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State of the art on the Nexus between sustainability, fashion industry and sustainable business model

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ABSTRACT

The fashion industry is one of the most environmentally impactful. It is estimated that about 9% of greenhouse gas emissions are attributable to this industry. It also turns out to be a highly resource-consuming industry with a rather low recycling rate. With this in mind, the authors wanted to further research the issue of sustainability in fashion.

This was done with two main purposes: to update the literature to investigate the latest scientific contributions, to foster their application in sustainable business models; and to help define the state of the art on the topic by investigating the application of sustainable best practices in the market. The study is intended as a basis for future work that will focus on the topic of fashion sustainability and to support the adoption of sustainable business models by companies.

This study analyses the fashion industry, particularly the textile, footwear, and leather industries, by searching the scientific literature and business cases for the current state of the art on recent best practices in process, product, and business strategies that have a positive impact on industry sustainability. A systematic literature review and business case research was conducted to identify best practices and gaps on areas of the fashion industry that can be catalysts for change toward a circular economy system based on sustainable business models. Policies and possible solutions to environmental problems related to the fashion industry were also considered.

The study showed that there are many technologies, best practices and innovations that aim to make the fashion industry less impactful and, most importantly, circular. Therefore, some representative results for each of the three areas investigated are explored in depth, keeping in mind that there are the companies and sectors involved have sometimes unique peculiarities and characteristics, so it is not possible to have results equally applicable to each business model.

1. Introduction

The fashion sector has a clear chance to operate differently, pursuing profit and growth while also adding new value to society. It comes with an urgent need for management to prioritize environmental measures. With the current speed of production and consumption the threat of environmental pollution grows every year.

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It is estimated that the apparel market worldwide revenue was around 1.55 trillion US\$ in 2021, with China and United States as leading countries (Statista, 2022), with a market size of more than 427 billion US\$ for China and over 364 billion US\$ for United States (Fashion United, 2021).

As for textiles and apparel, China and the European Union are the main exporters, with a share of more than 60 percent of global exports, while the European Union and the United States are the main importers, with a share of about 40 percent of global imports (Fashion United, 2021).

The fashion industry is still a linear system. Despite, the 3Rs system (reduce, reuse, recycle) (Wichai-utcha and Chavalparit, 2019), the 4Rs system (reduce, repair, recycle, remanufacture) (Barreiro-Gen and Lozano, 2020) and finally the 5Rs system (reduce, reprocess, reuse, recycle and recover) (Tony, M.A., 2022) are bringing the environmental approach to the production and consumption toward a more sophisticated and complex business model. Nonetheless, the rate of circularity understood as the level of recycling and reuse, is still low. It turns out that less than 1% of the more than 100 million garments produced globally are recycled into new products at the end of their life cycle (European Parliament, 2020).

Even worst the products of fast fashion, so-called ready-to-wear, make an important and direct contribution to the environmental impact of the fashion industry, second in terms of pollution, after that of oil, and among the first regarding the consumption of natural resources and energy.

Manufacturing processes are also responsible for the release of toxic substances into the wash waters, polluting the seas. In fact, the dyes of fabrics contain highly carcinogenic components, but also the raw materials, such as polyester, contain highly toxic synthetic material derived from petroleum, often not biodegradable nor recyclable.

Research published in Nature Reviews Earth & Environment states that the fashion industry released annually into the atmosphere about 5.000 million tons of CO₂, and it is responsible for about 9% of global emissions, as well as the accumulation in the oceans of more than a third of microplastics. It also contributes with 20% of industrial water contamination worldwide and produces more than 92.000 tons of textile waste per year, including new unsold clothing (Niinimäki, 2020).

At a global level, the figures define an important volume of material and resources consumption: 98 million tons per year of non-renewable resources, 93 billion cubic meters of water, 60% of the textile fibres used are synthetic and, among these, polyester, which is the most widespread, requires, for European consumption, more than 70 million barrels of oil (Ellen MacArthur Foundation, 2017).

In Europe, according to the estimates of the EEA (European Environment Agency, 2020), in 2017, for each EU citizen, there was a consumption equal to 1.3 tons of raw materials and 104 cubic meters of water with the emission of 654 kg of CO₂-eq. The same research also shows that people in Europe, in average, consumes 26 kg of clothes annually – three times more compared to 1975 – and throws away at least 11 kg.

The numbers of the fashion industry, according to 2019 data in Europe, shows that there are about 160.000 firms, which employ 1.5 million people and have a turnover of about 162 billion euros. The EU fashion industry is characterized by micro and small enterprises, as those with less than 50 workers hire more than 90% of the workforce with the generation of about 60% of the value-added (European Commission, 2020).

This article takes into consideration two main aspects of sustainability on fashion industry:

The first is to update the literature, in terms of a review, to investigate the most recent scientific contributions in terms of process, product and organizational best practices.

The second is related to the definition of a state of the art on the topic, capable of investigating the actual application of best practices in the market, delving into case studies of companies and virtuous realities from the point of view of sustainability.

The paper is structured in this way: Introduction, Material and methods, Results, Discussion, and Conclusions.

In the Introduction we underline the actual situation of the fashion industry in terms of impact. Then the paragraph *Material and methods* is structured in *EU policies and strategies on the fashion industry*, where circularity and sustainability strategies related to this industry in the EU are explored, and *Good practices and innovative sustainable solutions*, explains the purposes of the two investigation dimensions (scientific literature and firms practices). Then the *Methodology* is explained. Therefore, the *Results* section summarise the findings in the two dimensions, which are explained in the *Discussion* section, divided into 4 areas: *Textile, Footwear, Leather, and Firm-related best practices findings*. Finally, the authors provide their *Conclusions*.

2. Material and methods

2.1. European policies and strategies on the fashion industry

Companies and governments are increasingly sensitive to the benefits that a CE system in fashion brings on the various dimensions of sustainability. Many Sustainable Business Models have emerged that focus on eco-design, industrial symbiosis, R-strategies (reuse, remanufacture, recycle ...) and energy efficiency. These models need to be developed by the entire supply chain and be incentivized by policies and laws. Raising awareness and education on the issue is also of great importance, as it has a strong impact at all stages of the product life cycle. The European Commission has listed Textiles as a priority product in the CE (European Environment Agency, 2020).

As reported by the EU Commission in "Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling" (GROW et al., 2021), the EU, with objectives and policy initiatives, some still being defined, is helping to shape the future industrial trajectory of the sector. These documents provide guidance on product eco-design strategies and ways to apply circular models to encourage recycling through, for example, facilitating the deconstruction of end-of-life garments to recover secondary raw materials. They also have the character of guiding steps for future legislative changes.

The “New Circular Economy Action Plan - For a cleaner and more competitive Europe” is in this sense one of the main plans for achieving these goals and sees the textile industry as one of the pivotal for the transition to a circular economy, due to the potential amount of resources that can be saved and the measures in favour of recycling activities that it will have to activate, such as harmonizing the separate collection of waste throughout the EU, increasing the sorting and recycling of textiles. To make this feasible, innovation, eco-design requirements for products, ensuring and facilitating the use of secondary raw materials, combating the use of hazardous substances, and support for circular production must be provided.

Other aspects are covered, for example, by the revised Industrial Strategy for Europe, a proposal to strengthen the EU's industrial resilience, which aims to improve the traceability of traded items by monitoring the safety and routing of products, making more effective use of the digitization element. The document also calls for periodic assessment of the state of 14 “industrial ecosystems” in the internal market, including textiles.

Finally, the “Strategy on Chemicals for Sustainability - Towards a Toxic Free Environment” addresses the issue of safe recycling and specifically mentions the textile industry. The strategy on the transition to safe and sustainable chemicals early in the life cycle, emphasizes the need for non-toxic materials toward a sustainable and circular economic and production system.

2.2. Good practices and innovative sustainable solutions

The following analysis was carried out for two main purposes. The first is to update the literature, in terms of a review, to investigate the most recent scientific contributions in terms of process, product, and organizational best practices. In this way, the study serves as a basis for future work that will delve into the topic of sustainability in the fashion industry, investigating techniques and innovations useful for building Sustainable Business Models.

The second is related to the definition of a state of the art on the topic, capable of investigating the actual application of best practices in the market, delving into case studies of companies and virtuous realities from the point of view of sustainability.

So, technical solutions, processes, organizational structures, and indicators that can be considered examples of good practices that, once applied, will promote the transition to a circular and sustainable economy in an industry, that of fashion, which is highly impactful, were searched both in the scientific literature and among business cases.

With the results obtained, it will be possible to provide an overview of the existing situation as well as hints for improvement and for deepening the theme, at a time when the effort toward sustainability is strongly required and necessary.

The transition to CE is an indispensable process in today's production system, which is still characterized by a linear model that must necessarily be overcome in every sector. For fashion, looking at the numbers presented initially on environmental impact, it is important to find solutions to facilitate and enable the transition, precisely because of the potential benefit it would bring to the struggle for sustainability.

A circular model starts with production sustainability, both from the point of view of the product itself, and thus the resources consumed and the release at the end of life, and from the point of view of the process, such as the chemical residues for dyeing fabrics or the emissions generated by the production of adhesives for shoes.

So, we need to consider its impact throughout the life cycle, making it also important to monitor these stages, which allow us to identify areas of impact and improvement of a given process, translating the findings into impact indicators. All of this can only happen through a systemic approach to circularity and that starts with organizational and structural business choices, with the adoption of innovative digital, technological, and sharing solutions that foster approaches such as eco-design and industrial symbiosis.

In this sense, cooperation between firms, as well as with institutions and universities, become a strategic approach to pursue sustainability goals. Some important actors in the fashion industry already worked on this: e.g. Inditex, OVS, H&M and others supported and collaborates with universities and start-ups in innovative projects and participate in initiatives such as “Make Fashion Circular” of the Ellen MacArthur Foundation or “Accelerating Circularity” that involve big player with the same sustainable goals (Dragomir and Dumitru, 2022).

This is necessary to have an all-around positive impact: reduction and efficiency in the use of raw materials, use of secondary raw materials, products and processes designed upstream by providing for reuse, remanufacturing and recycling, lower use of energy and water resources, emissions abatement, efficient internal and external logistics, and products with extended usability.

2.3. Methodology

There are different methodologies which might be applied for a literature review in accordance with the purpose of the review. These approaches can be qualitative, quantitative or a mixed one. On the other hand, there are three broad types of methods commonly used: systematic review, semi-systematic review, and the integrative review. Furthermore, a literature review should have four phases: designing the review, conducting the review, analysis and writing the review (Snyder, 2019).

On the other hand, a literature review should take into consideration the following processes: assembling, arranging, and assessing existing literature in a review domain to stimulate the agenda to recommend avenues and directions for future research. In this case, there might be some other approaches on preparing a literature review: domain-based reviews, theory-based reviews, method-based review, meta-analytical reviews, and finally meta-systematic reviews.

The approach applied in this research is a mixed-method based on the steps proposed by the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol (Paul J., 2021) adapted for the purpose of the present article in Fig. 1.

2.3.1. Assembling

SPAR-4-SLR is a three-step process: Assembling, Arranging, Assessing.

Assembling		Identification Domain: Sustainability in the Fashion Industry Research questions: see Table 1 Source: Journals Source quality: Scopus
		Acquisition Search mechanism and material acquisition: Scopus Search period: 2020-2022 Search keywords: Boolean and wildcard search using combination of words in Title, Author keywords and Abstracts Total number of articles returned from the search 2,252
Arranging		Organization Organizing codes: Language, Documents Type, Source Type, Subject Area
		Purification Language: English Document type: Research articles Source type: Journals Subject areas included: see Table 2 Subject areas excluded: see Table 2 TOTAL DOCUMENTS RETAINED FROM ARRANGING STAGE 892
Assessing		Evaluation Analysis method: Contents analysis of representative results Agenda proposal method: best practices and gaps identification
		Reporting Reporting convention: words Limitation: Related to data type and subject areas considered Source of support: No fundings requested DOCUMENTS REPORTED IN DETAIL AS REPRESENTATIVE 9

Fig. 1. SPAR-4-SLR protocol applied to the present research.

Regarding the first phase, two sub-phases can be identified, namely, the Identification sub-phase, where the documents to be reviewed are identified, and the Acquisition sub-phase, where the first search for these documents is carried out on the selected databases.

For the first sub-phase, the Reference Domain is that of Sustainability in the Fashion Industry, considering everything included in it, thus products, processes, technologies, methodologies, and organizations pertaining to this domain, which have been explored in depth in the scientific literature by answering the Research Questions guiding the investigation (see Table 1).

As a type of sources, it was decided to limit it to Journals, as they are typically more aimed at giving specific input on best practices related to the topic under investigation. Other types of sources, such as books, were excluded as they usually have an explanatory and broad perspective on the topic under investigation.

For the quality of the sources, it was decided to use the Scopus database, which offers broad coverage and precise indexing of content, according to the guidance on this matter from (Paul J., 2021).

Relative to the Acquisition sub-phase, Scopus was also used as a search mechanism and to acquire the material, due to the wide range of integrated tools offered. In fact, in a first phase, a number of major online libraries were considered on which to conduct the search (i.e. Science Direct, Taylor and Francis, Wiley Online Library), however, the level of technical tools offered for the search leaned toward the use of Scopus.

Google Scholar was also initially considered, where an initial keyword search was conducted in the title. The search included a wide number of results, about 20,480, not only related to scientific publications but also to reports published on websites.

Table 1

Research Questions of the article.

RQ1	What could contribute to the implementation of Sustainable Business Model in the Fashion Industry?
RQ2	How many papers in the scientific literature report best practices in the field of sustainability in the Fashion Industry?
RQ3	What are the macro areas with the greatest achievement gaps in the scientific literature?

The choice of search period fell on the last three years, 2020 to 2022, when the review was completed. This choice was made in order to provide as recent an overview as possible, since other literature reviews on the same topic were conducted in slightly less recent years, e.g. (Yang and Song, 2017).

Search keywords, agreed in collaboration with other academics, were searched in the Title, Author keywords, and Abstract to cover the topic of Fashion Industry with reference to sustainability aspects, using Boolean operators and wildcards in searching for the following terms:

- In Title: (fashion OR textile OR clothes OR leather OR footwear)
- In Authors Keywords: (sustainab* OR industry OR bio*)
- In Abstracts: (fashion OR textile OR clothes OR leather OR footwear) AND (method* OR LCA OR alternative* OR approach* OR application*).

The chosen keywords aimed to identify scientific works that fell within the fashion industry areas of textile, footwear, and leather, referring to sustainability in terms of product or process, but also in terms of proposed methods. Issues related to the sustainability of products and processes are closely related to the product life cycle and the monitoring of production stages. Therefore, Life Cycle Assessment was also considered in the research to make it more consistent with the means of sustainability in terms of reducing impact through the life cycle.

At the end of the first phase the results obtained were 2252.

2.3.2. Arranging

The second phase also consists of sub-phases, Organizing and Purification, where the former lies in the choice of filters to be applied and the latter in the application of the filters themselves.

Since Scopus was used as the search mechanism, we proceeded to use the Organizing Codes (i.e., filters) made available by the database itself, going on to filter the results by (i) Language (i.e., English), (ii) Document Type (i.e., Research Article), (iii) Source Type (i.e., Journal), and (iv) Subject Areas. For the latter filter, the areas to be included and those to be excluded were defined as in Table 2, choosing from the afferent areas of the results obtained in the first stage. This choice was made in order to obtain more relevant results with respect to the research questions, excluding areas of relevance too far from the topic. At the end of this phase, 892 results were obtained.

2.3.3. Assessing

The last phase is Assessing, consisting of Evaluation and Reporting as sub-phases of the process.

Regarding the Assessing phase, the research was conducted by thematic areas, namely the search for best practices applicable to the areas of the Fashion industry, particularly Textile, Footwear and Leather, to make this industry sustainable through the application of less impactful solutions within its business models. So, the analysis methodology applied takes these aspects into account and analyses the results obtained in terms of quantity of results per area, identifying best practices and gaps in results.

Finally, at least three results were selected in the reporting phase for each area, considered by the authors to exemplify each aspect investigated, i.e., best practices related to products, technologies, processes, and organizational strategies.

The limitations identifiable in this work are dictated by a temporal aspect, in that it does not consider results prior to 2020; a linguistic aspect, as only results in English, as a widely recognized language for scientific communication, were chosen to be included; and finally, a scope aspect, limited to sustainability in the three areas of the Fashion Industry. As for financial supports, no support was requested or obtained to conduct this research.

The next section shows the results of the Reporting sub-phase followed by an in-depth discussion of each of them and the impact they could have on the business model of the adopting companies.

Table 2

Subject area to include/exclude after the Acquisition phase.

SUBJECT AREAS INCLUDED	SUBJECT AREAS NOT INCLUDED
<ul style="list-style-type: none"> • Agricultural and Biological Sciences • Arts and Humanities • Biochemistry, Genetics and Molecular Biology • Business, Management and Accounting • Chemical Engineering • Economics, Econometrics and Finance • Energy • Engineering • Environmental Science • Materials Science • Multidisciplinary • Psychology • Social Sciences 	<ul style="list-style-type: none"> • Chemistry • Computer Science • Decision Sciences • Dentistry • Earth and Planetary Sciences • Health Professions • Immunology and Microbiology • Mathematics • Medicine • Neuroscience • Nursing • Pharmacology, Toxicology and Pharmaceutics • Physics and Astronomy • Veterinary

3. Results

Fig. 2 shows the articles published by year from 2020 to 2022, broken down by Journal of publication. First of all, it can be seen that there is an increasing trend of publications on the topic over the past 3 years, with a 5% increase in 2021 compared to 2020 and a 27% increase in 2022 compared to 2020, underscoring the fact that the topic is also gaining increasing interest at the level of the scientific literature, given the impact that characterizes the fashion industry.

As for publication territories, represented in Fig. 3, countries with 25 publications and more in the three-year period were highlighted. It is evident that China and India made a very high contribution to the scientific literature in terms of output, both because of a trend that generally sees a large number of publications on many topics and because of the importance of the sector in these countries at the level of production and consumption of products. Also noteworthy are the contributions from Brazil and Turkey, countries in which several stages of world production are carried out, as well as the U.S. and U.K., which are particularly active on research in general and are affected in an important way by all stages of the fashion industry, from design to end-of-life. Other countries include Europe, where attention to sustainability is among the highest worldwide.

Fig. 4 also shows the trend in the number of publications per journal over the period investigated, considering those that published 15 articles or more. It can be seen that the fields they belong to are diverse, with journals that deal with the topic of sustainability both in terms of scientific research and production more specifically (Journal of Cleaner Production, Sustainability Switzerland, Environmental Science and Pollution Research, Desalination and Water Treatment), but also journals more related to fashion (Journal of Fashion Marketing and Management, Textile Research Journal) and journals of a scientific-engineering nature (ACS Applied Materials and Interfaces).

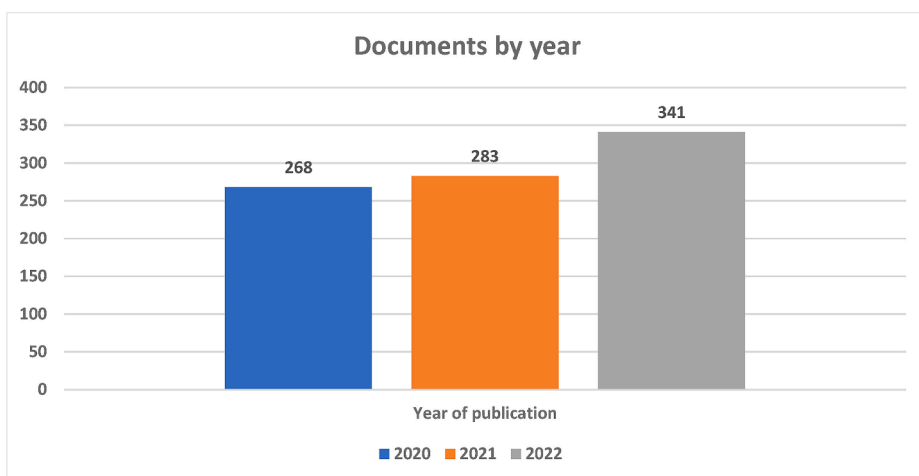


Fig. 2. Documents by year. Own elaboration based on Scopus search analysis.

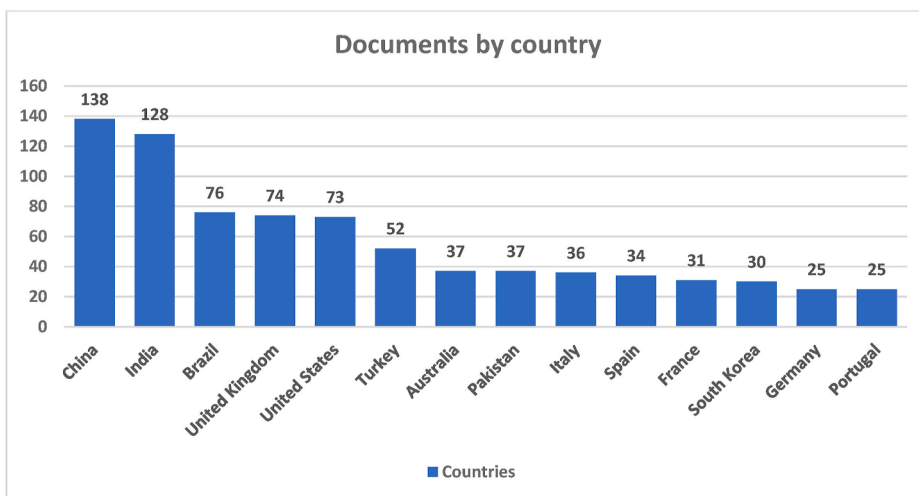


Fig. 3. Documents per country. Own elaboration based on Scopus search analysis.

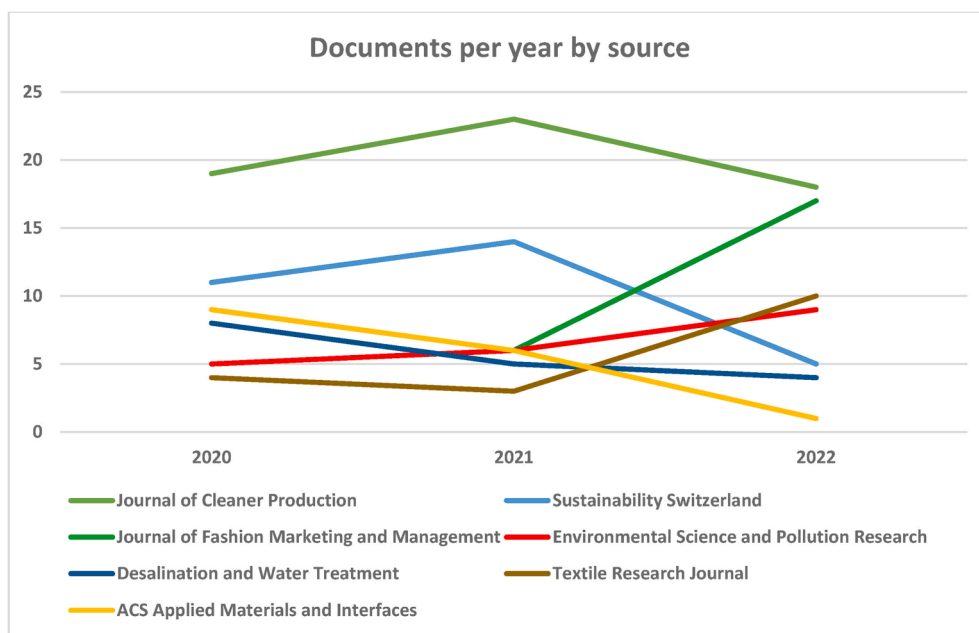


Fig. 4. Documents per year by source. Own elaboration based on Scopus search analysis.

As for the keywords analysis, it appears that “textile” has a large number of specific keywords used, while “footwear” and “leather” are less cited among the results obtained. Deepening the research with specific area-related words, it appears that the number of textile-related keywords in the results obtained in the Arranging phase is at least 5 times higher than that related to leather and more than 12 times higher than that related to footwear.

As mentioned in the methodology, the authors, by reading the titles and abstracts choose three representative findings to further discussion, for each area of the fashion industry, in order to present best practices and indicators that can help the industry towards the adoption of SBMs. A summary of these papers is reported as follows in Table 3:

Table 3

Main scientific work related to the textile, footwear, and leather industries.

AUTHORS	TITLE	YEAR	TOPIC
TEXTILE INDUSTRY			
Santal A.S., Rani R. et al.	<i>Biodegradation and detoxification of textile dyes using a novel bacterium Bacillus sp. AS2 for sustainable environmental cleanup</i>	2022	Use of bacteria capable of degrading mixed dyes
Fromhold-Eisebith M., Marschall P. et al.	<i>Torn between digitized future and context dependent past – How implementing ‘Industry 4.0’ production technologies could transform the German textile industry</i>	2021	Industry 4.0 contribution to improve process efficiency and minimise failure rates in textiles companies
Sun X., Wang X. et al.	<i>Textile Waste Fiber Regeneration via a Green Chemistry Approach: A Molecular Strategy for Sustainable Fashion</i>	2021	Method to convert waste textiles into regenerated materials
FOOTWEAR INDUSTRY			
Zenaide Paiva C. jr., Santana Peruchi R. et al.	<i>Performance of ethylene vinyl acetate waste (EVA-w) when incorporated into expanded EVA foam for footwear</i>	2021	Recycle EVA based waste to improve physical qualities of midsoles
Ruzafa-Silvestre C., Carbonell-Blasco M.P. et al.	<i>Robotised atmospheric plasma treatment to improve the adhesion of vulcanized and thermoplastic rubber materials for a more sustainable footwear</i>	2021	Atmospheric plasma treatment for the adhesives for the sustainable footwear production
Narwane V.S., Raut R.D. et al.	<i>Barriers in sustainable industry 4.0: a case study of the footwear industry</i>	2020	Barriers and interrelationship amongst barriers in Industry 4.0
LEATHER INDUSTRY			
Ding W., Liu H. et al.	<i>A step-change toward a sustainable and chrome-free leather production: Using a biomass-based, aldehyde tanning agent combined with a pioneering terminal aluminum tanning treatment (BAT-TAT)</i>	2022	New high-quality treatment for a more sustainable leather production as alternative to Cr-based techniques
Cabrera-Codony A., Ruiz B. et al.	<i>From biocollagenic waste to efficient biogas purification: Applying circular economy in the leather industry</i>	2021	Circular economy in the leather industry through the recycle of leather wastes
Hailu Y.	<i>Application of Modular Design in Upcycling Solid Leather Waste: A Sustainable Development Approach from Ethiopia</i>	2021	Modular design applied on leather waste in Ethiopia

4. Discussion

The results obtained are indicative of the growing popularity of the topic analysed across different scientific fields and countries that turn their interest to the issue, demonstrating how a holistic approach to the problem is the key to a shift in the fashion industry toward a circular economy concept.

The prevalence of textile-related issues over leather and footwear also emerged, related to the volume of textile-type products being made and the intensive use of resources for production, such as water, energy, and chemicals, making it very impactful and highly attentive.

The following subparagraphs focus on the three areas of fashion analysed, exploding the contents of the representative findings, highlighting the potential that the increasing adoption of such best practices could have in the transition to SBMs for overcoming the current prevailing linear economic model that characterizes the fashion industry.

4.1. Textile industry

The research work “Biodegradation and detoxification of textile dyes using a novel bacterium *Bacillus* sp. AS2 for sustainable environmental cleanup” (Santal and Rani, 2022) studied the biodegradation of pollutants from the dyeing process through a particular bacterium. This bacterium was isolated from soil contaminated with textile dye and it emerged that it was very efficient and rapid in the decontamination. It appears to be a valid solution to fight environmental pollution from textile-dye. Moreover, the study selected the better growth parameters and confirmed the ecologic nature of the strain.

The rapid growth in demand for textile products leads to an increase in clothing production and, consequently, an increase in dye-related pollution. The bio-based solution proposed in this paper is particularly interesting because, in addition to the effectiveness of the decontaminating action, it is also quick in the process thus helping to support the increasing production rates.

From an organizational point of view, the study “Torn between digitized future and context dependent past – How implementing ‘Industry 4.0’ production technologies could transform the German textile industry” (Fromhold-Eisebith M., Marschall P. et al., 2021), investigates the possible implications of implementing Industry 4.0 in textile companies at the level of improving product quality, process efficiency and competitiveness. In particular, it focuses on the elements of Industry 4.0 in Germany's technical textiles industries, identifying the key factors needed to implement aspects of digitization in production. The introduction of digital solution will have three main benefits: improved connection within the textile industry, attraction for IT experts, and increase German producers' competitiveness.

The digital tools offered by Industry 4.0 play a key role in the fashion industry: the monitoring and automation of processes make it possible to identify inefficient and polluting areas and facilitate the implementation of corrective solutions with a view to continuous improvement, with repercussions on the economic and environmental sustainability of production.

Shifting the focus to the end of the product life cycle, in the ecological transition required of the fashion industry, a key role is played by textile waste. The study “Textile Waste Fiber Regeneration via a Green Chemistry Approach: A Molecular Strategy for Sustainable Fashion” (Sun and Wang, 2021) presents a method for converting textile waste into remanufactured materials. In the study it is explained how the fabric originally constituted by natural fibres and polyester has been separated also by reusing the solvents. Multicomponent fibres and cellulose/wool keratin composite fibres are produced from waste textiles as secondary raw materials. The authors suggest ways to close the process by taking into consideration all the by-products deriving by the application of the method proposed and they state that it is a scalable solution.

The method suggested has a twofold positive effect when applied: first, it makes it possible to reduce the volume of waste, and secondly, makes it possible to recover secondary raw materials, thus reducing the consumption of natural raw materials.

4.2. Footwear industry

According to IMARC Group's report, in 2021 the world's footwear was a \$224.6 billion worth market, and it is estimated that it will reach \$288.2 billion (IMARC, 2021).

This gives the perception of the dimension of this industry and therefore its impact from a single product is very important to keep as low as possible. Massachusetts Institute of Technology (Chu J., 2013), value as 13.6 kg of CO₂-eq the emission from the realization of a pair of shoes, mainly from the production process, rather than extraction and buying phase, due to the electricity usage. China is one of the largest producers of footwear: as their primary energy source is coal the impact in this sense is more accentuated. MIT also states that a pair of shoes is composed of 65 parts and need 360 production processes, with higher energy consumption and emission production in the small-parts processing.

From a technological point of view, the sustainability is achievable starting to optimize and find more sustainable alternatives to the actual technologies used. The study “Performance of ethylene vinyl acetate waste (EVA-w) when incorporated into expanded EVA foam for footwear” (Zenaide Paiva and Santana Peruchi, 2021) studied how the addition of EVA (ethylene vinyl acetate) waste, derived from defective midsoles of tennis shoes produced by a Brazilian manufacturer, to expanded EVA foam can improve the strength qualities of the shoes. In this way it is possible to keep production waste - deriving from manufacturing errors and rejected shoes - within the production cycle. The study focuses on the physical properties of the material but also conducts a cost analysis and emphasizes the sustainable effect of the proposed technique.

The proposed method could be a solution in this specific area, as it reduces waste generation by obtaining added value from discarded products, keeping them within the production phase of the product life cycle.

The study “Robotised atmospheric plasma treatment to improve the adhesion of vulcanized and thermoplastic rubber materials for a more sustainable footwear” (Ruzafa-Silvestre C., Carbonell-Blasco M.P. et al., 2021) describe a sustainable technology for the ad-

hesive's junction in the footwear production. Focusing on an atmospheric pressure robotic plasma technology to increase the adhesion of thermoplastic rubbers. This approach appears to be more sustainable than current technologies used with solvent-based chemical compounds. Evaluation of the effects of plasma treatment, as the operating parameters change, shows that the strength values are positively beyond the minimum quality limits for shoes. The main advantage, the authors report, lies in the fact that it can be included in the production process dedicated to gluing in a totally autonomous way with the help of robots.

From an environmental point of view, the fact that this method avoids the use of solvent-based chemicals is an important aspect that makes this practice particularly attractive in this sector, as chemicals used in the footwear industry are a major source of pollution that must be strongly reduced. The study "Barriers in sustainable industry 4.0: a case study of the footwear industry" (Narwane and Raut, 2020) remarks the importance of the identification and overcome of the obstacles of the industry 4.0 integration in the production system of the footwear industry. Through the use of Fuzzy-DEMATEL technique, data from the Indian footwear industry were investigated, analysing eleven firms of various dimensions and three academic institutes, showing that the main hurdles are represented by "lack of new organizational policies", "lack of customer collaboration" and "lack of infrastructures". This put the accent not only on policy makers and firms, but also on the importance of the involvement and awareness of the customer, which are responsible of the end of life of the products they buy and use. Aware them about the importance of the R-strategies and putting them in condition to extend the life of the products are some of the main steps towards sustainability.

4.3. Leather industry

As stated by the Grand View Research (Leather Goods Market Growth & Trends, 2021) report, developing countries hold over 60% of the global leather production, led by China, with India as a fast-growing competitor, both in terms of consumption and production. Companies in Europe are the main actors in leather luxury products.

Italy is the global leader in terms of trade market, thanks to its high-tech leather processing industry. Moreover, the fashion industry, highly represented in Italy, has augmented the demand for leather items.

According to the data from UNIC Concerie Italiane, the Italian tanning industry concentrates the production within local production areas which have developed distinctive aspects in terms of product and process. In this industry 17.000 workers are employed in over 1.000 companies, and it is estimated a turnover of 3.5 billion euros a year (UNIC, 2020). In this context, the CE influences many parts of the process: 76% of waste produced is recovered; water undergoes cleaning processes before being released in the environment through specialized plants to completely remove the toxic components; the water consumption is strongly reduced thanks to investments in advanced production plants; focus on how to recover the production by-product of other sectors, such as the food industry (UNIC, 2021).

The study "A step-change toward a sustainable and chrome-free leather production: Using a biomass-based, aldehyde tanning agent combined with a pioneering terminal aluminum tanning treatment (BAT-TAT)" (Ding and Liu, 2022) presents a Chromium (Cr)-free technique for the production of high-quality products. Cr is a widely used substance in the leather industry despite its hazard to the environment and humans, so much so that it is subject to several restrictions. Sustainable alternatives do not always turn out to be at the same level as typical post-tanning treatments, so they are not always successful in the market. The technique proposed by the study analysed uses what is known as BAT, an aldehyde-based substance that fixes very effectively through the use of a special technique based on terminal aluminum called TAT. This BAT-TAT technique turns out to be environmentally friendly and carbon-free, making it a viable alternative to classical Cr-based techniques. Thus, an important aspect is highlighted that must be taken into account, namely, the fact that alternative and sustainable techniques often do not solve a fundamental aspect: the satisfaction of market standards. This is accentuated in an industry such as Fashion that makes detail and the satisfaction of aesthetic and functional tastes a fundamental principle. The proposed method could be a solution in this specific area, as it reduces waste generation by obtaining added value from discarded products, keeping them within the production phase of the product life cycle.

The study "From biocollagenic waste to efficient biogas purification: Applying circular economy in the leather industry" (Cabrera-Codony and Ruiz, 2021) underline that the yield of leather from animal skin of about 20 percent. This led to an important production of solid, liquid, and gaseous waste.

From these, it is possible to obtain sustainable and economical activated carbons to be used as biogas enrichers in the energy field, with a view to CE. From the experiments conducted, it is possible to produce carbon-based absorbents from solid waste from leather tanning, recovering the biogas for less impactful energy uses, leading to a reduction in the use, and therefore extraction, of fossil fuels. The result of the work is, therefore, a technique for the valorization of biocollagenic industrial waste for environmental applications.

Industrial symbiosis is one of the catalysts for the transition towards CE. It is not always possible to keep a close cycle within the same sector: it could be seen as a limit but it is also a potential opportunity to cooperate in the valorization of by-products that would otherwise be waste. This process found an interesting way to reduce the waste production and at the same time adding value to their by-products, positively affecting the energy sector.

Changes in fashion trends have led to rapid growth in consumer demand for leather. To meet this demand, unsustainable resource consumption and processing practices are used, resulting in waste production, mainly at the cutting stage, which is after the chemical treatment stages. Consequently, this means most of the residues, destined for landfill, contain all the chemicals used in the previous stages. The study "Application of Modular Design in Upcycling Solid Leather Waste: A Sustainable Development Approach from Ethiopia" (Hailu Y., 2021) proposes a strategic approach to waste management, with a modular philosophy, to be applied to the Ethiopian context. From industry waste, it will be possible to create long-lasting leather items in significant quantities, given the availability of waste evaluated from the production of leather products in Ethiopia. The study also analyzes the physical characteristics of the waste to evaluate the most easily scalable modular design that can be used on the greatest amount of waste.

The proposed method addresses the problem of leather processing waste by pursuing the path of re-thinking and recovery to create added value, while also taking into account scalability, as there are differences in the secondary raw materials used that are considered in defining the method. This approach is particularly useful in economies that are involved in the production stages of processes, as they generate a large amount of production waste.

4.4. Firm-related best practices findings

Besides the scientific literature review, it was also deemed necessary to analyze some virtuous examples of companies in the three macroareas. It can be seen that some small and large brands have embraced sustainable SBM or technology, indicating that this aspect is increasingly becoming an element of competitive advantage as in addition to environmental responsibility. In Table 4 are shown the main findings in the research for firms' best practices.

Parallels can be found with some of the literature cases, such as innovative dyeing technologies, highlighting how there is alignment on this issue on the needs of companies and those studied in the literature. In addition, it can be observed how some brands are born and built completely around the proposed sustainable technologies and processes, demonstrating how sustainability has become a fully integrated competitive element in the market.

As stated by H&M in their Sustainability Disclosure (H&M, 2021), the group is investing in innovative washing and dyeing technologies. Their goal is to maximize the usage of processes that assist reduce wastewater by 2030. They are also focused on saving and reusing water by investing in digital dyeing in cooperation with the Circular Innovation LAB, which uses a waterless smart dyeing technique. Reducing the environmental effect of these activities is a key step toward our climate and circular goals.

About colouring sustainably, the firm Colorifix (2017), a biotech firm backed partially by H&M, developed a colouring technique that decrease the environmental impact of industrial dyeing by replacing chemistry processes with biology processes from the creation of the dyes to their fixation into fabrics.

After the choice of a colour created by an organism in nature, via online DNA sequencing they pinpoint the exact genes that lead to the production of the pigment and then translate that DNA code into microorganisms. The resulting engineered microorganism can then produce the pigment as it produced in nature.

Garcia Bello (2022) represents an example of a textile company that adopts upcycling methods, that is, going beyond the concept of recycling, which often reduces the initial intrinsic value of the recovered product, going instead to add value. Specifically, the company restores obsolete clothing and makes high-quality products from it. The process involves two steps, the first is related to the standardization of patterns, and the second uses the fabric in rolls to serialize the garments. The garments used are donated by the community, thus also providing for societal involvement.

Ananas Anam (2017) is a company that uses the by-products of pineapple harvesting in the Philippines to create a sustainable alternative material to plastic. The material, Piñatex, is used for a variety of uses, including making footwear. In addition to the environmental aspect, given by the valorization of by-products and the reduction of fossil raw materials for the production of plastics, it also has positive effects on rural societies that see added value in what was previously just waste. The remaining parts also are used as biomass or biological soil conditioners for cropland.

Hilos (2022) is an ecologically conscious footwear company that combines 3D printing and computational design to reduce its carbon impact. Among the first to use 3D printing on an industrial scale without losing performance or efficiency. They claim to reduce the water consumption by 99% reduction and CO₂-eq emission by 48% for their "Emmett" pair of slippers. Their technology combines insole, midsole, and outsole in a single 3D-printed piece, which is easier to recycle and do not need to be disassembled as for traditional shoes.

Recyc Leather (2016) is a green tech firm. They produce from leather fibre scraps derived from traceable traditional manufacturing processes, and the resulting products are durable and lightweight, with an appearance true to real leather. One example is Unique Recyc Leather, a product made from industrial glove scraps. The starting mix sees a 60 percent composition of real leather recovered from waste and the rest derived from synthetic and vegetable materials, with a water-based polyurethane coating part and contains no hazardous chemicals.

Table 4
Main findings in firm-related best practices.

FIRM	BEST PRACTICE	SUMMARY OF THE PRACTICE
TEXTILE INDUSTRY		
H&M – Colorifix	Process efficiency – Bio-based dyeing	Investing in new washing and dyeing innovations – colouring technique based on biological organisms
Garcia Bello	Old clothes upcycling	Reusing, repairing, and recycling the outdated fabrics into high-quality products, extending the useful life of objects.
FOOTWEAR INDUSTRY		
Hilos	3D-printed shoes	The use of 3D printing to reduce the waste in shoe production and facilitate recycle avoiding composite products
Ananas Anam	Raw material from pineapple by-products	Piñatex is made from the leaves of the pineapple plant a by-product of fruit industry.
LEATHER INDUSTRY		
Recyc Leather	Recycled leather	Mixture of vegetables and synthetic product
Gucci	Metal and chrome free leather tanning	Use of sustainable alternatives to traditional tanning process

Gucci ([Gucci Equilibrium - Pelle Sostenibile, 2021](#)) pays special attention to the materials of its products, committing to ensuring the sustainability of the materials and leather used, positively impacting animal production methods. Among the virtuous behaviours on leather processing, it has promoted Chrome- and metal-free tanning, with the goal of achieving 100 percent of leather production in this way by 2025, reducing water consumption and air emissions, as well as waste production and energy consumption.

5. Conclusions

This paper aims to define a state of the art of current environmental impact and report some best practices in the fashion industry, one of the most polluting industries in terms of air and water pollution, raw material, and energy consumption. The goal is to provide an overview of the current situation in terms of recent scientific work and virtuous business practices which might be useful for future in-depth research and improvement.

The authors reviewed the main international English journals and selected the most important articles in accordance with the SPAR-4-SLR protocol conducting a systematic literature review and selecting representative results for each of the area researched in the fashion industry.

The authors gathered 2252 articles, selected 892 articles for their relatedness to the topics and presented 9 representative articles on the three areas of fashion industry (textile, footwear, and leather).

From the results, several innovative technologies and approaches aimed at sustainability in the industry emerge, providing encouraging input on the efforts made both at the level of scientific literature and application by companies, including those of different sizes.

It is therefore important that these best practices, and many more, are supported and applied by the entire value chain to make an impact on the entire sector, which is still among the most polluting and resource-consuming.

However, there is not a one fit-for-all solution and one actor that should be involved to tackle this problem. In fact, many are the solutions, and many are the actors that should be involved as emerged from the research of firms' best practices that shows the variability in dimensions of firms involved in this process as well as the centrality of sustainable solutions in small sustainable firms more than in big companies.

Therefore, to address this problem, companies in the industry should engage in the adoption of R-strategies at all stages of their production processes, so as to reduce raw materials used in favour of increasing secondary raw materials and decreasing waste generated, promote water- and energy-saving solutions, and adopt technologies and processes with a lower impact on the environmental pollution.

The McKinsey-GFA "Fashion on climate" report ([Berg and Granskog, 2020](#)) states that at the current rate, the fashion industry will fail to meet the 1.5 °C target in 2030 set by the Paris Agreement on climate change: accelerated abatement is therefore needed, starting with upstream operations that are the most impactful stage of the fashion supply chain, to reduce emissions by nearly 50% from the current rate.

This effort must certainly be supported by a stringent regulatory framework that provides incentives for such actions. If this is already in place at the European level, the same must be done in developing countries: the analysis shows that attention is growing in these countries as well, at the scientific level, with several recent publications addressing the issue of sustainability in this industry.

Consumer awareness of sustainable behaviours is key to achieving total circularity, as they are the ones who decide where to direct products at the end of the life cycle.

Eurobarometer data suggest how Europeans today want more engagement on the topic of sustainability with a fairly shared opinion that it should be large companies that make the most effort.

The data also indicate that 92 percent of respondents believe that fashion brands should ensure good working conditions for employees, also denoting attention to social sustainability, although 49 percent believe that prices should remain low, despite the extra effort required ([Kantar, 2020](#)).

Finally, scholars should support the aforementioned actors through evidence-based research and solutions which might be applied, monitoring and evaluated and thus starting again this process.

Therefore, according to abovementioned reasons, the fashion industry needs to replace the linear model with that of the circular economy, in which waste is limited, reused, and transformed from a problem into a resource. The new approach involves four key steps ([Ellen MacArthur Foundation, 2017](#)):

- use of non-polluting materials and avoid risk of microfibers dispersion.
- focus on quality to extend products' life cycle, starting with eco-design.
- support the application of R-strategies starting by the rethinking of the products and processes (eco-design).
- enhance a more efficient use of resources and renewable energy.

Commitment to sustainability supported by policies and regulations also brings competitive advantage to companies, both in terms of image and cost reduction through increased production efficiency. Redesigning products and processes to reduce consumption and waste is the way to meet global climate goals.

The incentive for the adoption of Sustainable Business Models pursues circularity goals that go beyond the territorial dimension, extending to the entire textile industry with sustainably produced materials ([European Environment Agency, 2020](#)).

In conclusion, it can be said that the circular economy represents today the most sustainable model for companies in all sectors, in particular it is clear that this must be assumed by the fashion industry and that the transition to the circular model is not that hard but requires an important design phase (i.e., eco-design).

From the scientific point of view, scholars should focus more on the most resources consuming industries in accordance with the EU Taxonomy, should base their research on evidence-based approach and quantitative one and should cooperate with policy makers and decision makers in order to test their solutions and apply them.

Therefore, the next step should be, for instance, more LCA on fashion industry, more cooperation with policy makers and decision makers and setting up more experimental projects with fashion industry firms.

Author contributions

Paolo Sospiro, Marco Ciro Liscio, Caterina De Ponte: Conceptualization, methodology, validation, formal analysis, investigation, data curation, original draft preparation, review and editing, visualization. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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