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Proceedings of Textile Intersections Conference 2023

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PROCEEDINGS OF TEXTILE INTERSECTIONS CONFERENCE 2023

Loughborough University, London, UK

20-23 of September 2023

DRS INTERDISCIPLINARY TEXTILES DESIGN RESEARCH SIG

Proceedings of Textile Intersections Conference 2023 - 3rd edition

Loughborough University, London Campus, 20 - 23 September 2023.

ORGANIZED BY:

Loughborough University, United Kingdom;
Royal College of Art London, United Kingdom;
University of Borås, Sweden;
Technical University Eindhoven, The Netherlands.

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ABOUT

TEXTILE INTERSECTIONS was a four-day conference, doctoral consortium and exhibition organised by Loughborough University, in collaboration with the Royal College of Art, London, UK, University of Borås, Sweden and Elisava, Barcelona, Spain.

The conference took place at Loughborough University London Campus between 20-23 of September 2023. It is a follow up of two previous conferences that have been held in London in 2017 and 2019 respectively. This third edition of the conference marks also the establishment of the new Interdisciplinary Textiles SIG of the Design Research Society. Textiles Intersections conference aims to become the international platform where the interdisciplinary research to textiles is presented and where the most acute and relevant aspects related to the ways we are producing, using, recycling, conserving and critically engaging with textiles are addressed.

The 3rd edition of the TEXTILE INTERSECTIONS conference explored and celebrated the nature of collaborations in textile design research through six themes: Textiles and Architecture, Textiles and Sports, Biotextiles and Sustainable Textiles, Interactive and Performative Textiles, Advanced Textiles Materials and Processes, Critical Textiles.

TEXTILE INTERSECTIONS Conference brought together topics related to connections and cross- or interdisciplinary collaborations furthering research in the field of textiles and textile design. The focus was on the nature of collaborations textiles design is susceptible to establish with other disciplines. The conference invited contributions related to the consequent opportunities each discipline might offer in terms of practices and reflective approaches.

Textiles proliferate many aspects of our daily life, they act as fluid objects, surface for decoration or more functional modulations, acting as “soft computers” (Berzowska, 2005) which may now incorporate sensors and actuators. They not only have high capacities, but they also offer a source for rich conceptual explorations and the embodiment of narrative. In most cases, textiles are “more than just textiles”, at the crossroad of different disciplines and scales (Heinzel, 2020). Physical and digital are negotiating their primacy, and material data dialogue with our biological homeostasis. This dialogue between digital and physical is ever present. In the context of digital fabrication, we see the transformation and democratisation of practices, as well as aspects of consumers’ personalisation of products. Through research at the intersection of organic and inorganic: we spin, weave, and knit textiles, we grow and regenerate our fabrics, we put spiders at work to produce synthetic nerves the size of nanowires. Textiles intersect and touch every aspect of our world and into the metaverse, textile intersections give space to explore and discuss our entangled relationship with textiles, through our work, research, and study.

The conference encouraged the advancement of new textiles related methodologies and the development of cross-disciplinary ones. What are the reasons for interdisciplinary research and who gets involved? How are these collaborations initiated? What makes a successful collaboration leading to innovative research? What are the issues? Why collaborate? What kinds of questions can different disciplines answer and in which cases is an interdisciplinary perspective essential? These were the questions the conference aimed to answer.

The proceedings are bringing together the 23 papers accepted for presentation out of 47 submissions. Alongside the proceedings, the catalogue of the exhibition presents the 16 selected works out of 55 applications, demonstrating the conference’s strong roots in both theory and practice of textiles.

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Anne Toomey (Royal College of Art London, United Kingdom).
Amy Twigger Holroyd (Nottingham Trent University, United Kingdom).
Louise Valentine (Heriot-Watt University, Dubai Campus, United Kingdom).
Katharina Vones (Royal College of Art London, United Kingdom).
Faming Wang (KU Leuven, Belgium).

ORIGINAL CALL FOR PAPERS

/// **DATES:** 20-23 of September 2023

/// LOCATION: Loughborough University London, Queen Elizabeth Olympic Park

/// KEY DATES:

* **Deadline for submission of full papers – ~~21st of May 2023~~ 19th of June 2023**;
* **Notification of acceptance – ~~9th of July 2023~~, 12th of August 2023**;
* **Camera-ready deadline – ~~20th of August 2023~~, 3rd of September 2023**;
* **Deadline for exhibition proposals – ~~5th of June 2023~~, 19th of June 2023**;
* **Notification of acceptance – ~~23rd of July 2023~~, 12th of August 2023**;
* **Deadline for the reception of art works – 1st of September 2023**;
* **Deadline for submission for the doctoral consortium – ~~21st of May 2023~~, 19th of June 2023**;
* **Notification of acceptance – ~~9th of July 2023~~, 5th of August 2023**.

The 3rd edition of the TEXTILE INTERSECTIONS conference explores and celebrates the nature of collaborations in textile design research through six themes: Textiles and architecture, Textiles and sport, Biotextiles and sustainable textiles, Interactive and performative textiles, Advanced textiles materials and processes, Critical textiles.

TEXTILE INTERSECTIONS is a four-day conference, doctoral consortium and an exhibition organized by Loughborough University, in collaboration with the Royal College of Art, London, University of Borås, Sweden and Elisava, Barcelona, Spain.

The conference will take place at Loughborough University London Campus between 20th -23rd of September 2023.

TEXTILE INTERSECTIONS conference is interested in topics related to connections and cross- or interdisciplinary collaborations furthering research in the field of textiles and textile design. The focus will be on the nature of collaborations textiles design is susceptible to establish with other disciplines. The conference invites contributions related to the consequent opportunities each discipline might offer in terms of practices and reflective approaches. The conference encourages the advancement of new textiles related methodologies and the development of cross-disciplinary ones. What are the reasons for interdisciplinary research and who gets involved? How are these collaborations initiated? What makes a successful collaboration leading to innovative research? What are the issues? Why collaborate? What kinds of questions can different disciplines answer and in which cases is an interdisciplinary perspective essential? These are the questions the conference aims to answer.

/// SUBMIT:
For a conference contribution please submit full-papers (3000-4000 words) no later than ~~21st of May 2023~~ **19th of June 2023**. The authors should also mention the track they are opting for.

Please submit an anomymised version of your full paper using the attached TEMPLATE.

/// SUBMISSION LINK: https://www.conftool.net/textile-intersections2023/**.**

The full papers will be double–blind peer reviewed, and accepted authors will be invited to submit camera ready full papers by ~~21st of August 2023~~, 3rd of September 2023. The accepted papers will be published online and available via Open Access through Design Research Society's Digital Library. A select number of accepted papers will be invited to contribute to a special issue of the Journal for Textiles Design Research and Practice.

There will be a further call for exhibition and doctoral consortium contributions in Spring 2023. The exhibition will show work which demonstrates textile design research through artistic experimentations, collaborations and cross/interdisciplinary practice. For example, submissions could include, practice resulting from collaboration/s, a collection of research samples which illuminate specific themes or cut across themes within the conference, collaboration as the focus of the research practice and/or practice that emerges through collaboration.

/// KEYNOTE SPEAKERS: **Mette Ramsgaard Thomsen** (Head of CITA, Centre for Information Technology and Architecture, Royal Academy of Fine Arts, Copenhagen, Denmark), **Ljiljana Fruk** (Cambridge University, UK) and **Anne Toomey** (Royal College of Art London, UK).

/// GENERAL PRESENTATION:

Anni Albers defined textiles as all work composed of threads and/or fibers (Albers, 1965). This definition may have changed, but textiles are still often defined by their form and/or structure, rather than by the nature of materials that compose them. Textiles offer qualities for different domains: from architecture to interiors and fashion, from agriculture to sport and medicine, from music to performance.

The ubiquity of textiles means we often don't think about their complexity because they can appear simple and humble. This complexity is hidden in their familiarity, it is seen and felt in their textures, it is observed in their ability to bring people together, it can be invisible in scale. Igoe's (2021) interlacing of textile design theories gives these nuances of textiles a louder voice and transmits the intangible within textiles in a palpable way. The "one and the many" (Albers, 1965) dilemma textiles present calls for their relationship in the history of philosophy, textiles' processes and materials, production economies, their use, contexts and cultural values, and their politics, to be further investigated. In this context an interdisciplinary perspective could reveal new knowledge and open up debate around how textiles are to be seen as specific for certain epistemologies, linking mathematics and mechanics, computation, and philosophy of technology (Heinzel, 2012).

Textiles proliferate many aspects of our daily life, they act as fluid objects, surface for decoration or more functional modulations, acting as "soft computers" (Berzowska, 2005) which may now incorporate sensors and actuators. They not only have high capacities, but they also offer a source for rich fictional explorations and narratives (Loeve, 2013). In most cases, textiles are "more than just textiles", at the crossroad of different disciplines and scales (Heinzel & Hinestroza, 2020). Physical and digital are negotiating their primacy (Lovink & Hui, 2016; Galloway & Hui, 2022), and material data dialogue with our biological homeostasis (Havenith, 2002). This dialogue between digital and physical is ever present. In the context of digital fabrication, we see the transformation and democratization of practices, as well as aspects of consumers' personalization of products. Through research at the intersection of organic and inorganic: we spin, weave and knit textiles, we grow and regenerate our fabrics, we put spiders at work to produce synthetic nerves the size of nanowires. Textiles intersect and touch every aspect of our world and into the metaverse, textile intersections give space to explore and discuss our entangled relationship with textiles, through our work, research and study.

At the same time, the volume of textile production poses a series of complex ethical and environmental challenges. The climate emergency calls us to action, we have exhausted resources and are filling our environment with waste and microplastic residue. We must pay attention to the ecologies of textiles! It is well known that the textile industry is one of the most polluting industries in the world, and we consume textiles at a speed and volume as never before (Fletcher & Tham, 2014). The multiple crises that are shaking our world are adding another layer to the already existing challenges we are facing. Not only do we have to reduce consumption, but we need to ensure that those who consume less can afford textiles, and that those textiles are of a better quality.

We also have to be aware of the relationship(s) between practices and discourses. If we accept that certain practices find it hard to translate experiences into concepts (Polanyi, 1967), then we also need to acknowledge that the articulation of theoretical positions, as well as the contexts of discourses are not neutral. We need proper translations between different modes of existence (Simondon, 2016), between different mediums (Jucan, Parrika, Schneider, 2018) and the ways we are framing the issues we encounter. If we are about to adopt Bruno Latour's perspective (Latour, 2017), we also need to ensure not only that we put in place "positive" policies, but also to ensure we do not simply replace old discriminatory patterns with new ones. Personal, local, and global politics are coming together, while we still need to address situations case by case.

The aim of the *Textile Intersections* conference is to offer a platform where the cross and interdisciplinary perspectives related to textiles are possible, to discuss the nature of collaborations textiles tend to establish with other disciplines, as well as to address the outgrowth for each discipline. Which are the reasons for interdisciplinary research and who gets involved? How are these collaborations initiated? What makes a successful collaboration leading to innovative research? What are the issues? Why collaborate? What kinds of questions can different disciplines answer and in which cases is an interdisciplinary perspective essential? The conference invites actors in the field of textiles to analyze the way we are negotiating between different interests, different knowledge domains, resources, contexts, group interests and beneficiaries. The aim of our conference is to listen to different experiences, to confront our problems and fears and advance new perspectives.

We are looking to receive papers that look both into the processes of fabrication and manufacturing, as well as in the contexts of consumption and the critical evaluation of these case studies, where both STEM and humanities approaches are encouraged. Collaborative, interdisciplinary and cross-disciplinary perspectives will aim to address the breadth of textiles: from materials and techniques to processes, from applications to social and industrial configurations, from historical to contemporary aspects related to textiles. Textile techniques are some of the oldest technologies, avant-garde of the industrial revolution and in many cases they continue to be a barometer of the changes and reconfigurations that are taking place in industry and society. We encourage an approach which allows concurrent epistemologies to come together to support multidimensional perspectives related to the complex phenomena of textiles.

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/// TRACKS

The 3rd edition of Textiles intersections conference will focus on six areas:

TEXTILES AND ARCHITECTURE.
This track will investigate the place of textiles in architecture and the built environment. It encourages submissions related to the use of textiles for architectural, structural or functional purposes, recycling and recycled textile materials in building construction, as well as textiles driven form-finding/form-giving processes that apply to both physical and speculative/computational design.
Keywords: textiles for architecture, textiles in architecture, textiles for interiors, textile driven form-finding, textiles principles in the domain of speculative/computational design, etc.
Convenors: Bastian Beyer (Humboldt University Berlin, Germany)**, Mariana Popescu** (TU Delft, Netherlands)**, Jane Scott** (Jane Scott, Living Textiles Research Group, HBBE, Newcastle University, UK), **Christiane Sauer** (Weissensee School of Art and Design Berlin, Germany).

TEXTILES AND SPORTS.
This track cuts across other themes as when we think about advanced textiles, interactive and performative textiles and biotextiles there are many examples of their development for sport and health applications. Textiles and Sports offers a metaphorical connection between the nature of advanced textiles materials, the competitive nature of sports and the demands of textiles for health applications. In this track we are looking to address topics related to the use of textiles for health and body monitoring, activewear (sports/outdoor), as well as the use of textiles for extreme environments. We are looking for presentations that focus on the application of advanced techniques of fabrication and testing of textiles materials for sport related activities.
Keywords: textiles for health and body monitoring, textiles for sports and activewear, textiles for extreme environments, etc.
Convenors: Martha Glazzard (University of Dundee, UK), **George Havenith** (Loughborough University, UK), **Clemens Thornquist** (University of Boras, Sweden), **Anne Toomey** (RCA London, UK).

BIOTEXTILES AND SUSTAINABLE TEXTILES.
In this emerging and vital area of research we see many developments which explore the associations between textiles, nature and agriculture, as well as bioprocesses in connection to textiles (such as growing textiles) or bioelectronics for medical applications. This track invites papers that address the relationship between organic and inorganic, biomimetics in textiles and biocompatible structures for medical, agricultural applications and beyond, sustainable aspects related to textiles.
Keywords: growing textiles, textiles for/in agriculture, bioprocesses related to textiles, bioelectronics and use of textiles for medical applications, biomimetics, biocompatible textiles, sustainable textiles, etc.
Convenors: Faith Kane (Massey University, New Zealand), **Elisa Mele** (Loughborough University, UK), **Aurélie Mossé** (ENSAD Paris), **Laura Morgan** (UWE Bristol).

INTERACTIVE AND PERFORMATIVE TEXTILES.
The fields of reactive textiles have seen important developments over the last 20 years. Applications are often related to the field of media performance (or performance art), including the use of output modes such as visuals, sound, light, and shape-change, and body actuation. At the same time, there is increasing interest in the more everyday performative nature of identity, gender-fluidity, and the ways in which textiles play a role at the intersections of social life. How does the digital, electrically or computationally enabled making, perception or using of textiles amplify notions of individuality or community? How are these new textiles being used to explore constructs of the person, and what do they bring to our attention regarding

culture, or nature? This track invites papers that discuss collaborations in the development, deployment and critical assessment of the use of textiles in interactive environments for both performance and performativity.
Keywords: digital textiles, computational textiles, interactive textiles, textiles and AI, textiles for/and performance, etc.
Convenors: Berit Greinke (UdK Berlin, Germany), **Sarah Kettley** (University of Edinburgh, UK), **Irene Posch** (University of the Arts Linz, Austria), **Afroditi Psarra** (University of Washington at Seattle, USA).

ADVANCED TEXTILES MATERIALS AND PROCESSES.
Similar to the development of materials sciences, a series of (re)discoveries took place in the field of textiles. Electronic textiles couldn't expand without the development of conductive threads, for example. Material design enabled by nanotechnologies offered new ways to impact the development of sensing and functional textiles. In recent years biomaterials have been subject to considerable interest, which in some cases were related to Metal Organic frameworks, or nanotechnologies. For this track, we are looking for papers focusing on experimental aspects of textiles and surfaces that challenge the making and processes through materials innovation, sustainable design, and new ideas on aesthetic value and scaling up strategies.
Keywords: electronics textiles, nanotextiles, experimental textiles, textiles applications, materials innovation, etc.
Convenors: Anne Louise Bang (Via University, Denmark), **Pirjo Kääriäinen** (Aalto University, Finland), **Marjan Kooroshnia** (University of Boras, Sweden), **Elif Ozden Yenigun** (RCA, London, UK).

CRITICAL TEXTILES
Interdisciplinary research in textiles requires a focus on the theory and to mediate between different frameworks of thinking that underpin diverse practices in the field. This track invites papers that offer insight into systemic approaches related to textiles, textile design epistemologies and ethical aspects related to textile production and consumption. Submissions exploring 'textiles pedagogies', 'textiles and emancipation', 'critical perspectives on the digitalisation of textiles', ethical practices and/or the speculative/future oriented nature of textile design are particularly encouraged.
Keywords: social, economic and political aspects related to textiles, emancipatory textiles, critical perspectives related to textiles industry, textiles epistemologies, textiles and systemic thinking, ethical practices related to textiles, etc.
Convenors: Rachael Grew (Loughborough University), **Delfina Fantini van Ditmar** (RCA London, UK), **Zuzana Šebeková** (VSVU Bratislava, Slovakia), **Amy Twigger Holroyd** (Nottingham Trent University, UK).

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Unpacking strategies toward E-textile Design for Disassembly. A preliminary literature review

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The demand for E-textiles is anticipated to experience substantial growth in the future, particularly in the realm of sports and fitness applications. However, the increased usage and rapid obsolescence of E-textiles could result in a substantial accumulation of electronic textile waste, leading to environmental and health risks if not properly managed. The recycling and disposal of E-textile waste currently face significant obstacles as existing normative, classifications and technologies have not adapted to this new waste stream. To address these challenges, researchers have proposed the implementation of eco-design principles from the early stages of product design, emphasizing waste prevention through design for recyclability (DfR), modularity (DfM), and disassembly (DfD). However, the research on these principles in E-textiles remains scant. This paper conducts a comprehensive literature review complemented by several industrial case studies on DfD, DfM and DfR principles in E-textiles to understand their feasibility and effectiveness from both the academic and industrial perspective. The main finding of this preliminary study is the framing of four distinct strategies of Design for Disassembly (DfD) for E-textiles, based on the adopted disassembly methods that have crucial repercussions on the design and creative phases: (i) Modular designs aimed at fast disassembly of e-textiles; (ii) Bonding, printing, and 3D printing electronics; (iii) Disassembly techniques of woven or embroidered electronic integration; (iv) embedded electronics biodegradability). From these strategies, the paper aims to draft guidelines for designers and manufacturers in the E-textile industry aiming to start a dialogue to promote innovation and sustainability and foster a more environmentally conscious approach to E-textile design and manufacturing.

Keywords: E-textiles, End of Life (EoL), Design for Disassembly (DfD), Design for modularity (DfM), Design for Recyclability (DfR)

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1. Introduction

The demand for E-textiles is rapidly increasing, particularly in sports and fitness applications. However, the recycling and disposal of E-textile waste face significant challenges due to outdated waste management systems. To tackle this issue, researchers advocated for eco-design principles such as design for recyclability (DfR), modularity (DfM), and disassembly (DfD). While DfR and DfM have received some attention, the aspect of DfD in E-textiles has been largely overlooked. In addition, current eco-design methods lack legislative and practical solutions (Veske and Ilen, 2021). Therefore, this paper aims to unpack strategies for e-textile DfD to draft guidelines to foster a more environmentally conscious approach to E-textile design and manufacturing. The paper provides an introduction to the problem of E-textile waste and highlights the importance of eco-design principles in Section 1. Section 2 outlines the methodology employed in the study to illustrate practical strategies for E-textile designers and manufacturers in Section 3. Lastly, the discussion of the results in Section 4 leads to the proposal of preliminary guidelines focused on E-textile design promoting disassembly, and circularity.

1.1 The functionalized fabrics: Smart-, e-, and functional/technical fabrics

In the realm of functionalized fabrics, an array of terms has emerged. Therefore, definitions of this evolving landscape aim to define differences between smart clothing, e-, smart-, intelligent-, technical, and functional textiles. Smart clothing is an intelligent system that senses and reacts to the changes and stimuli of the environment and the wearers' conditions (e.g. electrical, thermal, and magnetic) (Li et al., 2022). Smart/intelligent textiles can sense and react to environmental stimuli, which may be mechanical, thermal, chemical, biological, and magnetic amongst others (Tao, 2001). E-textiles are a sub-category of smart/intelligent textiles that focuses on the seamless integration between fabrics and electronic components such as batteries, actuators, sensors, and microcontrollers (Stegmaier, 2012; Anwer, 2021). Additionally, functional/technical textiles possess some functionality by either incorporating special fibers and polymers or by applying some surface finishing agents and surface treatments to accomplish some special purposes rather than comfort and aesthetics (Maity et al., 2023).

1.2 E-textiles' market trend

The E-textiles market is experiencing an unprecedented surge in growth. Recent research reveals that the smart clothing and E-textiles market is poised to surpass $780 million by the year 2033 (Skyrme, 2023). This growth is expected due to the increasing interest in applications of E-textiles in sectors such as health, sports, professional protection, and entertainment. Of these sectors, commercially available E-textiles are predominantly found in two main categories: sports and healthcare (Sayem et al., 2020). In addition, E-textiles designed for sports performance have garnered significant attention due to their potential to revolutionize the way athletes monitor and enhance their performance (Figure 1). Embedded with electronic components, sportive e-textiles offer features such as biometric sensing, data collection, elaboration, and archival, and real-time feedback, enabling athletes to track vital metrics, optimize training routines, and prevent injuries. E-textiles for sportswear are more likely to gain acceptance in the mass market, as demonstrated by the rate of growth of the wearable fitness market to US$34 billion in 2020 (Meena et al., 2023).

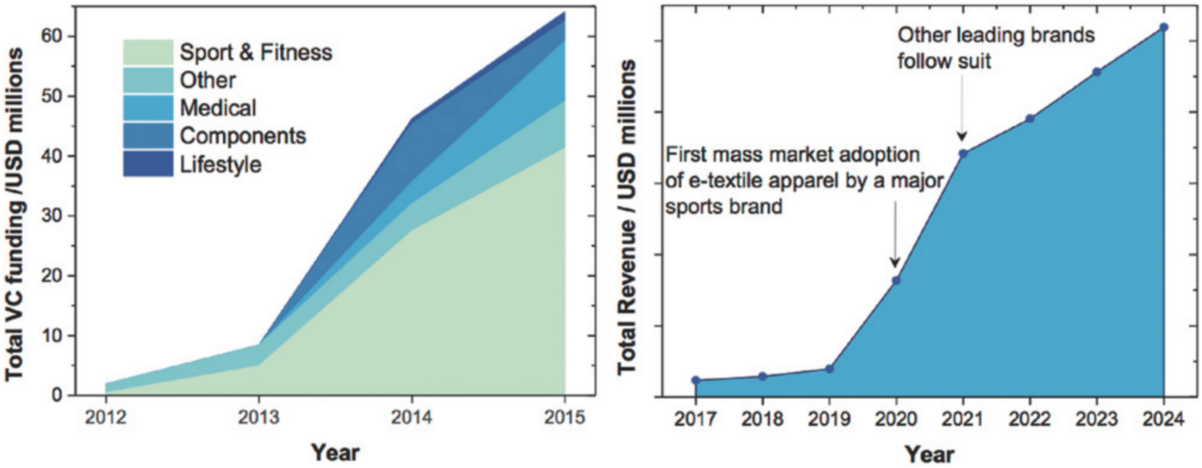


Figure 1. Evolution of E-textile22 (left) market and provisional growth23 (right) from De Mulatier et al. (2018)

1.2 E-textiles circularity and sustainability

However, as a nascent product, a larger market also implies greater unforeseen risks. Hazardous substances such as lithium batteries pose substantial risks during the recycling phase. Direct landfill or incineration of E-textiles contributes to health and environmental risks, including the generation of harmful substances through combustion (Schischke et al., 2020). As E-textiles continue to evolve, there is a growing need to address the challenges of sustainable manufacturing by considering the product circularity and End of Life (EoL) ahead in the design phases. This is a crucial design problem, due to the differing obsolescence of textiles and electronic components, the evolving trends for textiles' styles and aesthetics, and the quick update of the performance of electronic products. However, there has been no Life Cycle Assessment (LCA) study conducted on smart textiles. (Dulal et al., 2022). Moreover, the unmanaged EoL of E-textiles could result in a significant influx of discarded E-textiles into landfills or developing countries (Köhler et al., 2011).

Currently, the disposal and recycling of electronic textile waste face significant challenges. Firstly, feasible recycling classifications for E-textiles have not yet been established in the actual textile recycling legislation (Xie et al., 2021), and existing e-waste recycling financing schemes, as per the WEEE (Waste from Electrical and Electronic Equipment) Directive, do not cover this new type of waste. Besides, recycling technologies have not adapted to it yet (Köhler & Som, 2014). Moreover, there are currently no labeling standards for washing smart textiles and no systems available for recycling these types of garments (Smart Textile Alliance, 2021).

Secondly, the rare micro materials (e.g. silver and gold) and e-components within E-textiles are irregularly dispersed on the fabric surface or integrated within the yarns, making them difficult to disassemble and recycle. The costs associated with the processing are estimated to be prohibitively high due to the fact that precious metals are not concentrated in printed wiring boards (PWBs) as they are in conventional waste of electrical and electronic equipment (WEEE). Additionally, adequate training for personnel at collection points and recycling workshops is crucial to enable them to identify and discern the presence of minuscule electronic devices that are seamlessly integrated into textiles (Köhler et al., 2011).

Furthermore, there is a lack of awareness about E-textile recycling. Köhler & Som (2014) observed that most E-textile entrepreneurs perceive a general need to develop recyclable products. However, they tend to deem other players in the supply chain to responsibly take action. In consequence, the waste problem is not addressed in the design stage but only postponed.

1.3 E-textiles design for disassembly

E-textiles consist of various essential elements, including conductive materials (e.g. yarns, coated threads/fabric, conductive ink) or printed circuit board (PCB) for facilitating electrical flow and conductivity among microcontrollers, actuators and sensors for control and data gathering, power sources (e.g. batteries) for operation, and connectors for establishing electrical connections. These components are generally integrated into the textiles using conventional methods like sewing, embroidery, printing, bonding, and lamination. Researchers have recognized the importance of considering the EoL impact of E-textiles and have explored eco-design strategies, and recycling approaches for these textiles. For example, Veske and Ilen (2021) noted that there is still limited focus on design for disassembly in E-textiles, and current design methods primarily cater to rapid prototyping and lack legislative and practical solutions. Conversely, it is crucial for the industry to proactively tackle these challenges and promote sustainable practices in the manufacturing, use, and EoL stages of E-textiles. Köhler (2008) highlights that waste prevention in product design is more important than recycling. He proposes recommendations for designers, such as Design for Recyclability of Materials (DfR), Design for Modularity (DfM) through modular construction for easy removal and replacement of the obsolescent parts, and Design for Disassembly (DfD) into the early stages of E-textile design and development. Also, Ossevoort (2013) developed a general list of guidelines for the design of sustainable smart textile products, suggesting to keep micro-controlling circuit separate from the smart-textile material or provide an easy way to separate them (DfD).

DfD is defined as the creation of materials or products that can be easily and economically taken apart at the end of their useful life allowing for re-use in appropriate cycles (Forst, 2018). While DfD has been extensively explored in product design, there is limited dedicated research on Textile Design for Disassembly (TDfD) due to the complex life cycle and recycling process assessment of textiles (Forst, 2018). In addition, E-textile DfD is a topic that has received little attention. Recognizing this gap, the focus of this paper is to delve into the feasibility of integrating design for disassembly principles in the context of E-textiles for sports performance.

2. Methodology

The research was developed by conducting a comprehensive literature review to delve into the state of the art of academic studies, and integrated by analyzing relevant case studies to access the state of the art of companies working in the design and manufacturing of sustainable and circular E-textile in the sportive performance sector. The focus is on finding current and perspective eco-design strategies to allow longer life of E-textiles for sport performance garments through the integration of electronics that allow advanced multiple functionalities (e.g., motion monitoring, heart rate, and body temperature detection), with specific features linked to comfort (e.g., breathability, stretchability, and durability).

To conduct the literature review, we used the following keywords "E-textiles," "smart textiles," "sustainability," "end-of-life (EoL)," "design for disassembly (DfD)," "design for Recycling (DfR)," and "design for modularity (DfM)" on the most relevant academic databases including ScienceDirect, Springer, Wiley Online Library, ACM Digital Library, ResearchGate. The search was limited to scientific literature published between 2010 to 2023. Only English-based papers and articles were included in the review. The literature review searching process is shown in the figure 2 below.

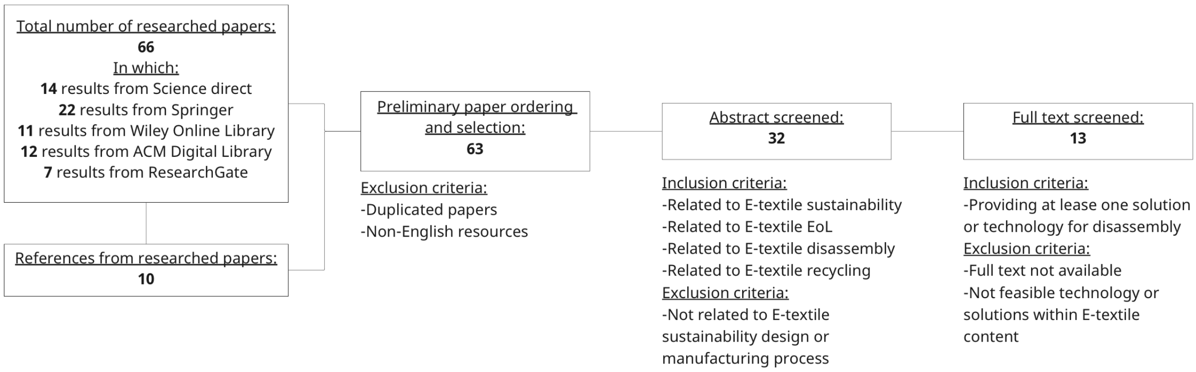


Figure 2. Flow chart of literature review presenting research results

Furthermore, to gain deeper insights into the feasibility of incorporating DfD, DfM and DfR into design, manufacturing, and EoL processes, several case studies have been conducted to integrate the academic perspective of the literature review. The research of case studies was based on desk research of the grey literature available from the companies online.

3. Results

The obtained literature has been categorized, compared, and analyzed based on how E-textiles are adopted, integrated, and combined, as defined by Köhler (2013), and focusing on the current available eco-design strategies at academic and industrial levels to achieve circularity and sustainability in the E-textiles for sports performance. Following the literature selection criteria outlined in the methodology, a total of 13 papers have been identified for inclusion in this research (Table 1). These papers can be classified into four distinct strategies of DfD, based on the various disassembly methods employed. Figure 2 shows their different ways of assembly and disassembly:

a. Modular designs aimed at fast disassembly of e-textiles: The modules are mainly on the textile surface; they are connected by mechanical techniques.

b. Bonding, printing, and 3D printing electronics: The electronics, circuits, and textiles are made by layers and either bonded or printed together.

c. Disassembly techniques of woven or embroidered electronic integration: The electronics and conductive materials are all integrated into the textile by embroidery or woven methods (knitting or weaving).

d. Embedded electronics biodegradability: The e-textile are made by either inorganic or organic biodegradable polymers and will be recycled at the EoL.

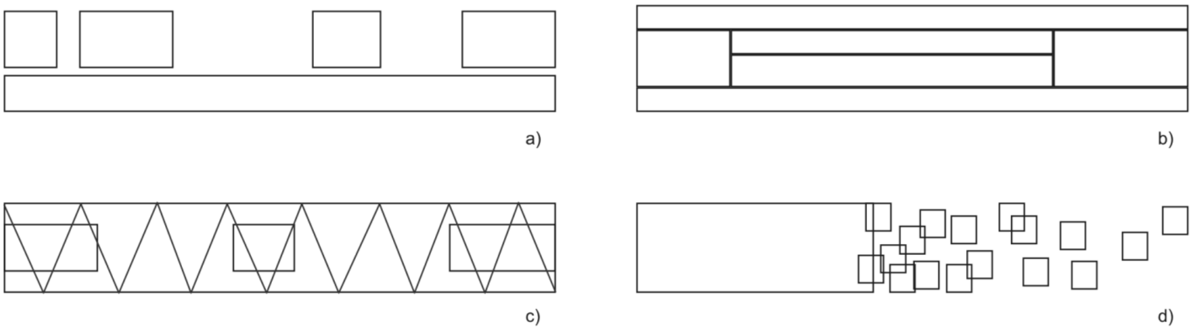


Figure 3. a) Modular designs aimed at fast disassembly of e-textiles. b) Bonding, printed, and 3D printed electronics. c) Disassembly techniques of woven or embroidered electronic integration. d) Embedded electronics biodegradability.

N.	**Author(s) (Year)**	**Title**	**Findings**	**Disassembly solution**
1	Kazemitabaar et al. (2016)	ReWear: Early Explorations of a Modular Wearable Construction Kit for Young Children	Provide a modular 'plug-and-play' construction kit designed to engage young children in the creative design, play, and customization of E-textiles into wearables.	Modular design kit for electronic modules, connected by double-sided fabric adhesive tape
2	Jones et al. (2020)	Swatch-bits: Prototyping E-textiles with Modular Swatches	Developed a system that turns E-textile swatches into easily connectable “bits” so that swatches can move from being an idea tool into a prototyping tool(kit)	Modular design E-textile swatch, connected by repeated interlocking pattern
3	Garbacz et al. (2021)	Modular E-Textile Toolkit for Prototyping and Manufacturing	Presented a novel E-textiles toolkit that can be used after the initial manual prototyping, to be directly transferred to reliable industrial integration using the E-textile Bonder	Modular design toolkit, collected by sewing or adhesive
4	Linz et al. (2010)	Novel Packaging Technology for Body Sensor Networks Based on Adhesive Bonding A Low Cost, Mass Producible and High Reliability Solution	Introduced a bonding technology by employing a non-conductive TPU adhesive which can be re-melted and recycled.	Disassemblable TPU bonding technology
5	Vilas et al. (2022)	Folded Electronic Textiles	Developed pressure sensors by employing layering and bonding techniques that enables the disassembly of fabrics into their individual components	Layering and bonding techniques
6	Chen et al. (2021)	3D printed stretchable smart fibers and textiles for self-powered e-skin	Developed a 3D printing stretchable smart fibers that can be used in customized manufacturing for tactile sensing e-skin	3D printing

7	Ma & Yamaoka, (2022)	SenSequins: Smart Textile Using 3D Printed Conductive Sequins	Designed a 3D printed sequins e-textile that offers a creative avenue for designing disassemblable E-textile circuits approach	3D printing, assembly by sequin embroidery sewing machines
8	Jones et al. (2021)	Punch-Sketching E-textiles	Introduced a technique called Punch-Sketching E-textile, which utilizes a punch needle to prototype circuits and can be easily removed	Punch sewing/embroidery technique
9	Wu and Devendorf (2020)	Unfabricate: Designing Smart Textiles for Disassembly	Investigated various modifications in knitting fabric structure, physical hardware, and design software that could be made to implement a designed-for-disassembly E-textile lifecycle	Knitting structure innovative design for disassembly e-textile
10	Fu et al. (2020)	Wood-Based Flexible Electronics	Describe a recyclable wood-based flexible and transparent substrate that they used to fabricate printed strain sensors	Biodegradable materials
11	Wang et al. (2019)	Self - Healable Multifunctional Electronic Tattoos Based on Silk and Graphene	Introduced a healable and multifunctional E-tattoo with potential applications in monitoring electrocardiograms, breathing patterns, and temperature variations	Biodegradable materials
12	Hosseini et al. (2020)	Glycine – Chitosan-Based Flexible Biodegradable Piezoelectric Pressure Sensor	Developed a flexible biodegradable piezoelectric pressure sensor using a glycine-chitosan composite	Biodegradable sensor
13	Duque (2022)	Print, Recycle, Repeat: Scientists Demonstrate a Biodegradable Printed Circuit	Developed a fully recyclable and biodegradable printed circuit consists of a biodegradable polyester adhesive, conductive fillers such as silver flakes or carbon black, and commercially available enzyme cocktails	Biodegradable printed circuit

Table 1. Summary of selected literature review papers.

The following sections will elaborate on each strategy in detail.

3.1 Modular designs aimed at fast disassembly

The first generation of E-textiles involves a hard component, such as an antenna or electronics, sewn or attached to the surface of the garment (Meena et al., 2023). These electronic devices typically include rechargeable batteries and housed PCBs, sensors, and actuators. Solutions adopting modular design aim at fast and accessible prototyping through buttons, Velcro, and other tools that ease the assembly and disassembly of E-textile designs. Kazemitabaar et al. (2016) introduced ReWear, a modular 'plug-and-play' construction kit designed to engage young children to design E-textiles. The kit comprises 12 different modules (Figure 4a). The back of the modules is covered with double-sided fabric adhesive tape allowing children to easily attach/detach the modules to their clothing without creating a strong adhesive bond. Jones et al. (2020) have developed a system that turns E-textile swatches into easily connectable “bits” so that swatches can move from being an idea tool into a prototyping toolkit (Figure 4b). Based on the laser cutting shape design by Soepboer (2009), the pieces can be connected together through the repeated interlocking pattern. Moving from prototyping to industrial manufacturing and business models for smart clothing, Garbacz et al. (2021) presented a novel E-textiles toolkit that can be used after the initial manual prototyping, to be directly transferred to reliable industrial integration using the E-textile Bonder, a machine capable of mechanically and electrically connecting modules to textiles with integrated conductors.

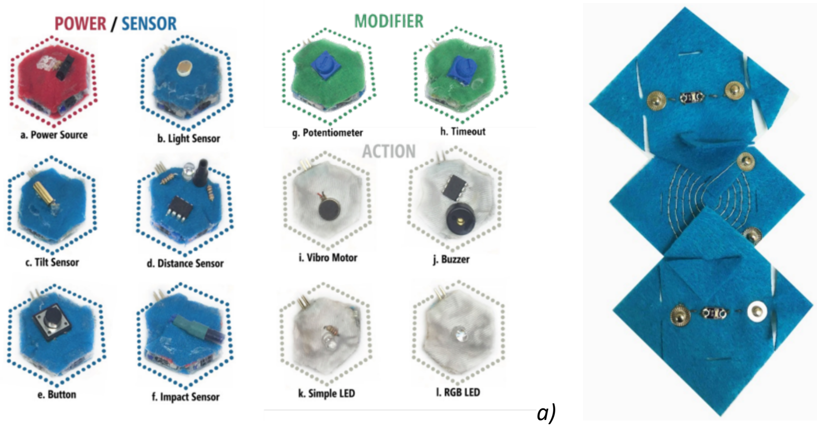


Figure 4. a) E- modules from Kazemitabaar et al. (2016); b) Modular E-textile swatch-bits from Jones et al. (2020)

Funktion (2022), an innovative provider of digital smart clothing manufacturer solutions, has pioneered the development of magnetic electronic modules (Figure 5) with versatile functionalities such as power, induction, heat, light, or touch. These modules can be easily switched, rearranged, and adjusted to cater to the specific needs of users toward the customization of smart clothing.

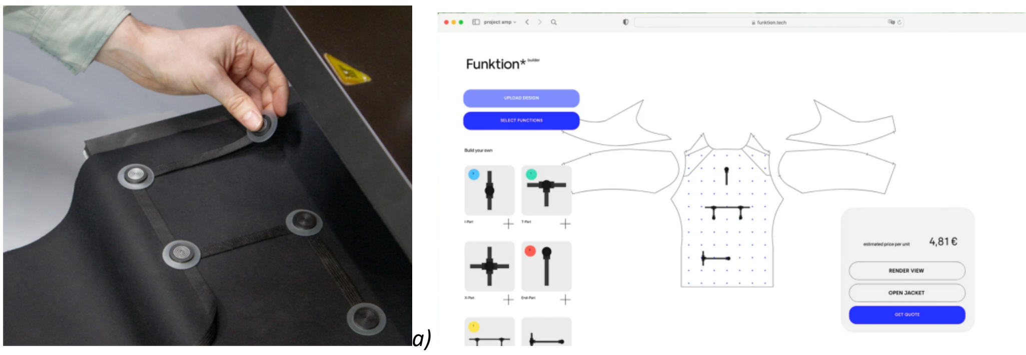


Figure 5. a) Magnetic electronic modules (Funktion, 2022); b) electronic modules customization tool (Funktion, 2022)

Funktion's E-textile integration method involves using the hot-pressing process to integrate the "Kontakt Grid Technology" onto textile surfaces. This allows users to attach different sensor modules to specific connection points on the grid. The textile acts as a base layer for connecting various sensor modules, which can be easily attached and detached by snapping them onto the grid. A dedicated application allows users to select desired modules and automatically connect them to perform specific functions. This approach offers a personalized experience and simplifies the assembly and disassembly processes. It also enables users to actively participate in the disassembly process, facilitating recycling. From a commercial perspective, Funktion's technology provides a cost-effective, washable, sweat-resistant solution that allows for single-component repairs and replacements.

3.2 Bonding, printing, and 3D printing electronics

Currently, flexible printed circuits stand as the most widely used technology for the second generation of E-textile, enabling the utilization of various fabric types (woven, knitted, and nonwoven). The same applies to the conductive material (e.g., conductive ink on TPU substrate) that can be mechanically adhered to the fabric (Agcayazi et al., 2018). From the industry, there are already many companies and institutes developing printed electronics on textiles. Danish Technological Institute developed printing technologies such as screen, flexographic, and inkjet printing, together with functional materials and inks to fabricate electronics directly onto plastic foils, paper, or textiles. Towards a sustainability approach, they have developed copper inks that can substitute silver and have demonstrated how carbon can be used as skin sensors (Davis, 2022). However, when circuits are printed on fabrics, they tend to remain on the surface of the textile, making yarn disassembly and recycling challenging.

One effective solution to separate the circuit and textile involves layering and bonding techniques with a non-conductive adhesive. Linz et al. (2010) proposed a cost-efficient and reliable bonding technology with textiles, by employing a non-conductive thermoplastic polyurethane (TPU) adhesive, that can be repairable and recyclable through re-melting. Additionally, Vilas et al. (2022) developed pressure sensors with variable electrical resistance by employing layering and bonding techniques using a combination of fabric substrates. This approach not only enables the straightforward disassembly of fabrics into their individual components but also enhances their potential for recyclability.

The Closed loop smart athleisure fashion project (Toeters, 2018) (Figure 6) devised a smart shirt in Econyl, a recyclable polyamide material, equipped with advanced printed sensors, enabling continuous monitoring of the user's biometric data. The business concept embraces a closed-loop service system, wherein the garment is recycled after use, and the product and its components are deliberately designed for easy disassembly to facilitate the creation of new products or reuse.

Figure 6. Closed loop smart athleisure fashion project (Toeters, 2018)

Sensors are created through silkscreen printing of conductive ink on TPU (Thermoplastic Polyurethane). The disassembly is based on a de-lamination process, facilitating the reassembly and reuse of the sensor for at least 25 cycles. This approach ensures a sustainable and environmentally friendly approach to sensor utilization and recycling (Veske et al., 2019). In terms of business model, the project presents a concept that incorporates customization, circuit replacement, and closed-loop recycling of products. The authors also propose the implementation of a leasing system for smart clothing, which would encompass services for care, recycling, and reuse, ensuring the responsible tracking and EoL management of the garments.

The Fraunhofer IZM has developed non-conductive adhesive bonding technology that possesses the remarkable capability of mechanically and electrically interconnecting textile substrates and electronic modules in a single, seamless step. Expanding upon this technology, Garbacz et al. (2021) have introduced the E-textile Bonder, an innovative tool that facilitates the reliable connection of a wide range of textile-integrated circuits. Whether they are embroidered, woven, knitted, or textile-based circuits, this bonder ensures secure connections, even for circuits with (thermoplastic) insulation. However, they lack specific information regarding the disassembly process.

3D printing is an additional technology still in its experimental stage that promises to ease the disassembly stages of conductive materials. In particular, it offers the possibility of printing elastic conductive PLA onto textiles to connect electronic components and textile fabrics (Grimmelsmann et al., 2016). While enabling customization and the creation of highly complex structures and circuits, 3D printing onto textiles still presents several challenges in its assembly and disassembly stages. At the current research practices, the main difficulty is providing stable adhesion of the print to the fabric and, therefore, this is affecting also the detachment process at the EoL stages.

3D printing of textile-like structures can be another viable option. Xiao and Kan (2022) have reviewed different approaches, including 3D-printed functional garments and electronic textiles which are allowed by the use of flexible smart conductive filaments that could be 3D printed in active yarn materials and conductive fabrics. An example by Chen et al. (2021) is the 3D printing of stretchable smart fibers and textiles, prepared with a coaxial core-sheath structure, consisting of a conductive core and insulative shell. This technology of direct 3D printing smart fibers can avoid the necessity for integration with conventional fabrics. Therefore, this approach may directly solve the disassembly problem of traditional 3D printing materials on textiles. However, it is still unclear how these composite material filaments used for 3D printing conductive textile-like structures could be separated and recycled at the EoL of the products.

Another interesting design approach is provided by Ma and Yamaoka (2022) through the prototyping of an innovative E-accessory that leverages 3D printed conductive sequins to establish a personalized and interactive design environment. This technology offers a creative avenue for designing a separable E-textile circuits approach (Figure 7). By employing this technique to print flexible structural units, it becomes feasible to interlink electronic components with discrete structural elements using sewing or a chainmail structure arrangement. This setup facilitates convenient disassembly in the future.

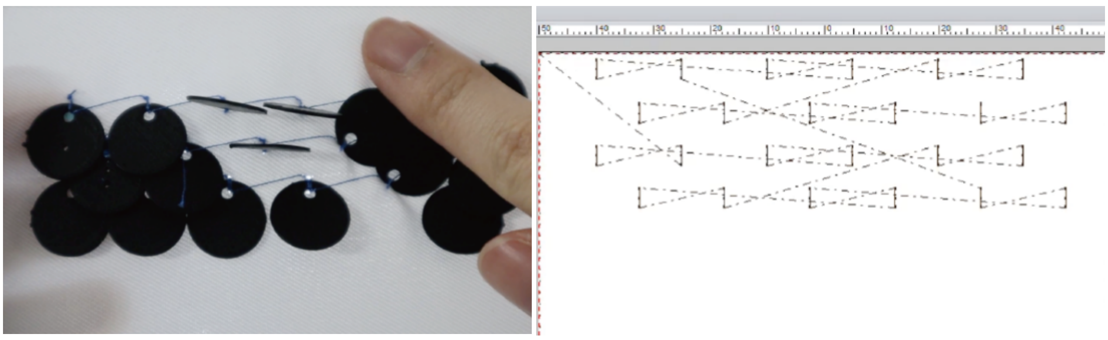


Figure 7. Automatic manufacturing process for conductive SenSequins textile

3.3 Woven embedded integration disassembly

With the third generation of E-textiles, deep integration takes place aiming at seamlessly incorporating electronic components into/onto the textiles using embroidery or stitching techniques. Embroidery as an E-textile joining technology was first proposed by Post et al. (2000). Embroidering connections with conductive thread can be performed by hand, with a sewing or embroidery machine. The integration of E-textiles through sewing or embroidery allows for flexible circuits and the incorporation of hard electronic components. One key advantage is the ability to easily detach components from the textile surface by cutting the conductive thread attached to the solder pad. This practical recycling strategy offers a solution for E-textile disposal (Domskiene et al., 2023). Additionally, researchers are developing disassembling stitches. Jones et al. (2021) introduced a technique called Punch- E-textile (Figure 8), a technique that uses a punch needle to prototype circuits. With a single conductive thread, users can "draw" circuits and easily redo them by removing threads. This approach provides sustainability and reusability advantages, as circuits can be removed without damaging materials.

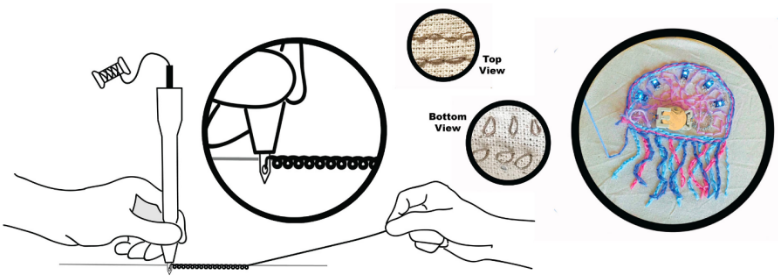
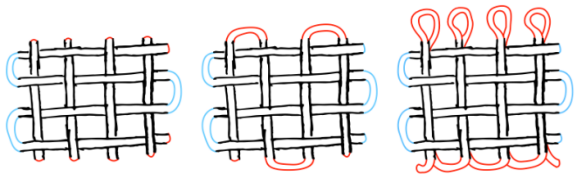


Figure 8. Punch-sketching is a solution to disassemble the conductive thread from the textile (Jones et al. 2021)

To achieve seamless integration, electrically conductive fibers and yarns are typically routed or interlaced within the textile fabric through weaving or knitting techniques. Knitted fabrics are particularly advantageous in wearable applications, offering flexibility and elasticity. Wu and Devendorf (2020) explored sustainability and scalability in smart textiles by investigating disassemble-able E-textile design possibilities (Figure 9). They discussed modifications in fabric structure, hardware, and software to enable a designed-for-disassembly E-textile lifecycle. The authors also discussed the potential future of unraveling and disassembling as integral parts of a smart textile's lifecycle, including 3D shape weaving, yarn repair and modification, and modular unraveling.


a)

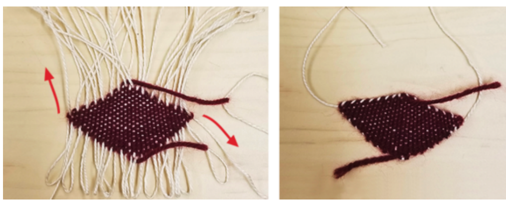

b)

Figure 9. a) Diagrams of the three warp securement experiments for quick disassembly; b) Modifying the woven structure to facilitate disassembly (Wu and Devendorf 2020)

On the industry side, seamless knitting technology is welcome because of its potential to minimize textile material waste by streamlining the cutting and sewing process (Maiti et al., 2022). Moreover, it enables the integration of conductive yarns and fibers, facilitating the creation of strain sensors (Xu et al., 2023) and textile-based triboelectric nanogenerators (Dong et al., 2020).

These technological advancements empower electronic textiles to gradually phase out rigid electronic components like power supplies, sensors, and circuits. This simplifies assembly steps, and production processes, and ultimately enhances the overall wearing experience. As a result, E-textiles constructed exclusively from textile structures are anticipated to become the prevailing standard in the future. In line with this trend, dedicated disassembly and recycling methods should prioritize the elimination of manual cutting operations and strive to develop industrialized and user-friendly disassembly processes.

3.4 Embedded integration biodegradability

Biodegradable materials are instrumental in the advancement of sustainable E-textiles, offering solutions for embedding circuitry and sensor disassembly. Incorporating biodegradable substrates, conductive inks, and encapsulation materials enables the creation of E-textiles that degrade without leaving harmful residues. This facilitates efficient disassembly and separation of electronic components from textile materials, promoting recycling or composting.

In the realm of biodegradable materials, extensive research has been conducted on paper, wood derivatives, easily oxidizable metals or carbon derivatives, and silk (Piro et al., 2020). For example, Fu et al. (2020) developed a flexible and transparent wood-based substrate for printed strain sensors. They used a conductive ink made of lignin-derived carbon nanofibers to print on a strong, flexible, and transparent wood film. Combining transparent wood films with conductive inks offers potential for environmentally friendly and sustainable wood-based electronics, with possibilities for scalable manufacturing processes and end-of-life recyclability.

Wang et al. (2019) introduced a healable and multifunctional E-tattoo made of graphene, silk fibroin, and calcium ions (Gr/SF/Ca2+). These E-tattoos are highly flexible and can be created by printing or writing using a Gr/SF/Ca2+ suspension. The E-tattoo serves as a strain, humidity, and temperature sensor, demonstrating high sensitivity, rapid response, and long-term stability. It also possesses remarkable self-healing capabilities, allowing it to recover from damage caused by water through the reformation of hydrogen and coordination bonds at the fractured interface. This technology has potential applications in monitoring electrocardiograms, breathing patterns, and temperature variations.

Hosseini et al. (2020) developed a flexible biodegradable piezoelectric pressure sensor using a glycine-chitosan composite. The results demonstrate the potential of this biobased piezoelectric material for wearable biomedical diagnostics and highlight its promising application in biodegradable sensor development.

Berkeley Lab has developed a fully recyclable and biodegradable printed circuit using a biodegradable polyester adhesive, conductive fillers (silver flakes or carbon black), and enzyme cocktails (Duque, 2022). The conductivity of the ink comes from silver or carbon black particles, while the adhesive acts as glue. The researchers found that after seven months of storage and a month of continuous voltage application, the conductivity remained unaffected. To test recyclability, the circuit was immersed in warm water, resulting in the separation of silver particles from the polymer adhesive and the decomposition of the polymer into reusable monomers. Approximately 94% of the silver particles were successfully recycled with similar device performance. However, further development is needed to control the detachment process of the technology only at the end of a garment's life, potentially using chemical markers that can be activated with specific substances.

4. Discussion

This study contributes to the development of preliminary guidelines that foster eco-design and DfD in the E-textiles industry. Through the literature review and case studies, the research provided valuable insights and discussions for the different methods of E-textile disassembly. From the research, it emerged that DfD is a topic that requires further research and attention in the field of E-textile systems development.

The eco-design principle of DfM offers several advantages in terms of DfD, including the ability for designers and users to easily replace parts of smart clothing, simplifying the design and production process, and enabling customization on demand. It also facilitates repairing and replacing damaged components, extending product lifecycles, and promoting better separation of textiles and electronic components for recycling purposes. However, there are certain drawbacks to modular design in E-textiles. The inclusion of modular components increases the volume and weight of the E-textile system. Additionally, the connection mechanisms of these modules can impact the stretchability of the textile, resulting in reduced flexibility and comfort, particularly in lightweight and form-fitting sports smart clothing. Another drawback is the hand-made assembly that is not included in the manufacturing processes at the moment. This requires a modification of assembly processes in the industry. Furthermore, the complex integration of modular E-textile systems and the limited combination and configuration of connectable modules may render some products unsuitable for modular design (Diaz, 2022).

DfD is further supported by layering and bonding technologies for entire circuit integration that are employed in many commercial smart clothes, offering simplicity and speed in-circuit production, assembly, and disassembly. These technologies have also demonstrated excellent performance in water washing tests. (Tao et al., 2017). However, challenges remain, such as achieving matching elasticity and breathability between the TPU bonding and elastic textiles used in sports garments. Unfortunately, the elastic TPU materials used for bonding do not possess the same elasticity as elastic fabrics, and the multi-layer bonded structure can make the textile thicker and stiffer, potentially leading to delamination under strain or deformation (Veske et al., 2021). 3D printing conductive yarns shows a possible path to produce E-textile and smart fabrics, and present advantages in terms of design freedom of the several material composite that could be used for actuation, conduction and sensing purposes. However fabrics stemming from 3D printing manufacturing processes still present issues of comfort, breathability, stiffness and production scalability. Therefore the implementation of sportswear from 3d Printing is far from being an acceptable and feasible solution. However, 3D printing conductive yarns on textiles could be a viable option and solves problems of comfort and softness of textiles put in contact with the skin of the wearer. The conductive polymers deposited via 3D printing onto the textiles could be heated again to allow for the disassembly at the EOL. However, this technology is still in experimental stage, lacking evidence on the material disassembly process and recycle analysis, thus requiring more research on this aspect. A possible research path could be also the deposition of conductive flexible circuits via 3D printing on materials such as bio-based bacterial cellulose so that the disassembly is simplifies thanks to biodegradability (Adamatzky et al., 2023).

Embedded integration technology, which involves directly integrating microelectronic components into the textile structure, ensuring a more comfortable wearing experience and enabling aesthetically pleasing designs. This approach represents a significant research trend in E-textiles. However, disassembling deeply integrated E-textiles can be complex, and processes for separating and recovering electronic components from textile structures are still manual. In the future, it is anticipated that by integrating with emerging technologies like additive manufacturing and chemical disassembly, there will be opportunities to develop sustainable one-piece E-textiles that are easily separable and recyclable.

Biodegradable E-textiles have gained attention as a sustainable and eco-friendly technology, offering easy disposal and pollution reduction. Although still in the experimental stage, they hold promise as a green solution for the future. Challenges remain, including complete solubility of advanced polymers without toxic residue, cost reduction, and scaling up soft, transient electronic components for mass production. Overcoming these challenges will drive widespread adoption of biodegradable E-textiles, enhancing sustainability in the field.

5. Conclusions

In conclusion, E-textiles have emerged as a promising field with significant market growth. However, the disposal and recycling of electronic textile waste face significant difficulties, including the absence of established recycling classifications and inadequate recycling technologies. Especially, the complex nature of E-textiles and the dispersed micromaterials within them make disassembly and recycling crucial and challenging. Furthermore, there is a lack of awareness and knowledge about E-textile recycling among designers and manufacturers. To address these challenges, it is crucial to integrate eco-design practices into the manufacturing, use, and EoL stages of E-textiles. DfD principles can play a significant role in improving the recyclability of E-textiles. Based on the literature review, case study, and discussions, it is recommended to consciously incorporate E-Textiles Design for Disassembly (DfD) principles, by following these draft guidelines:

- Modular Design: Implement a modular design approach by dividing the E-textile into separate components or modules that can be easily disassembled. Carefully consider the shape and material of the modules, ensuring that the placement does not compromise wearing comfort.
- Avoid Permanent Attachment: Minimize the use of permanent adhesives or irreversible attachment methods. Instead, opt for non-conductive TPU adhesives or reversible attachment techniques such as hook-and-loop fasteners, snaps, or buttons. This allows for convenient detachment and reattachment of components during the disassembly process. Pay attention to the stability and durability of the connectors.
- Design for Recycling: Consider the recyclability of the E-textile during the design phase. Utilize materials that can be easily recycled and design the textile in a way that enables efficient separation of different material types during recycling. For example, incorporate repairable stitching as a replacement for standard stitching and embroidery.
- Washability: Test the washability of the E-textile and ensure that the assembled modules and layers remain stable under washing conditions.
- Labeling and Marking: Clearly label and mark different components and their connections to facilitate disassembly. Provide detailed design documentation and instructions for disassembly and recycling. This ensures that users can easily identify and remove specific components without causing damage to the textile or other components.

- Material Selection: Choose recyclable, environmentally friendly, and safe-to-dispose materials. Use non-toxic substances and minimize the integration of materials that are challenging to separate during the end-of-life stage.
- Standardized Interfaces: Adopt standardized interfaces and protocols for electronic components to ensure compatibility and easy integration. This allows for effortless replacement or upgrading of components with newer versions, without requiring significant design modifications.

E-textile designers and manufacturers can contribute to the development of more sustainable, recyclable, and easily disassembled electronic textiles, minimizing waste and maximizing the value at the end of the product's life cycle.

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