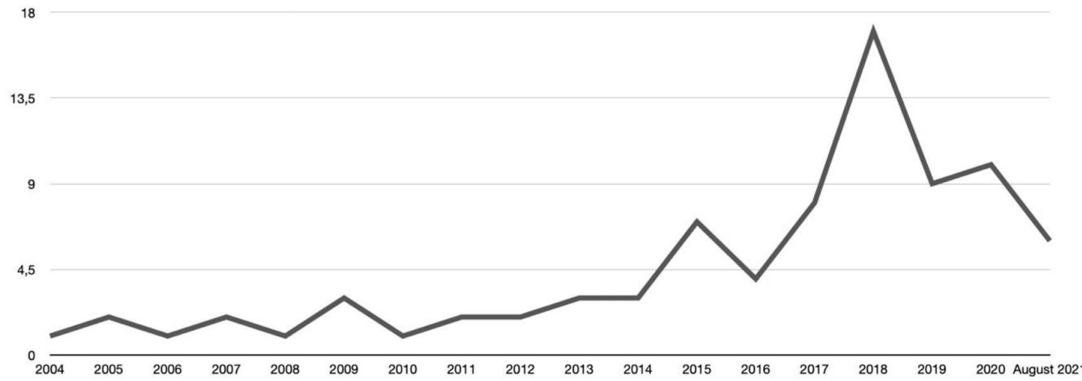

Figure 2. The timeline of the publications of computational fashionable wearables.

Wang et al. (2018) in International Journal of Clothing, and Genç et al. (2018) in International Journal of Design.

4.2. Wearables domains

Table 1 displays the distribution of the included studies according to the domains of the CFWs they were intended for. This section will also answer Research Question (RQ) 1 which inquiries about the key domains in CFWs. The research domains of the CFWs in this systematic review were categorized into eight macro domains of Fashion design, Communication, Education, Sustainability, Marketing, Performance, and Well-being (Table 1). The categorization was done according to the purpose for and/or the application of the wearables prototype mentioned by the author(s) of the paper. The definition of each domain will be presented in the relevant domain section.

As the data in Table 1 shows out of 82 CFWs, the highest number of the studies belongs to macro-domains of Fashion design and Communication respectively with 25 and 19 fashion wearables studies, i.e., 30 and 22% of all the studies. The macro-domains of Wellbeing with 10 studies and Performance with 9 studies respectively received the third and the fourth highest number of the total CFWs studies. In the following section, we present some examples from the domains mentioned in the table and discuss why they are related to the fashion domain in general and why they are relevant to the subsequent subdomains in particular. It should be noted that some of the studies (7 of them) were mentioned under multiple domains and/or subdomains. The reason is that these studies mentioned multiple domains for their works in their articles.

4.2.1. Fashion domain

The Fashion Design domain focuses on the purpose of experimenting with technology on the body to come up with new aesthetical languages rather than concentrating on functionalities. Although all the included studies have attended to the pleasing aspects of the wearables, studies under "Fashion" domain have a particular emphasis on aesthetics aspects such as visual appeal, form factor, volume, proportion and fashionability. The included research studies in the "Fashion" domain intended to develop wearables in which aesthetic aspects were regarded as equally important as function. Aesthetic aspects, in effect, were considered a function to be developed in the wearables. Studies which go under "Fashion" are divided into three subdomains of Accessories (and Jewelry), Apparel, and Textiles.

Accessory subdomain (also including jewelry) generally corresponds to items such as ties, belts, suspenders, muffs, pins, scarves, piercing, bracelets, necklaces, etc. that mostly have decorative and supplementary function. Accessories complement an outfit or the wearer's look and contribute to the expression of an individual's personality and identity (Cumming et al., 2017). Embellished robotic flowers (Pan et al., 2018; Pan & Pan, 2018); detachable cuffs and zippers (Kim et al., 2017); the fur piece for shoulder (Zdziarska et al., 2019); the scarf (Von Radziewsky et al., 2015); the jewelry earrings, necklace, pendent, anklet (Buruk et al., 2021), the amulet (Sorensen & Thummanapalli, 2017), the brooches (Koulidou & Mitchell, 2021; Kao et al., 2017) are examples of the category of accessory identified in the included studies. In Buruk et al. (2021), for instance, the designers created three pieces of smart jewelry prototypes called IlluminEar, Rhythm Shoe and PubliNeck. Embellishment elements such as ornamental casings and 3D-printed beads were applied. The different interactive arrangements of the ornamental casings, the hexagonal shapes and decorative cord contribute to the aesthetics aspects of the jewelry.

The sub-domain of Apparel refers to the main wearing items such as garments (dress, shirt, skirt, etc.) and shoes. The included papers which correspond to this category include the high heel shoes (Mphepö et al., 2014), and the costumes (McMillan, 2018; Perovich et al., 2014; Hye & Achituv, 2012; Bian et al., 2011; Berglund et al., 2018). Berglund et al. (2018), for instance, developed a gown named "Sleeping Beauty," which changed its surface color according to the input from two wand controllers. The color change, flower embroidery, and manual Zigzag stitches enhanced the aesthetics aspects of this wearable.

Textiles subdomain of Fashion Design has to do with fabric manipulation, surface treatment and adding or embedding electronic parts in the textiles to develop interactive or smart fabrics. Studies such as illuminated polymeric optical fiber (POF) fabric (Chen et al., 2020), ultra-sheer fabric (Wu et al., 2020), magic lining (Kuusk et al., 2018), shape-

Table 1. Domains identified in the included studies.

	Fashion domains											
	Fashion design			Communication			Interaction design					
Domains	Accessories & jewelry	Apparel	Textiles	Self-expression	Social	Education	Environmental	Physiological	Marketi ng	Performance	Sustainabilit y	Well-being
REFERENCE	Carpenter & Overholt, 2018; İnsel, et al., 2018; Zdziarska, et al. 2019; Juhlin, et al. 2013; Kao, et al. 2017; Kim, et al. 2017; Koulidou, & Mitchell, 2021; Pan & Pan, 2018; Pan, et al. 2018; Sorensen& Thummanapalli, 2017; Buruk, et al. 2021; Von Radziewsky et al., 2015	McMillan, 2018; Mphepö et al. 2014; Perovich et al. 2014; Hye, & Achituv, 2012; Bian & Hirsch, 2011; Berglund, et al., 2018	Chen, et al. 2020; Du, et al. 2018; Durbhaka, 2016; Perovich et al. 2014; Moere, & Hoinkis, 2006; Fox, 2020; Devendorf, et al. 2016	Hayashi et al., 2019; Neidlinger, et al., 2019; Genç, et al. 2018; Kleinberger & Panjwani, 2018; Elblaus, et al. 2015; Kooroshn ia, et al. 2015; Heiss, 2007; Berzowska & Coelho, 2005	Wang, &Godoy, 2021; Wang, et al. 2018; McMillan, 2018; Kim, et al. 2017; Tomico & Wilde, 2015; Chui, & Taylor, 2012; Rossi, et al. 2011; Lewis, 2009; Baurley et al., 2007; Berzowska, 2005; Farahi, 2016	Han et al. 2021; f 2021; Woop, et al. 2020; Klamka, et al. 2020; Seyed, & Tang, 2019; Lau, et al. 2009	Lee, 2020; Ozkan, 2015; Tan, 2015; Tomico & Wilde, 2015; Frankjaer, & Gilgen, 2014; Roinesa lo, et al. 2017	Lee, 2020	Orzan et al., 2020; Nelson et al. 2019; Ouverson, et al., 2017	Poluchovi ch et al., 2021; Cardoso, et al. 2019; Koon, et al. 2018; Honauer, 2018; Birringer & Danjoux, 2013; Murray-Browne, et al. 2013; Birringer & Danjoux, 2009; Honauer, et al. 2017; Berzowska, 2005	Wu, & Devendorf, 2020; Vasquez & Vega, 2019; Lee, 2018; Mihaleva, & Pataranutap orn, 2018; Ueoka, et al. 2010; Kobayashi, et al. 2008; Iossifova & Kim, 2004	Fangmeng, et al. 2020; Wang, et al. 2019; Callari, et al. 2019; Markvicka et al. 2019; Marti, Iacono, et al. 2018, Marti, Tittarelli,et al. 2018; Oh, & Gross, 2015; Duvall, et al. 2016; Pataranutaporn, et al., 2017; Lee, 2018
Total	12	6	7	8	11	6	6	1	3	9	7	10
	25			19			7					

changing fabric (Du et al., 2018), adaptive fabric (Durbhaka, 2016), fabric folding display (Vande Moere & Hoinkis, 2006), laser cut shape-changing fabric (Fox, 2020) and woven and crochet fabric (Devendorf et al., 2016) fall into this category. For example, study (Perovich et al., 2014) demonstrates a dress called "Awakened apparel" which has shape-changing mechanisms. The designers applied advances in soft robotics and transformable fashion by blending pneumatics and folding to fabricate aesthetically and tactilely pleasing shape-changing fabric for constructing garments.

The studies in the Fashion Design domain are mostly populated around accessories and the development of new computational textile samples. Only a few studies include aesthetic exploration of apparels and among them only six focuses on apparels that covers a bigger part of the body. This might be an indicator that the exploration of fashionable aspects is happening in smaller pieces, which might be due to the lack of reliability and affordability of electronics components, along with lack of established practices for designing CFWs.

4.2.2. Communication domain

Communication domain received the second highest number of studies (Table 1). Nineteen studies (23%) out of the total 82 studies were related to this domain. The studies in the domain of Communication with two sub-domains (Self-expression and Social communication) mainly aimed to create non-verbal communication in social situations through wearables. Self-expression includes wearables which are responsive to the person wearing it, whereas social communication contains wearables that react to the others around. Pneu-skin (Wang & Godoy, 2021), Connecting couture (McMillan, 2018), Closer project (Lewis, 2009), Communication wear (Baurley et al., 2007), and Caress of the Gaze (Farahi, 2016) are some instances of *Social Communication* sub-domain. Caress of the Gaze (Farahi, 2016), for example, was constructed by shape-changing 3D printed structures that move based on detecting others gaze. Self-expression is the other *Communication* sub-domain, some examples of which include Kinetic garments (Hayashi et al., 2019; Berzowska & Coelho, 2005), Nebula (Elblaus et al., 2015), enchanted dress (Kleinberger & Panjwani, 2018), and Awe Goose bumps garment (Neidlinger et al., 2019). "AWE," a wearable piece created in the study by Neidlinger et al. (2019) is an inspiration of human and animal skin, which mimics the physiological functions by illuminating (pink for excitement, and teal blue for inhale and exhale) and inflating silicones. The designers applied volume and silhouette to create aesthetically pleasing inflatables goosebumps, which animate the sense of surprise and wonder. Awe Goosebumps garment translates the biometric information into colors and haptic feedback to externalize and magnify feelings of awe and goosebumps.

In sum, a good proportion of studies were categorized under the Communication domain including fashion wearables, which were responsive either to the person wearing it, or to the others around. The SRL shows that research in this domain acknowledges that fashion techniques such as fabric construction and surface manipulation methods can move beyond being static aesthetic effects, but can facilitate novel non-verbal communication in social situations.

4.2.3. Interaction design domain

The studies particularly focused on designing interactions among the environment, the wear and the wearer were categorized as the domain of Interaction Design. Fall (Ozkan, 2015), Photonic fabric (Tan, 2015), and Dawn Jacket (Roinesalo et al., 2017) are some examples from the *Environmental Interaction* sub-domain, where the wear reacts to environmental stimuli (i.e., light and humidity). Fall (Ozkan, 2015) for instance, responds to environmental factors such as temperature and light, and displays a gesture like trees' foliage. The designer used mimicry of nature to create a kinetic and dynamic piece to show the falling leaves. In addition to the environmental interaction, one study (Lee, 2020) was identified as the *Physiological Interaction* The researchers developed four smart jackets with vital-sign monitoring (measuring the user's heart-beat rates), and body heating control (sustaining the user's body heat in harsh climate) functions. The designers asserted they attempted to develop visually balanced platform designs to enhance garment' wearability, comfort, and aesthetics. The silhouette, patterns, and color selection, and the location of technology brought "coolness" in the developed wearables.

The studies in the Interaction Design domain mainly focus on environmental interaction with one exception focusing on physiological interaction, which reacts to the data collected from the body. This shows that using cues from surroundings for enhancing the aesthetic qualities of wearables was preferred more by researchers, while bodily data has also been in the design space. This exemplify that using environmental cues relatively well-established in the interaction design domain while opportunities of using technology to support fashion design by investigating possible interactions between the body of the wearers and the worn remain to be explored further.

4.2.4. Other domains

Fashion wearables studies in the domain of *Education* mostly dealt with developing toolkits or tools for rapid prototyping for beginner fashion designers (Berglund et al., 2018; Han et al., 2021; Vahid et al., 2021; Klamka et al., 2020; Woop et al., 2020), or with designing and organizing a course on wearable computing, fashion and design (Lau et al., 2009). The domain of *Marketing* aimed at customers and businesses' familiarity with the markets of fashion smart wearables (Orzan et al., 2020), and the social acceptability and adoption of fashionable wearables (Nelson et al., 2019; Ouverson et al., 2017). The studies in Education suggests that hands-on solutions such as toolkits are an important facet for involving future fashion designers in the design of CFW. When it comes to Marketing, familiarity and the social acceptance seem to be the main focus which is considered as an important aspect which will drive further adoption of CFW either for businesses and customers.

Studies (Poluchovich et al., 2021; Cardoso et al., 2019; Honauer, 2018) which demonstrate dance costume are related to the *Performance* domain. Cardoso et al. (2019), for example, is an interactive luminous ballet costume called Lightness, which transforms movements into light and colors with different intensities. They used white-colored light fluid materials, such as tulle fabric and a light plain weave, to create a diffusion effect with the light casted from LEDs under the fabrics. While their approach adds aesthetically pleasing effects, it also contributes to a sense of directionality on the garment. The studies in the Performance domain shows that CFW can also be important for complementing the bodily performances by augmenting the aesthetic impact of body movement with technology and stage performances can be one of the important domains benefiting from CFW.

The domain of *Sustainability*, that addresses works focused on minimizing the environmental damage (Gurova & Morozova, 2018) was also received substantial attention from the researchers. Myco-accessories (Vasquez & Vega 2019), for instance, uses biodegradable materials (mycelium) to embed an electronic circuit to make an accessory. The electronic components can be reused and the mycelium skin would compost after the accessory has been worn. The accessories produced were fashion items such as necklace, crown and bracelets with appealing design, texture and color. Unfabricate (Wu & Devendorf, 2020), a smart textile for disassembly and reuse, and Coral Reef Inspired Dress (Mihaleva & Pataranutaporn, 2018) combining Shibory techniques - traditional fabric dyeing techniques in Japan- and LED light to demonstrate coral bleaching, are other instances in this domain. The studies in sustainability domain uses technology as a means of producing decomposable and reusable fashion items or for forming a bodily connection between the wearer and the environmental issues (e.g., coral bleaching). Thus, CFW field has also potential to promote sustainable fashion practices as well as facilitating environmental communication.

Finally, the domain of *Well-being* in this paper includes studies on fitness and assistive wearables. For example, Lee's (2018) work is an interactive cycling outfit incorporating solar powered LED sensor lights, which automatically turned on and off depending on the surrounding brightness. The semi-transparency of Hanji fabrics, and high-tech trim materials (3 M reflective strips, stretch air-mesh fabric, fluorescent tape), and the light pattern design used created an aesthetic language on this outfit. Some other instances of this domain include EEG cap for detecting emotions of elderly patients (Fangmeng et al., 2020); interactive clothing for patients with communication disorder (Wang et al., 2019); Maturolife project (smart footwear) (Callari et al., 2019) to assist the older adults with the risk of falling; Electrodermis bandages (Markvicka et al., 2019); interactive jewelry for deaf people to experience sound (Marti, Tittarelli,et al. 2018); and Awareable Steps shoes helping patients with dementia (Oh & Gross, 2015). Among these, ElectroDermis (Markvicka et al., 2019) had stretchable and on-skin compliant wearable electronics, with multiple applications for wellbeing. Several bandage-like wearables such as a temperature mask, vital monitoring earrings, food detecting necklace, smart wound healing bandage, and environment color mirroring were developed. They sense bio-signals of the wearer and visually display these with LEDs on the wearable. Applying Rhino Grasshopper's app, the designers created bandage designs, which were soft, elastic, and aesthetically and visually appealing.

The convergence of the features of well-being with CFWs can provide the users with the functions besides experiencing better looks and feelings. The CFWs, in this domain, support the wearers' well-being, i.e., by being compatible to the dynamic nature of the human body (Markvicka et al., 2019), providing a high level of ventilation and wicking properties (Lee, 2018), maintaining balance and temperature, adapting to swelling of the feet, and addressing pains (Callari et al., 2019), dealing with communication disorders (Wang et al., 2019), detecting emotions (Fangmeng et al., 2020), while also considering the users' needs and preferences in terms of user friendliness, wearability, comfort and ergonomic design as well as visual appeals such as style, color, and material.

Figure 3 displays the distribution of the CFWs in the domains and subdomains. According to this pie chart, in total the macro domains of Communication and Fashion Design were examined by around 51% of the included studies, which means the scholar are more inclined to study the aesthetic and communicational aspects of CFWs.

4.3. Theories/theoretical framings

This section intends to answer RQ2 – "What are the theories or theoretical underpinnings applied in the previous CFWs' researches?" Theories are sets of interrelated constructs and definitions which can provide the researcher with a systematic view of the phenomenon under study and helps him/her to make predictions about it. Likewise, a theoretical framework as a collection of interconnected concepts connects the researchers with the existing literature and shows them the gaps in knowledge and practice, enabling the predictions, explanations and interpretation of the

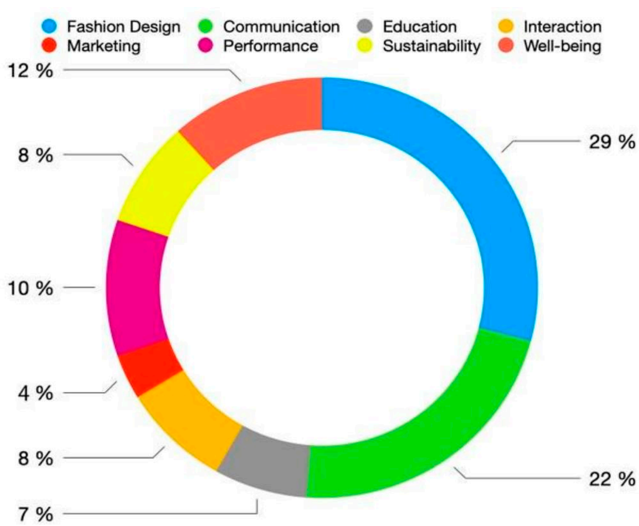

Figure 3. Domains of computational fashionable wearables.

results (Kerlinger, 1986). On the grounds of that, the present SLR also examined the included studies in terms of the theories they discussed or mentioned they were based on. Here, it should be noted that all these included studies generally fall in the realm of HCI/Interaction design and fashion design, since they were systematically selected according to search strings including these terms. However, depending on their background or interest, the researchers or authors of the included studies put more or less emphasis on certain theories. See Table 2 for an overview.

The most frequently mentioned theory in the included studies was the *embodiment or embodied interaction theory*. Embodied interaction theory seeks for creation and manipulation of meaning by means of tangible interactions and physically embodied experiences (Dourish, 2001) and is mentioned by seven papers (Koulidou & Mitchell, 2021; Wang & Godoy, 2021; Neidlinger et al., 2019; Nelson et al., 2019; Du et al., 2018; Kleinberger & Panjwani, 2018; Tomico & Wilde, 2015). For instance, PNEU-SKIN (Wang & Godoy, 2021) is a pneumatic wearable made of inflatable fabric which embodies sensory feedback at varying interpersonal distances. The designers experimented with inflatable fabric modules to achieve embodied computation through parametric design and patterning. The AWE Goosebumps (Neidlinger et al., 2019) is an emotion prosthesis based on embodied interaction theory, in which the designers attempted to animate and physically express the feeling of goosebumps and communicate emotions. AWE (Neidlinger et al., 2019) is a biofeedback loop which consists of three components: a detection system (sensing), controlling system (think), and feedback system (actuation). It translates biometric information and physical sensation into observable, tangible and real-time transformations; the prosthesis reacts to actions such as inhale, exhale, and excitement and create feedback loops through color changes, haptic feedback and expanding inflatables.

Embodied interaction approaches have been implemented in the different parts of the research phases across the 7 projects here. It served as a way to understand the design space either through first person bodily experiences (Wang & Godoy, 2021) or observing how wearables act on the moving body (Tomico & Wilde, 2015), as a lens for framing and inspiration (e.g., searching for types of goosebumps and their associations, Neidlinger et al., 2019), for more technical quantitative analysis (Nelson et al., 2019) or as a design purpose focusing on bodily performative aesthetics (Du et al., 2018; Kleinberger & Panjwani, 2018). Considering the significance of embodied interaction theory both in HCI and fashion design, it is not surprising that it has been incorporated in diverse ways, although only 7 out of 82 studies intentionally incorporated it.

Environmental sustainability theory was attended to in six studies following Embodied Interaction theory. Sustainability emphasizes balancing human activities in relation to the natural environment in order to minimize the damage on both the environment and human beings (Gurova & Morozova, 2018). In Myco-Accessories (Vasquez & Vega, 2019), which are a series of biodegradable mushroom-based accessories, the researchers utilized the sustainability theory to detail the life-cycle of

Table 2. Theories/theoretical framings in the included studies.

Studies	Theoretical/Conceptual framings	Definition/Description	Total studies
[Wang, & Godoy, 2021; Neidlinger et al. 2019; Nelson, et al. 2019; McMillan, 2018; Du, et al. 2018; Kleinberger, & Panjwani, 2018; Tomico, & Wilde, 2015]	Embodiment theory	Refers to our being living, feeling, bodily entities situated in a physical world (Marshall & Hornecker, 2013).	7
[Wu, & Devendorf, 2020; Vasquez, & Vega, 2019; Lee, 2018; Mihaleva, & Pataranutaporn, 2018; Sorensen, & Thummanapalli, 2017; Kobayashi, et al. 2008]	Environmental sustainability	Balancing human activities in order to minimize the damage on both the environment and human beings (Gurova & Morozova, 2018).	6
[Zdziarska, et al. 2019; Marti, Tittarelli,et al. 2018; Kao, et al. 2017; Berzowska, & Coelho, 2005]	Kinetic (fashion)	Reconfiguration (shape changing) of fashion items through the use of some sort of mechanical or electronic process (Berzowska & Coelho, 2005; Lindqvist, 2015).	4
[Kooroshnia, et al. 2015; Birringer, & Danjoux, 2013; Birringer, & Danjoux, 2009]	Performativity	Derived from Austin's (1975) speech act theory, performativity refers to the function of an object to induce a bodily reaction based on its form and matter.	3
[Han, et al. 2021; Lee, 2020]	Theory of convergence education	The integration of knowledge, techniques, and expertise from various fields to form new frameworks and solutions to address scientific and societal challenges (Herr, et al., 2019).	2
[Nelson, et al. 2019; Ouverson, et al. 2017]	Technology acceptance theory	Individual's intention to use new technology including two main factors: perceived ease of use and perceived usefulness (Davis, 1989).	2
[Buruk, et al. 2021; İnsel et al. 2018]	Custom design framework	A design framework based on conventional jewelry developed by Genç, et al. (2018) to design and experience aesthetic interaction in smart jewelry.	2
[Han et al. 2021]	Explorative/Task-oriented learning theory	Learning through trial and error and interacting with other users (Rieman, 1996) and interacting and engaging in meaningful tasks (activities) (Han et al., 2021).	1
[Vahid et al. 2021]	Scaffolding learning	Providing support structures to get the students to the next stage or level (Raymond, 2000).	1
[Wang et al. 2019]	Cyber-physical-clothing systems (CPCS) model (custom-made)	The technical development process of interactive clothing from clothing to data, information, knowledge, wisdom, services, humans, and then back to clothing (Wang et al., 2019).	1
[Vasquez & Vega, 2019]	Biological human computer interaction framework	The relationship between human, computer and biological systems by redefining biological materials as design components (Pataranutaporn et al., 2018)	1
[Neidlinger et al., 2019]	Intimacy/Extimacy theory	The externalized intimacy that occurs when intimate internal feelings are exposed to the external world (Neidlinger et al., 2017)	1
[Heiss, 2007]	Tele-presence theory	The technology-enabled feeling that a person is present in a different place or time' (Greene 2004).	1
[Lewis, 2009]	Mediated social touch theory	Touching another actor over a distance by means of tactile or kinesthetic feedback technology (Haans & IJsselsteijn, 2006).	1
[Wang, & Godoy, 2021]	Proxemics theory	The personal space and the distance individuals maintain between each other in social encounters (Brown & Edward, 2001).	1
[Ueoka, et al. 2010]	Human–computer biosphere interaction (HCBI)	Symbiosis between humans and pets via computer and the internet as a new form of media (Kobayashi et al., 2009).	1
	In total: 35 [33 + 2 (two studies mentioned two theoretical framings)]		

interactive accessories. They proposed a cycle where the mushroom part of the accessories is composted and regrown whereas the electronics are reused. In another study (Mihaleva & Pataranutaporn, 2018), coral reef bleaching was demonstrated by a responsive dress, which resembled coral reef and was made of recycled plastic bottles. The study aimed to show the destructive invasion of human beings to marine space, which caused the vulnerability and death of coral reefs. The designers adopted biomimicry design approach and interactive multimedia systems to emphasize the balance and coexistence between water and coral, as well as eco-friendliness and people friendliness of wearables. They constructed the garment based on Shibori, an old Asian fabric manipulation technique to display the morphology of coral reef. Three-dimensionality, transformation and active agency are pivotal in Shibori tradition. Altogether, environmental sustainability theory has been applied to CFWs to evaluate and create more sustainable practices around wearables.

Table 3 shows studies that either spared mentioning any theoretical or conceptual framing or briefly mentioned the field related to their work. The fields mentioned in these studies included Interaction Design, Human-Computer Interaction

Table 3. Included studies with no specific theoretical framings.

	Studies	Total
No theoretical perspective mentioned or elucidated	Baurley, et al. 2007; Berglund, et al. 2018; Berzowska, 2005; Bian et al. 2011; Briot et al. 2020; Callari, et al. 2019; Cardoso, et al. 2019; Carpenter & Overholt, 2018; Chen, et al. 2020; Devendorf, et al. 2016; Durbhaka, 2016; Duvall, et al. 2016; Fangmeng, et al. 2020; Elblaus, et al. 2015; Farahi, 2016; Fox, 2020; Frankjaer & Gilgen, 2014; Genç, et al. 2018; Hayashi, et al. 2019; Honauer, 2018; Honauer, et al. 2017; Hye & Achituv, 2012; Iossifova, & Kim, 2004; Zdziarska, et al. 2019; Juhlin, et al. 2013; Kim, et al. 2017; Koon, et al. 2018; Koulidou, & Mitchell, 2021; Kuusk, et al. 2018; Lau, et al. 2009; Markvicka, et al. 2019; Marti, Iacono, et al. 2018), (Marti, Tittarelli,et al. 2018); Moere & Hoinkis, 2006; Mphepö, et al. 2014; Oh, & Gross, 2015; Murray-Browne, et al. 2013; Orzan, et al. 2020; Ozkan, 2015; Pan, & Pan, 2018; Pan, et al. 2018; Perovich, et al. 2014; Poluchovich, et al. 2021; Rossi, et al. 2011; Seyed, & Tang, 2019; Tan, 2015; Von Radziewsky, et al. 2015; Wang, et al. 2018; Woop, et al. 2020; Wu, et al. 2020;	49

(HCI) or fashion design. For example, Markvicka et al. (2019), mentioning drawing from the field of HCI, created new computing interactions and introduces on-body stretchable electronic bandages with computational capabilities to interact with the body and environment. Similarly, Caress of the Gaze (Farahi, 2016) is also an interactive dynamic design created by 3D printing, embedded computing and bio-sensing technologies, which interacts with the surroundings and body. To sum up, a number of studies in the domains of HCI, Interaction design, and fashion preferred to talk about the technical and practical procedures they adopted, and only a few studies managed to explained the theoretical frames behind their works.

We came across a number of theories and concepts such as *Scaffolding Learning* (Raymond, 2000), *Technology Acceptance Theory* (Davis, 1989) and *Intimacy/Extimacy Theory* (Neidlinger et al., 2017) which were not originally related to the fields of human-computer interaction science and/or fashion design (Table 2 for an overview). It is worth mentioning that some of the studies in Table 2 specified they were drawing on concepts and models from two or more fields in their works, such as Buruk et al. (2021) and Sorensen and Thummanapalli (2017), drawing from interaction design and environmental sustainability, Nelson et al. (2019) from technology acceptance model theory and embodiment theory, Sorensen and Thummanapalli (2017) from bio-design and sustainability. However, some other studies (see Table 3) simply mentioned the general theory connected to their works, including Tomico and Wilde (2015) on human-computer interaction and bio-design, and Juhlin et al. (2013) on fashion theory and interaction design, without explicating the concepts or sub-theories. Incorporation of these theories well outside of fashion design or human-computer interaction indicated that the macro domain of computational fashion is an interdisciplinary field which draws on diverse conceptual and theoretical underpinnings from various disciplines such as human-computer interaction (HCI), design, material science, fashion design, education, psychology, sociology, and several others.

Nonetheless, the studies applying concepts and theories from diverse disciplines showcase how interdisciplinary approaches to CFWs can enrich the field.

The Sankey chart (Figure 4) below visualizes the theoretical framings used in each domain. As the chart shows more than one framing were employed in most of the domains. For instance, proxemics theory, social touch theory, telepresence theory, intimacy/extimacy theory as well as embodiment theory were detected in the Communication domain. However, embodiment theory was more frequently applied than other theories in this domain. As another example, embodiment, environmental sustainability, custom design framework, and kinetic fashion were seen in Fashion design domain. That confirms the multi-disciplinary nature of computational fashion wearables. Seemingly, embodiment theory has been used across domains which shows that the concept of embodiment has been found relevant by researchers across disciplines. In Communication and Fashion design domains, as well as the environmental interaction subdomain, the use of embodiment theory suggests that body-oriented design approaches are effective for non-verbal communication and the creation of new aesthetic languages and interaction modalities for CFWs. A study focused on Marketing domain underscored the significance of considering embodiment in conceptualizing the acceptance of CFWs. Furthermore, while performativity theory (Kooroshnia et al., 2015) observed in only one study in Communication domain, the Sanky chart revealed the potential of conceptualizing wearables with performances that complement non-verbal communication in CFWs. Another noteworthy point is that Fashion design domain either included custom design frameworks or kinetic fashion as a theory driven from hands-on design practice without engaging with societal and cultural framings of fashion.

4.4. Materials

In this section we aim to examine the findings for RQ3 - "What are the main materials used in the design of computational fashion wearables?" A variety of materials were applied in the included studies; however, the main ones are presented in Table 4.

According to Table 4, conventional fabric with the highest frequency of 44 times use (around 53%) was the most commonly applied material in the included studies. When conductive fabric is also added to the fabric category, the frequency use of fabric increases to 48 (58%). Conductive yarn with the frequency of 14 (17%) was the second most used material. Figure 5 displays the types of fabric used in the included studies. Leather, Organza, and Silk each applied in 7 studies (21 studies in total), and next is Conductive fabric which was used in 5 studies; however, fourteen studies didn't mention what type of fabric they used for their research.

The conventional fashion textiles applied in 21 of the studies (Figure 5) included fabrics, such as satin, cotton, tulle, synthetic fur, linen, wool, muslin, leather, organza, and silk.

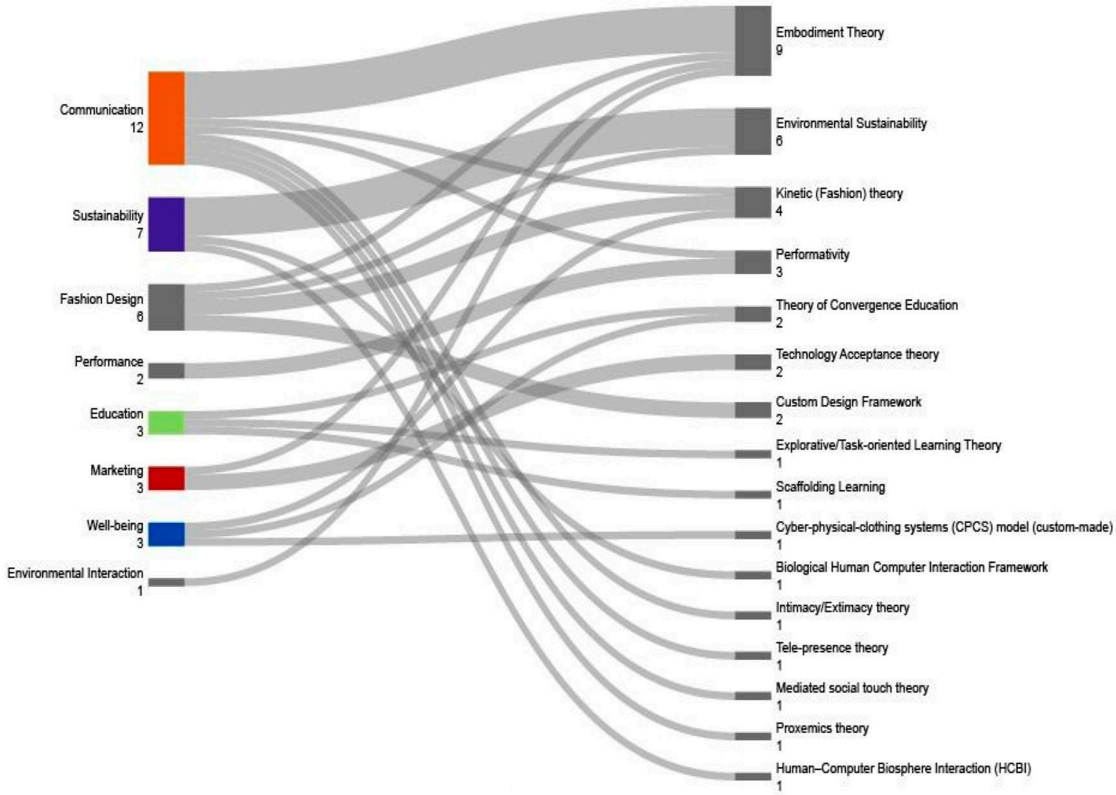

Figure 4. The Sankey chart for the theoretical framings.

Among those, leather, organza, and silk, might be argued to be popular also in conventional fashion. In addition to these conventional fabrics, several studies used textiles which are more technology-oriented such as luminous and conductive fabrics; 14 studies applied conductive yarns for making fabrics conductive (Table 4). It is not surprising to find that fabrics are the most used materials considering that the production of fashion pieces also heavily rely on textiles; textiles are in fact the main ingredient of fashion (Chau, 2013; Hallet & Johnston, 2014). Fabric is fundamentally essential in generating silhouette and aesthetic languages.

Among the fabrics in the included studies, the heavy utilization of silk, organza and leather demonstrate the versatility and practicality of these fashion materials in functional aesthetics research. Furthermore, while none of the studies motivated the usage of particular fabric types, from the fashion perspective, each type of fabric can be associated with different aesthetic affordances: for instance, leather with its flexibility and silhouette can be linked with a smart look and a distinct style; organza with a translucent and highly twisted filament yarns can demonstrate a dreamy look; and silk fiber with its triangular prism-like structure enables a shimmering appearance.

Some studies applied materials such as feathers and jewels. For instance, Stymphalian Birds (Briot et al. 2020), and Feathery Touch Memory Dresses (Berzowska, 2005) aimed to demonstrate adornment, playfulness, and poetic and aesthetics aspects by blending feathers with technology. Studies (Marti, Iacono, et al., 2018; Marti, Tittarelli, et al., 2018) demonstrated a variety of fashionable jewelry including necklaces, armbands, brooches, which let people with hearing impairment experiment with sound through other senses, like touch and sight by providing them with vibrations, light, or kinetic modifications. Another study (Carpenter & Overholt, 2018) presented four jewelry artefacts, Trace, Connect, MirrorMirror, and Fibo, as an annotated portfolio, that were intended to be aesthetically pleasing to wear to meet a friend and facilitate richer personal and interpersonal experiences.

Looking at Table 4, we also come across with some materials which might seem unconventional in designing and producing fashion wearables such as flour in study (Vasquez & Vega, 2019) was used to produce mycelium skin to make accessories, and the result products were wearables accessories with biodegradable materials. Likewise, study (Lee, 2018) introduced a shirket, an interactive cycling outfit with eco-friendly and aesthetic appealing design, produced with Hanji fabric, a fabric made from inner bark of mulberry trees.

In conclusion the choice and the color of the materials or fabric in the design of wearables are of crucial importance. For instance, the stiffness of the leather in Van Dongen's "Solar Dress" not only has a protective aspect for the functional parts, but also supports the square-cut shape of the dress. Furthermore, leather can be left raw edge at the seams of the incisions, which creates a unique look communicating a feeling of power (Smelik, et al., 2016). Smelik, et al. (2016) add that Van Dongen's use of black materials both matches the dark cells on the dress, and gives it a clean, minimal and fashionable look. The designers of ShapeTex (Du et al., 2018), who initially applied copper in fabrication, found that copper is aesthetically restrictive and they decided to use

Table 4. Materials identified in the included studies.

	Materials												
Type	Acrylic fiber	Aluminum	Conductive fabric	Conductive yarn	Conventional fabric	Copper	Feather	Flour	Jewel	Optical fiber	Paper	Plastic	Shape memory alloy
Reference	Chen et al. 2020	Du et al. 2018	Woop et al. 2020; Hayashi et al., 2019; Tan, 2015; Tomico, & Wilde, 2015	Han, et al. 2021; Woop, et al. 2020; Zdziarska et al. 2019; Genç, et al. 2018; Tan,2015; Elblaus et al. 2015; Kobayashi et al. 2008; Baurley et al. 2007; Berzowsk a & Coelho, 2005; Fox,2020; Berglund, et al. 2018; Devendorf et al. 2016; Pataranut aporn et al. 2017; Berzowska 2005	Han, et al. 2021; Wang, & Godoy, 2021; Klamka, et al. 2020; Wu, et al. 2020; Fangmeng, et al. 2020; Lee, 2020; Wang, et al. 2019; Seyed & Tang, 2019; Markvicka, et al. 2019; Zdziarska, et al. 2019; Cardoso, et al. 2019; Genç, et al. 2018; Lee, 2018; Koon, et al. 2018; Mihaleva, & Pataranutaporn, 2018; Wang, et al. 2018; Du, et al. 2018; Kleinberger, & Panjwani, 2018; Kao, et al. 2017; Ozkan, 2015; Oh, & Gross, 2015; Tan, 2015; Elblaus et al. 2015; Kooroshnia, et al. 2015; Perovich et al. 2014; Birringer, & Danjoux, 2013; Ueoka, et al. 2010; Birringer, & Danjoux, 2009; Lewis, 2009; Kobayashi et al. 2008; Heiss, 2007; Baurley, et al. 2007; Moere, & Hoinkis, 2006; Berzowska & Coelho, 2005; Iossifova, & Kim, 2004; Duvall, et al. 2016; Von Radziewsky, et al. 2015; Fox, 2020; Briot et al. 2020; Berglund, et al. 2018; Roinesalo et al. 2017; Juhlin, et al. 2013; Honauer, et al. 2017; Berzowska, 2005	Markvicka et al. 2019; Du et al. 2018	Briot et al. 2020; Berzo wska, 2005	Vasquez & Vega, 2019	Carpenter & Overholt, 2018	Chen, et al. 2020; Honauer, 2018; Frankjaer & Gilgen, 2014; Baurley et al.2007	Vahid et al. 2021; Pataranutaporn et al. 2017	Buruk, et al. 2021; Woop, et al. 2020; Marti, Iacono, et al. 2018; Marti, Tittarelli,et al. 2018; Sorensen & Thummanapalli, 2017; Farahi 2016; Honaue r et al. 2017; İnsel et al. 2018	Pan, & Pan, 2018; Baurley, et al. 2007; Moere & oinkis, 2006; Berzowska, & Coelho, 2005; Fox, 2020; Farahi, 2016
Total	1	1	4	14	44	2	2	1	1	4	2	11	6

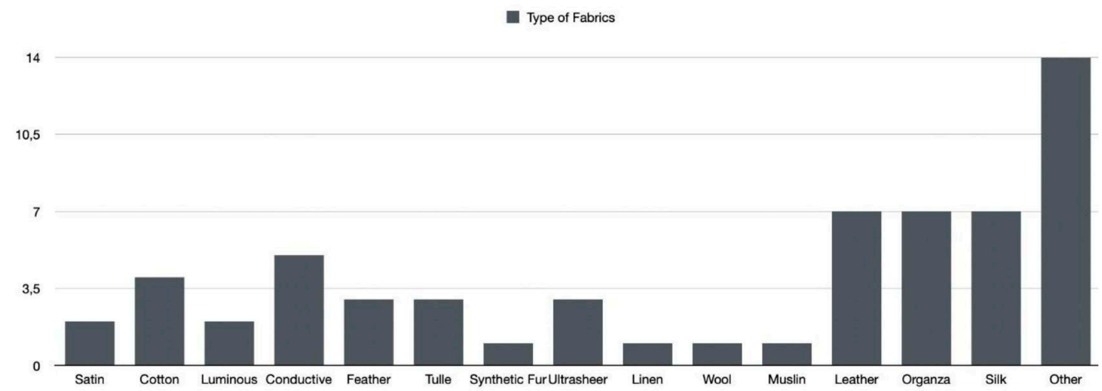

Figure 5. Fabrics identified in the included studies.

also aluminum for a different color alternative. The designers observed that the white color of aluminum had the potentiality of integrating in semi-transparent garment designs. Aluminum not only has a higher resistance and heat capacity than copper, it also comes in various colors. Although almost one third of the studies in the present SLR used fabric as the main material, they neither detail the type of the fabric, nor they notably focus on the aesthetics material properties (i.e., weight, stiffness, texture, color, glossiness, etc.). However, it is a common practice of the CFWs to focus more on the function or the technical issues regarding integration of technologies to achieve interactive end points. Still, our findings suggest that inclusion of computation to fashion brings along many novel materials (e.g., wires, chips, panels) that needs to be combined with the traditional materials (e.g., fabric, leather). Thus, there is a need for further practices to explore the affordances of various materials, as well as exploring methods to modify their visual properties in the design of fashionable expressions since metaphorically wearers "do not want to wear screen (Devendorf et al., 2016)." This section served as a comprehensive overview of designers' material choices and inform designers and researchers of computational fashion for the possibilities of design when it comes to material choices and the current design space.

4.5. Interaction modalities

This section deals with interaction modalities i.e., the type of "input and output" associated to a specific interaction in the included studies and aim to examine the findings for RQ4 - "Which interaction modalities have been adopted in computational fashion wearables research?" The findings for interaction modalities input and output are presented in the following sections.

4.5.1. Interaction modalities: input

As Figure 6 displays, the reviewed papers reported numerous input modalities categorized under three big categories: (1) embodied interactions, (2) psycho-physiological input, and (3) ambient information.

According to Table 5, embodied interaction modalities include bodily movements and senses such as touch and tap,

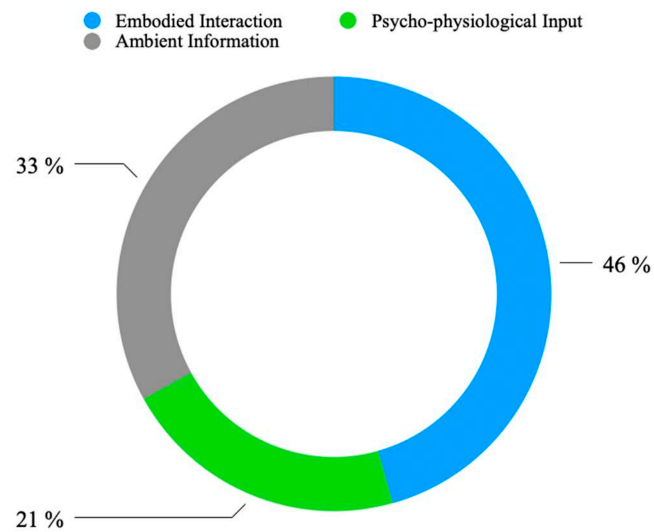

Figure 6. Interaction modalities: input pie chart.

whereas psycho-physiological inputs are related to unconscious inputs from the body such as stress, heart and pulse rates. Ambient information category is based on CFWs reacting to inputs from the environment such as temperature, noise/sound and light levels.

Embodied interaction input modalities which are mostly gestural movements are seen in various forms such as head movement (Buruk et al, 2021), knee movements (Markvicka et al., 2019), arm and leg movements (Honauer, 2018), movement of wearer in sleeve and skirt areas as well as the movement of people in the vicinity (Mihaleva & Pataranutaporn, 2018), dancer's and wearer's movements, especially involving arms (Birringer & Danjoux, 2009; Cardoso et al., 2019; Elblaus et al., 2015; Honauer et al., 2017; Rossi et al., 2011). "Touch" as an input interaction modality, in which the wearer's sense of touch stimulated some kinds of reactions in the wearables was applied in several studies including (Baurley et al., 2007; Berzowska, 2005; Briot et al. 2020; Chen et al., 2020; Fox, 2020; Genç et al., 2018; Insel et al., 2018; Zdziarska et al., 2019; Klamka et al., 2020; Koulidou & Mitchell, 2021; Kuusk et al., 2018; Murray-Browne, et al. 2013; Roinesalo et al., 2017; Wang & Godoy, 2021). For example, touch was used for social interactions in diverse interpersonal distances in PNEUSKIN (Wang & Godoy, 2021). Or using Polymeric Optical Fibers placed in the woven fabric, Chen et al. (2020)

Table 5. Input interaction modalities identified in the included studies.

Interaction modality/input	Ambient information	Proximity	Buruk, et al., 2021; Wang, & Godoy, 2021; Wang, et al., 2019; Wang, et al., 2018; Pan, & Pan, 2018; Frankjaer & Gilgen, 2014	34
		Wind/breeze	McMillan, 2018; Tomico, & Wilde, 2015; Heiss, 2007	
		Temperature	Genç, et al., 2018; Koon, et al., 2018; Du, et al., 2018; Pan, & Pan, 2018; Ozkan, 2015; Roinesalo, et al., 2017	
		Rain/water	Genç, et al., 2018	
		Noise/sound	Marti, Iacono, et al.,, 2018; Marti, Tittarelli, et al., 2018; Ueoka, et al., 2010; Kobayashi, et al., 2008; Heiss, 2007; Iossifova, & Kim, 2004	
		Movement	Tan, 2015	
		Light/darkness	Lee, 2018; Wang, et al., 2018; Pan, & Pan, 2018; Ozkan, 2015; Heiss, 2007; Roinesalo, et al., 2017	
		Electrical wave	Hayashi, et al., 2019; Neidlinger et al.,, 2019; Heiss, 2007; Duvall, et al., 2016	
		Air pressure	Vahid, et al., 2021	
	Psycho-physiological input	Body temperature	Neidlinger et al.,, 2019; Markvicka, et al., 2019; Genç, et al., 2018; Durbhaka, 2016; Kooroshnia, et al., 2015; Roinesalo, et al., 2017; Pataranutaporn, et al., 2017	22
		Skin conductance	Neidlinger et al.,, 2019	
		Pulse rate	Markvicka, et al., 2019; Fox, 2020	
		Oxygen saturation	Markvicka, et al., 2019	
		Heart rate	Neidlinger et al.,, 2019; Du, et al., 2018; Pan, & Pan, 2018; Frankjaer & Gilgen, 2014; Fox, 2020	
		EEG Signal	Fangmeng, et al., 2020	
		Breathe	Neidlinger et al.,, 2019; Fox, 2020	
		Stress	Neidlinger et al., 2019	
		Mood	Kleinberger, & Panjwani, 2018	
		Anger	Neidlinger et al., 2019	
	Embodied interaction	Touch	Koulidou, & Mitchell, 2021; Genç, et al., 2018; Wang, & Godoy, 2021; Chen, et al., 2020; Klamka, et al., 2020; Zdziarska, et al., 2019; Kuusk, et al., 2018; Du, et al., 2018; Kao, et al., 2017; Murray-Browne, et al., 2013; Kobayashi, et al., 2008; Baurley, et al., 2007; Fox, 2020; Briot et al., 2020; Berzowska, 2005; İnsel, et al., 2018	48
		Tap	Koulidou, & Mitchell, 2021; Birringer, & Danjoux, 2013	
		Sweep	Birringer, & Danjoux, 2013	
		Press	Vahid, et al., 2021; Koulidou, & Mitchell, 2021; Klamka, et al., 2020; Koon, et al., 2018; Birringer, & Danjoux, 2013	
		Move	Buruk, et al., 2021; Markvicka, et al., 2019; Cardoso, et al., 2019; Genç, et al., 2018; Mihaleva, & Pataranutaporn, 2018; Honauer, 2018; Durbhaka, 2016; Tan, 2015; Tomico, & Wilde, 2015; Elblaus, et al., 2015; Kooroshnia, et al., 2015; Murray-Browne, et al., 2013; Rossi, et al., 2011; Birringer, & Danjoux, 2009; Honauer, et al., 2017	
		Lift	Hye & Achituv, 2012; Rossi, et al., 2011	
		Hug	Lewis, 2009	
		Hover	Buruk, et al., 2021	
		Hold	Lewis, 2009	
		Gaze	Farahi, 2016	
		Fold	Moere, & Hoinkis, 2006; Pan & Pan, 2018	
		Fasten	Koulidou & Mitchell, 2021; Von Radziewsky, et al., 2015	
	Input		Ref	Total

demonstrated illumination through touch. Hooze (Zdziarska et al., 2019), a furry kinetic fashion accessory, aimed to express intimacy and connection with animals via touch; or wearer's self-image and self-perception is explored in Magic lining's (Kuusk et al., 2018) constant touch with body. Moreover, Memory rich clothing study (Berzowska, 2005) produced costumes that can show personal memory data, such as intimate contact, when and where the wearer was last touched.

Temperature as an interaction input modality used either for reacting to the wearer's body temperature (Du et al., 2018; Durbhaka, 2016; Kooroshnia et al., 2015; Markvicka et al., 2019; Neidlinger et al., 2019), or reacting to the thermo signals from the environment (Du, et al. 2018; Koon, et al. 2018; Roinesalo, et al. 2017) Proximity is the next common input modality in these included studies. For instance, in "Grape necklace" (Buruk et al., 2021) the proximity of the hand and/or the lifting gestures of the wearer caused different colored lights, or PNEU SKIN (Wang & Godoy, 2021) responses to varying social distances in interpersonal communication by changing sizes, or physical distance caused pattern change in interpersonal interaction among different family members (Wang et al., 2019), or whenever the distance between two individuals reduced, the LEDs embedded in the wearables gradually illuminated (Wang et al., 2018), or the floral clothing accessory displayed dynamic visual effects when received signals from surrounding (Pan & pan, 2018), or the wearable entered into "interactive mode" by exchanging patterns and hues, when coming into close proximity of other similar wearables (Frankjaer & Gilgen, 2014).

In the same line with our review, Shilkrot et al. (2015), working on finger augmented devices (FAD) as finger wearables, recorded thirteen input modalities in their systematic survey. They found pressure or force and proximity as some of most used input modalities, and thermal and bending as the least applied input modalities applied. Vatavu and Bilius (2021)'s systematic review on ring devices as a finger wearable and ring-based gesture input, showed tapping, touching, pressing, and grasping gestures among their seven-category classification of input modalities.

Input modalities which have been used in our review on CFWs heavily rely on three main categories: embodied interactions, signals from the environment or ambient data, and psychophysiological data. This further emphasizes that CFWs have a potential to be a bridge among the wearer, worn and the outside world by interacting through embodied and situated body (Tomico & Wilde, 2015), with the contextual inputs such as temperature or light (Genç et al., 2018; Tomico et al., 2017), and with physiological input from the body (Markvicka, 2019). Diverse input modalities can bring about distinct interactions and different messages between the wearer, the worn and the surroundings (Genç et al., 2018; Tomico et al., 2017). Form as one of the main elements of design is also a crucial factor in input modalities (Shilkrot, et al. 2015; Vatavu and Bilius, 2021). For instance, ring, which is worn on the proximal phalanx of the finger, is considered to have the most practical and convenient form factor for hands to interact with other devices (Shilkrot, et al. 2015). Accordingly, comfort and appealing form factor take on more importance when the designers are concerned with more proximal and visible wearables such as fashion wearables or sensitive and visible body parts. Through their form, design and materials, clothing is a part of body schema and bodily sensations. Although we come across more conventional control schemes, such as capacitive touch controls, CFWs manifest a similar interaction between the wearer and the worn through less common interaction methods, such as temperature, ambient light level, body movement or the heart rate with a considerable prevalence. That might indicate further opportunities to integrate somaesthetic approaches to the production of computational fashion, in which those modalities might be considered not only as a part of the function (Jung & ståhl, 2018), but also as a contributor to the holistic aesthetic expression of wearing a computational device.

4.5.2. Interaction modality: output. The output interaction modalities spotted in the reviewed studies which were classified into 5 categories: (1) kinetic transformation, (2) visual display, (3) haptic, (4). thermal, and (5) olfactory (Figure 7).

According to Table 6 below, luminous effect from visual display with the occurring frequency of 27 (in 33% of the studies) was the most commonly seen output in these original studies. Vibration from haptic, sound from audio, shape changing from kinetic, color changing and light pattern from visual display, and movement from kinetic modalities with occurring frequencies of 12, 11, 10, 9, and 8, respectively were the next most seen outputs after luminous effect.

As the table displays, in addition to more conventional output modalities such as illumination, sound, color change, and vibration, there were some rare and less frequent but prevalent output interactions especially in kinetic transformation modalities. For example, output modalities of "defoliation" (Ozkan, 2015), in which the interactive

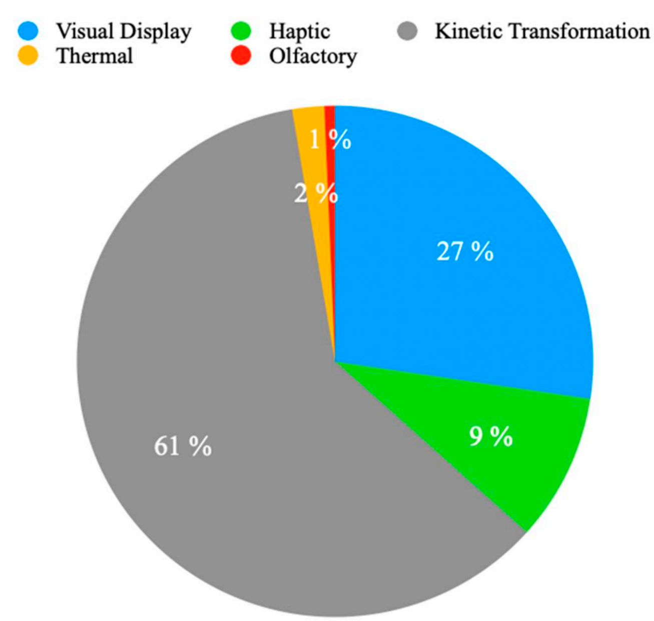

Figure 7. Interaction modalities: output pie chart.

Table 6. Output interaction Modalities Identified in the Included Studies.

Output	Interaction	Thermal	Heat	Lee, 2020; Du, et al., 2018; Baurley, et al., 2007	3
	Modality	Visual Display	Color change	Neidlinger et al.,, 2019; Seyed, & Tang, 2019; Markvicka, et al., 2019; Tan, 2015; Kooroshnia, et al., 2015; Lau, et al., 2009; Berglund, et al., 2018; Devendorf, et al., 2016; [Juhlin, et al., 2013; Berzowska, 2005	41
			Camouflage	Kao, et al., 2017; Birringer & Danjoux, 2009	
			Coloration	Birringer, & Danjoux, 2009	
			Text	Lee, 2020	
			Graphic	Fangmeng, et al., 2020	
			Light pattern	Wu, et al., 2020; Markvicka, et al., 2019; Marti, Tittarelli,et al., 2018; Genç, et al., 2018; Frankjaer & Gilgen, 2014; Mphepö, et al., 2014; Ueoka, et al., 2010; Moere, & Hoinkis, 2006; Iossifova, & Kim, 2004	
			Luminous effect (glow effect by LEDs, screens or other light emitting material)	Buruk, et al., 2021; Koulidou, & Mitchell, 2021; Poluchovich, et al., 2021; Wang, & Godoy, 2021; Chen, et al., 2020; Wu, & Devendorf, 2020; Wang, et al., 2019; Vasquez, & Vega, 2019; Markvicka, et al., 2019; Cardoso, et al., 2019; Genç, et al., 2018; Lee, 2018; Mihaleva, & Pataranutaporn, 2018; Wang, et al., 2018; Honauer, 2018; Kim, et al., 2017; Hye, & Achituv, 2012; Rossi, et al., 2011; Lewis, 2009; Kobayashi, et al., 2008; Heiss, 2007; Baurley, et al., 2007; Carpenter & Overholt, 2018; Berglund, et al., 2018; Roinesalo, et al., 2017; Honauer, et al., 2017; İnsel, et al., 2018	
			Blink	Wang & Godoy, 2021; Markvicka, et al., 2019; Lau, et al., 2009	
		Olfactory	Smell/perfume	Wang & Godoy, 2021	1
		Haptic	Vibrate	Buruk, et al., 2021;Lee, 2020; Zdziarska, et al., 2019; Marti, Iacono, et al.,, 2018; Marti, Tittarelli,et al., 2018; Honauer, 2018; Kuusk et al., 2018; Wu, et al., 2020;Tomico & Wilde, 2015; Heiss, 2007; Von Radziewsky,et al., 2015; Carpenter & Overholt, 2018	14
			Tremble	McMillan, 2018	
			Flap/wave	Pan & Pan, 2018	
		Kinetic	Defoliation	Ozkan, 2015	54
		Transformation	Fanning	Buruk, et al., 2021	
			Wrinkle	Berzowska, & Coelho, 2005	
			Tight/loose	Genç, et al., 2018	
			Size change	Genç, et al., 2018	
			Shape change	Vahid, et al., 2021; Hayashi, et al., 2019; Marti, Iacono et al.,, 2018; Marti, Tittarelli,et al., 2018; Genç, et al., 2018; Du, et al., 2018; Kao, et al., 2017; Tomico, & Wilde, 2015; Von Radziewsky, et al., 2015; Fox, 2020; Juhlin, et al., 2013	
			Move	Zdziarska, et al., 2019; Marti, Iacono, et al.,, 2018; Genç, et al., 2018; Koon, et al., 2018; McMillan, 2018; Pan, & Pan, 2018; Pan, et al., 2018; Farahi, 2016; Honauer, 2018	
			Inflate/deflate	Vahid, et al., 2021; Wang, & Godoy, 2021; Neidlinger et al.,, 2019; Durbhaka, 2016; Pataranutaporn, et al., 2017	
			Fold/unfold	Vahid, et al., 2021; Perovich, et al., 2014	
			Contract/extension	Duvall, et al., 2016	
			Blooming	Vahid, et al., 2021; Du, et al., 2018; Pan, & Pan, 2018; Pan et al., 2018, 2017; Berzowska, & Coelho, 2005; Pataranutaporn, et al., 2017	
			Animated con	Sorensen, & Thummanapalli, 2017; Birringer, & Danjoux, 2009	
		Audio	Sound	Lee, 2020; Genç, et al., 2018; Kuusk, et al., 2018; Kleinberger, & Panjwani, 2018; Sorensen, & Thummanapalli, 2017; Kao, et al., 2017; Tomico, & Wilde, 2015; Elblaus, et al., 2015; Birringer, & Danjoux, 2013; Murray-Browne et al., 2013; Lewis, 2009; Briot et al., 2020	12
	Output			Reference	Total

garment "Fall" responded to the environment by losing its leaves, or output interactions "blooming" (of the robotic flower), "bending" and "swaying" (Berzowska & Coelho, 2005; Pan & Pan, 2018; Pataranutaporn et al., 2017), occurred due to signals coming from the surrounding, someone's approaching, or light from surrounding. Many studies also used deformation and shape changing. For instance, in Fox (2020) and Von Radziewsky et al. (2015), the textiles crumpled up and smoothed according to the wearer's state, or in Du, et al. (2018) and Genç, et al. (2018), the garment respectively reacts to the temperature of the environment and the user by shape and pattern changing.

Moreover, some of output interactions in sound output modality took unusual forms as soothing sound in Closer (Lewis, 2009), which were two pullovers; and jarring sounds including the crackle of leaves, dropping of salt onto the floor, the exhale of bandoneon, the glitches of claves, the hands on the skin of the drum, the rustle of paillette sleeves and clicking of magnets against speaker in Kinaesonic Garments (Birringer & Danjoux, 2013).

Our results demonstrate that the visual and kinetic output modalities are the most common ones. Visual expressions have been mostly about color change through materials or illumination, yet dynamic kinetic changes which push the boundaries of fashionable expressions have also been common trends; especially studies (Fox, 2020; Hayashi et al., 2019; Genç et al., 2018; Kao et al., 2017; Von Radziewsky et al., 2015) are good examples how computation can take fashionable expressions further. Seeing that in a bigger picture, it can be said several output modalities found in this review (Table 6) can be associated with the first class of output detected by Shilkrot et al. (2015) in their FAD study. In their survey, they classified the output modalities into two categories of Human-Detectable Output – HDO (such as vibration, light, tactile, display, and audio which are detectable by the human senses), and Non-Detectable Output – NDO (such as radio and magnetic energy). However, we found some unique output modalities such as defoliation, crumpling, or blooming, which contribute to the aesthetic features of the wearables. In other words, another highlight of the results of our SLR is that computation can lead to the exploration of less common sensory stimulations and thereby add new layers to clothing design. Accordingly, the unpacking of haptic, olfactory, audial, or environmental output proposes an immensely rich but complex design space for the design of computational fashionable expressions.

5. Discussion and a future agenda

The present systematic study reviewed a big portion of literature on computational wearables from the viewpoint of fashion, which previously received less attention when it comes to a systematic overview. The study aimed to examine the current state of CFWs studies in terms of domains, theories, materials, modalities, and gaps. This section answers RQ5 and deals with the gaps spotted in current CFWs' research, and further illustrates challenges and an agenda for the way forward. Each agenda point and challenge are derived based on the findings above and the relations between findings and the agenda points can be explicitly seen in Tables 7 and 8's Related Finding Section column. We have defined future directions in a way that would correspond to the challenges based on our critical engagement, hands-on experience and knowledge in the field of computational fashion wearables.

5.1. Challenges and future agenda for theories

Theories and theoretical frameworks play a pivotal role in systematically addressing the research topic and shaping the academic knowledge generated from studies (Kerlinger, 1986). In the context of smart wearables, a prior systematic literature review conducted by Niknejad et al. (2020) revealed that most wearable studies predominantly revolved around IT-oriented theories such as the Technology Acceptance Model (Davis, 1989) to conceptualize individuals' acceptance of these devices. Our study, on the other hand, identified theories from various disciplines (see Section 4.3 and Table 2). However, according to the present SLR only a small minority of studies utilized fashion-related theories in their work. Moreover, 47 studies did not clearly elucidate any prior framings for their works. This shows that, although studies included here aimed at creating fashionable wearables, there is a gap in bridging fashion theories with CFWs.

One challenge regarding this gap is to establish an engagement between HCI disciplines with fashion theories (C1 in Table 7). Although the CFW is an interdisciplinary field, there is historical friction between HCI approaches and fashion. The traditional HCI culture centers on scientifically sound solutions, whereas fashion is seen as subjective, aesthetic-driven, and creatively oriented, striving to find appealing tastes and styles for people (Joseph et al., 2017). This trend is apparent in how the theories are applied within CFWs and most of the studies focused on deriving actionable framings from theories to develop or evaluate wearable applications (see section 4.3). In this regard, while HCI theories focused on software and hardware fall short in

Table 7. Future agenda for theories.

Related finding section	Challenges	Agenda	Future directions
Section 4.3 Lack of fashion theories	C 1. Engagement between HCI disciplines with fashion theories	A1. Body and embodiment	Explore new fashion expressions for CFWs through body-oriented design processes using embodiment (Tomico & Wilde, 2015; Wilde, et al. 2017) and somaesthetics (Schiphorst, 2009) theories.
		A2. Theories derived from fashion practices	Utilize actionable methods from fashion design practices, such as Fashion Thinking (Nixon & Blakley, 2012), Kinetic Fashion Theory (Berzowska & Coelho, 2005; Lindqvist, 2015) and Fashion as a Social phenomenon (Thornquist, 2018).
		A3. Aesthetics theories	Consider Pragmatic Aesthetics (Heinrich & Marino, 2020) and Aesthetic Interaction (Petersen, et al. 2004) as guides in design and the diversity of interaction modalities used CFW field can help achieve this
		A4. Multidisciplinary research	Investigate strategies to familiarization strategies (Moirano et al., 2020) and participatory design approaches (Sanders, et al., 2010) with fashion designers and researchers from other disciplines to combine theories from diverse disciplines.

Table 8. Challenges & future agenda for design practice.

Related Finding Sections	Challenges	Agenda	Future directions
4.2 Lack of studies in the marketing domain	C1. Understanding value of complex and subjective fashion-aspects	A5. End-user studies	More studies in the marketing domain are needed to explore fashionability's into industry Practice and adoptability and social acceptance by consumers
4.4 Studies not focusing on aesthetic affordances of the materials used	C2. Limited look and feel of the electrically functional materials	A6. Variety of conductive materials	Look and feel of conductive materials should be diversified more for designers to explore CFWs that might suit a wider audience.
		A7. Alternative materials	New materials, i.e., biomaterials (Vasquez & Vega, 2019), and computational composites (Genç, et al. 2018) should be explored by applying material manipulation and fabrication techniques to create new aesthetics for CFWs
4.5 Promising but unexplored utilization of dynamic, kinetic components and multi-sensory modalities	C.3 Designing the interactive aesthetics of CFWs	A8. Dynamic designs	Examining dynamic interaction aesthetics [give reference to valgarda's interaction aesthetics paper) that can be created with the combination of fashion production and body crafting techniques.
		A9. Kinetic transformations	Exploration of materials for kinetic transformations, while considering the emotional and socio-cultural meanings of the dynamic transformations.
		A10. Novel modalities & multisensory-approach	Exploring underrepresented areas of modality interactions such as space and volume, thermal and olfactory might be paths to the future of computational fashion, and designers should adopt a multisensory approach for fully exploring the potential of computational fashion design.

guiding fashion-oriented wearable designs (Ryan, 2014), traditional fashion theories do not suffice for crafting soft wearable technologies (Joseph et al., 2017).

A theory that might bridge two domains is the notion of embodiment, which is shared between fashion and HCI in designing worn artifacts and was seen in 7 included studies (see Figure 4 and Table 2 in Section 4.3). In HCI, embodied interaction is a perspective of technology design by considering how we understand the world happens through our bodies that are physically and socially situated (Dourish, 2001). The potential convergence of fashion and embodied interaction has been examined by HCI researchers. For instance, Tomico and Wilde (2015) and Wilde et al. (2017) highlight how technology can be designed by exploring the materials on the body and situated in particular context. Bridging embodied practices and designing aesthetic interaction, the field of somaesthetics highlights the value of paying attention to sensory experiences (i.e., touch) for designing new aesthetic expressions (Schiphorst, 2009). Aligned with embodiment approaches in fashion, i.e., (Entwistle, 2000), these views have the potential to create novel wearing experiences and new ways of expressing the self through not only visual but also embodied performances. Moreover, since the somaesthetic design approaches concentrate on Turning Inwards (Höök et al, 2015), applying this theory can deepen engagement with the felt body and contribute to wellbeing research. Accordingly, our work proposes an agenda for designing with body by considering theories of embodiment (Tomico & Wilde, 2015; Wilde et al., 2017) and somaesthetics (Schiphorst, 2009) *(*A1 in Table 7*)*.

Another way to overcome this challenge can be to prioritize theories derived from the fashion practices (A2 in Table 7*)*. For example, Thornquist (2018) considers fashion as a social phenomenon and puts emphasis on human activities around fashion such as fashion as interactive wearing, fashion as active negotiations between wear, and fashion activities as intense emotional experiences, which could help HCI researchers in designing and evaluating CFWs. Moreover, Fashion Thinking (Nixon & Blakley, 2012) borrows methods from fashion design practice to inform an actionable methodology for broader contexts. It puts emphasis on fashion design practices analyzing the past, present, and future trends of wearing, as well as leveraging discourses and feedback on existing trends in society while designing fashionable services and products. Applying this to CFWs might enable explorations of interactive and aesthetic opportunities considering the broader context of society. Kinetic Fashion Theory (Berzowska & Coelho, 2005; Lindqvist, 2015), as well, has been considered a practice-driven fashion approach in some works of our SLR to explore shape-changing garments, i.e., with changing silhouettes and patterns on the garment.

Furthermore, to provide a better understanding of aesthetics for HCI-oriented CFW works, Pragmatic Aesthetics Theory (Heinrich & Marino, 2020; Ross & Wensveen, 2010) and Aesthetic Interaction (Petersen et al, 2004) can also be useful (A3 in Table 7*):* Aesthetics in interactive designs need a new language of form which goes beyond the conventional static form aspects and includes the dynamics of behavior (Ross & Wensveen, 2010). Shusterman (2008 cited in Heinrich & Marino, 2020) and later Ross & Wensveen (2010) enumerate several principles demarcating Pragmatic aesthetics, such as (1) the instrumental value of the design, (2) the sociocultural context of the design, (3) form as a dynamic interaction of components, (4) the role of the body in aesthetics experience. Following and advocating Shusterman's Pragmatist Aesthetics, Petersen, et al. (2004) maintained that aesthetic interaction should stimulate curiosity, imagination and engagement, so the designs should elicit a kind of engaging, intriguing, vitalizing and serendipitous experience. These, taken as guiding principles, can provide important insights in designing computational fashion wearables.

Finally, our findings regarding theories applied (see Figure 4) indicate more dialog and collaboration between engineers, interaction designers and fashion designers are becoming inclined towards more dialog and collaboration in designing and creating CFWs, which can lead to diverse scientific knowledge in the conceptualization of CFWs. Yet, the majority of the studies excluding fashion-oriented theories might be interpreted as there is still a need for fostering multidisciplinary collaborations with CFW research. In this direction, future works can consider employing creative collaboration strategies (Moirano et al., 2020) and participatory design (Sanders et al., 2010) approaches to enhance collaboration between HCI and fashion. The former presents strategies like creating educational approaches to introduce researchers to other disciplines and summarizing key paradigms and methodologies before interdisciplinary meetings which might be useful in familiarizing disciplines. Aligned with this, participatory design approaches (Sanders et al., 2010) including fashion design practitioners and researchers might provide the application of theories and practices that are inherently internalized by these individuals (Wong & Radcliffe, 2000) (A4 in Table 7).

A summary of the main points of the agenda of theories is presented in the following table (Table 7).

5.2. Challenges and future agenda for design practice

The practice of fashion design does not only focus on functionality of what is worn (i.e., heat preservation of the body) but also constantly seeks for the creation of new expressive and aesthetical languages by exploring fashion materials and human bodies (Lamb & Kallal, 1992; Sorger & Udale, 2017). In this regard, we observed a strong emphasis on fashion-oriented concerns in our study with fashion design being the most examined domain followed by communication (See Table 1). The studies in fashion design emphasized creating wearables that are not only functional but also fashionable and visually appealing whereas communication domain studies highlighted aspects such as self-expression and social interaction which are key concerns of fashion-oriented wearables (Pan and Stolterman, 2015). Additionally, in the context of well-being, fashion-related elements of appropriation of the aesthetics to the wearer, played a significant role in assistive technologies, as they can help reduce stigmatization and foster emotional connections among disadvantaged individuals (Fayazi and Frankel, 2020).

On the other hand, our findings regarding domains show that the marketing domain of CFWs received little attention. This might indicate a challenge in research focusing on commercial value of novel and interactive aesthetics put forth through CFW is lacking (C1 in Table 8). This can be due to the fact that highly complex and subjective values of fashion (Eckersley & Duff, 2020) make it hard for researchers to capture and make sense of individual's unique experiences with CFWs. This requires new tools and methods adapted to CFW studies to assess how aesthetics and communicative features posited by CFWs contribute to individuals' subjective experiences (A5 in Table 8). For instance, WEAR Scale (Nam and Lee, 2020) is a tool, including fashion-oriented metrics such as aesthetics, self-expression and social consequences, for evaluating the acceptance of wearables. Assessment of CFWs that put forth novel aesthetical approaches with different user groups can provide a comprehensive understanding of CFWs. In addition to quantitative approaches ethnographic data collection and analysis of how different individuals experience the CFWs can also yield a deeper engagement with the complex and subjective values of fashion-oriented approaches (Eckersley & Duff, 2020). Here, future researchers can focus on the diffraction framework that has been used in HCI to evaluate the differences and similarities between the experiences of different individuals with technology (Rajcic & McCormack, 2023).

Furthermore, our findings suggest a research gap in developing materials by considering their affordances in blending aesthetics and interactive functionalities such as electronic conductance. This is important in fashion approaches, as material characteristics such as colors, textures, and weight provide a ground for designers to compensate aesthetical needs of various user groups, as well as allow the creation of new aesthetical languages (Sorger & Udale, 2017; Lamb and Kallal, 1992). While there were some attempts to manipulate conventional fabric by embedding electronic pieces or conductive yarn to come up with smart textiles or garments to appropriate their aesthetics (Devendorf et al., 2016; Du et al., 2018; Rossi et al., 2011; Vande Moere & Hoinkis, 2006), almost one-third of the studies reviewed in this SLR did not thoroughly elaborate on how the aesthetic properties of the materials (i.e., colors, stiffness, texture). This necessitates future studies to examine how functional materials can afford aesthetic qualities in the design of CFWs.

One specific challenge in that direction is to develop electronically functional materials to provide diversity in the look and feel (C2 in Table 8). Conductive materials such as copper, yarns and fabrics were used in the majority of the reviewed CFW studies (Table 4). Yet, these materials come in limited forms in terms of how they look and feel. Here, the next steps for CFW studies will probably be producing and applying various types of conductive fabric (A6 in Table 8), which can give further flexibility and space to the designers to create more seamlessly interactive and stylistically aesthetic wearables. Furthermore, applying different methods of materials manipulation and fabrication can also contribute to the development of novel and aesthetic materials for designing wearables (A7 in Table 8). For instance, the integration of alternative materials, such as Nanocotton made conductive through Caleo-Tex (2019) and Blown fabric (Etherington, 2009) to computational fashion design, along with the development of new "computation-supporting" fabrics would be one of the expected developments in the area. Architectural materials can also be used for fabrication; 'Intimacy', developed by Studio Roosegaarde and V2-Lab, is a high-tech garment made with wireless, interactive technologies and smart foils that respond to the flashlight and can become fully transparent in a flash (Seymour, 2010).

Apart from aesthetics of materials, considering the aesthetics of CFWs, also all interactive designs in general, brings in the challenge of creating a new language of form, and aesthetic interactions, that goes beyond the conventional static form aspects (Ross & Wensveen, 2010) (C3 in Table 8). In this regard, exploring aesthetic interaction necessitates explorations exceeding static look and feel to dynamic and interactive expressions. Our findings on output modalities (see Section 4.5.2) suggest that the interactive aesthetics of CFWs can be explored through visual, auditory, haptic and kinetic modalities, as well as unique modalities such as defoliation, crumpling, or blooming derived from mimicking nature. In addition to these reported modalities, a direction in future research can examine how traditional fashion production and body crafting techniques can inspire new interaction aesthetics (A8 in Table 8).

Fashion design provides diverse conventional methods of making a piece of wearable fashionable and more pleasing, such as applying silhouette, proportion, detailing, embellishment, embroidery; fabric manipulation techniques like creating dimensions, quilting, pleating, ruffles, wrinkles, scale work, geometric origami forms, and a lot more (Burns, 2022; Lee & Steen, 2014; Sorger & Udale, 2017; Vuruskan &Burns, 2017). Some dynamic examples are already demonstrated in, for instance, using sculptural methods to dynamically exaggerate and manipulate silhouette and scale; body sculpture to embody an event and body extensions (Seymour, 2019). Genç et al. (Genç et al, 2018) also show that the application of computational materials in the fabric structures and/or on the fabric surfaces can create dynamic expressiveness of the wearables. In addition to fashion techniques, combining body crafting techniques, such as tattooing, make-up and body piercings and implants, with body-integrative technologies (Mueller, et al., 2020) can also be examined to directly modifying the body, i.e., from color-changing make-up (Kao, et al., 2016) to under-skin implants (Holz, et al., 2012) and synthetic limbs (Buruk, et al., 2023).

In the direction towards achieving interactive aesthetics, our findings also posit kinetic transformations as one trending output modality that has the potential to change the future of fashion s (A2 in Table 8), employed by 41 studies (Section 4.5.2). Kinetic wearables are configurable garments or accessories, which can inflate or change shape or function. Through using some kind of mechanical or electronic process (Berzowska & Coelho, 2005; Hayashi et al., 2019; Zdziarska et al., 2019; Kao et al., 2017; Perovich et al., 2014), the shape could basically be altered. Material explorations for the kinetic transformations, as well as consideration of the emotional and sociocultural meanings of the dynamic transformations can be future lines of research. Perhaps two good examples of designing kinetic transformation of CFWs in the fashion domain are the works done by Hussein Chalayan and Van Harpen in the fashion domain. Hussein Chalayan's Table Skirt (Quinn, 2002), for example, explored the transformation of the skirt into a coffee table while carrying the sociocultural message about how people (i.e., refugees) needs to carry their commodities with them when they migrate. In light with this, we propose future studies should take the emotional and sociocultural meanings of the kinetic modalities into account while developing them (A9 in Table 8). While the reviewed studies focus more on material exploration, for fashion wearables to be successful, it is crucial to consider variation in design and form (Woolsey in Palladino, 2014).

Regarding the interactions design of CFWs, our findings related to both input and output modalities (Section 4.5) indicate that the aesthetic experience of these artifacts constitutes a bi-directional interaction with the body and the environment. Philosophically this also bears a resemblance to the fashion understanding because clothing, apart from signaling to outside, is affected by the context and is in relation with the skin and can even be conceptualized as the second skin (Bruno, 2008; Joseph et al., 2017). Integration of computation to this equilibrium promotes this interaction to a very active one, where the clothing can be physically affected by the body and the environment (e.g., through their sensors), and physically react to it (e.g., through color change, vibration, temperature). Especially the input modalities (section 4.5.1) which received substantial attention such as temperature, ambient light level, body movement or proximity to others, and output modalities (section 4.5.2) such as kinetic expressions, haptic, olfactory and auditory feedback push us to reframe the aesthetic interactions from a visually heavy one to a multisensory one (A10 in Table 8). Here, the movement of the body and the limbs can provide novel input modalities such as tapping, touching, pressing, and grasping gestures (Shilkrot et al., 2015; Vatavu and Bilius, 2021), to blend human movement into aesthetic interactions with CFWs. The results also suggest that studying underrepresented areas of modality interactions such as space and volume, thermal and olfactory might be paths to the future of computational fashion, and designers should adopt a multisensory approach for fully exploring the potential of computational fashion design. In this regard, fashion design practice suggests paying attention to the aesthetic and expressive needs of individuals and societies might be helpful while designing apparel (Lamb & Kallal, 1992).

In sum, CFWs are at the juncture of computer-human interaction design, science, and fashion (Seymour, 2008), therefore aesthetics in CFW designs requires a new language of the form which is interactive (Ross & Wensveen, 2010) and naturally necessitate novel materials and innovative construction approaches to augment aesthetics and fashionability in order to be more welcomed by the society. The findings of our SLR suggest that the potentiality of fashion design practices was not sufficiently attended to in designing wearables. That being the case, applying different methods of materials manipulation and fabrication and taking a multisensory approach in designing computational wearables, as well as evaluating the value of these fashion-oriented approaches from user's perspective, can aid in developing aesthetically pleasing designs with novel interactions.

6. Limitations

We examined the *academic* fashion literature in the realm of wearables available in *Scopus*. Although Scopus is the largest meta database that includes studies from a wide diversity of fields, there might be a fraction of studies that were overlooked in this SLR. Moreover, only the literature which was written in English was the focus of the study. Therefore, the studies, not indexed in the selected database, or written in a language different from English were missing for our systematic review. Our search string also looked specifically to studies that included the words fashion, couture and haute, and although we have reached ample amounts of studies, there might still be some other studies that are relevant to this SLR but did not appear in our search results. Thus, this study needs to be seen in the light of these limitations. The subjective way of analysis of the content may be another limitation. Although the present SRL used two coders from different backgrounds to analyze and synthesize the obtained data for ensuring objectivity, our analysis might have been influenced by the perspective of coders. Therefore, further studies might employ more objective analysis methods e.g., quantitative semantic analysis (Wang et al., 2016). Also, further studies may serve for the validation of our findings through methods such as expert interviews or co-design workshops with expert computational fashion wearable designers.

7. Conclusion

The present study was a systematic literature review of CFWs to explore the current state of computational fashion wearables research, which was not delved enough heretofore. For the purpose of the study, 82 papers with studies in "academic" settings which passed our inclusion and exclusion criteria were thoroughly analyzed in terms of the key domains, the adopted theoretical frameworks, the applied materials, the interaction modalities, as well as the existing gaps. The results show that the number of studies in the area of the CFWs is growing, and that the research in this area is getting more inclined towards aesthetic aspects by fabricating smart textiles and producing accessories, and towards communicational aspects, especially social interaction and self-expression. Moreover, although a great number of studies did not talk about their theoretical frameworks, theories related to embodied interaction and sustainability are the most mentioned ones in these studies. Concerning the materials employed, the findings indicate despite various materials applied in these included studies, a good deal of them manipulated conventional fabric by embedding conductive yarn or electronic parts to devise smart textile or garment.

Regarding modalities, the SRL data show that the most input modalities applied in the included studies have to do with ambient data or signals from surroundings and embodied interactions (touch and move), and the most output modalities seen in these studies were related to visual display and kinetic transformations. The findings of our SLR also suggests further studies on methods of engaging HCI Disciplines with fashion theories through multidisciplinary research to explore (a) new fashion expressions for CFWs (Table 7), (b) marketing and end-user impacts, (c) alternative materials i.e., new computational and functional materials, and (d) novel modalities and multisensory-approach for designing the interactive aesthetics of CFWs. The realm of computational fashion wearable technology is vast owing to its multidisciplinary nature and researchers from diverse but related fields are attempting to explore its scopes and limits. Fashion designers with their primarily aesthetic mindset and computing and interaction designers with their initially functional mentality together can create fashion wearables, which are functional, aesthetic, pleasing and valuable. The findings of this SLR would assist both interaction and fashion designers for future practice and research studies in CFWs.

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No potential conflict of interest was reported by the author(s).

ORCID

Shiva Jabari http://orcid.org/0000-0002-6852-1334
Asif Shaikh http://orcid.org/0000-0003-1458-3836
Çağlar Genç http://orcid.org/0000-0002-8156-8495
Oğuz Buruk http://orcid.org/0000-0002-8655-5327
Johanna Virkki http://orcid.org/0000-0002-2216-7296
Juho Hamari http://orcid.org/0000-0002-6573-588X

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About the authors

Shiva Jabari is a fashion-tech designer, prototyper and doctoral researcher at the Gamification group, Tampere University, Finland. Her work focuses on the integration of design and technology, playful smart clothing design and interaction design. She is the leading author of this study and one of the data coders as well.

Asif Shaikh is a doctoral researcher at the Intelligent Clothing Group and collaborated with Gamification Group, Tampere University, Finland. He has a Mechanical Engineering background. His current research focuses on the design, development, fabrication, and launching the battery free UHF RFID Cloth. He is the other data coder of the study.

Çağlar Genç has expertise in creating wearable ambient displays. Dr. Genç holds a Ph.D. in interaction design from Koç University and works as a Postdoctoral Fellow in Gamification Group at Tampere University, Finland. He contributed to the overall structure, meaning-making of the data as well as the editing of manuscript.

Oğuz Buruk is an Assistant Professor of gameful experience at the faculty of information technology and communication sciences, Tampere University, Finland. Dr. Buruk's work is focused on creating novel interactive environments for gaming purposes. He contributed to the overall structure, meaning-making of the data as well as the editing of manuscript.

Johanna Virkki is an Associate Professor at the faculty of information technology and communication sciences, Tampere University, Finland, where she leads an intelligent clothing research group. Her current research interests include augmentative and alternative communication, smart clothing, and radio-frequency identification. Dr. Virkki contributed to the overall vision of the work.

Juho Hamari is a Professor of Gamification at the Faculty of Information Technology and Communications, Tampere University as well as the Faculty of Humanities at University of Turku, Finland. Prof. Hamari leads the Gamification Group (GG), a multidisciplinary research group in information technologies. He contributed to the overall vision of work.