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Toward Textile 4.0: A comprehensive analysis of industrial perspectives for the textile industry

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***Résumé* – À l'ère de l'industrie 4.0, toutes les industries doivent être agiles et conscientes de la transformation qui se produit en termes sociaux et technologiques. Le textile, en tant qu'industrie majeure, doit être conscient de cette transformation digitale et de cette évolution technologique communément identifiée comme Textile 4.0. L'objectif principal de cet article est de fournir un aperçu complet de l'industrie textile dans le passé, le présent et le futur. Les principaux défis de cette industrie sont analysés avec un accent particulier sur les transitions technologiques et sociales. Cet article identifie et met en évidence les principaux problèmes et les différentes feuilles de route décidées par les différents pays.**

***Abstract* – In the era of industry 4.0, all industries must be agile and aware of the transformation occurring in social and technological terms. Textile, as a major industry, must be aware of this digital transformation and technological evolution commonly identified as Textile 4.0. The main objective of this article is to provide a comprehensive overview of the textile industry in the past, present, and future. The main challenges of this industry are analyzed with a particular focus on technological and social transitions. This paper identifies and highlights the major issues and the different road maps decided by different countries.**

***Mots clés* – Textile, habillement, mode, industrie 4.0, textile 4.0.**
***Keywords* – Textile, Garment, Fashion, Industry 4.0, Textile 4.0.**

1 INTRODUCTION

The textile industry played an important role in the industrial revolution. Weaving, knitting, crocheting, knotting, and pressing fibers together, form textiles. The textile industry contains a whole value chain including obtaining raw materials, spinning, weaving, dyeing, and printing, as well as product sales [Duarte et al. 2018].

The industrial revolution modified the production-consumption strategy and social organization. In this competitive industrial world, the development of a new product needs the technological tools and decision-making approaches that must satisfy the social and environmental responsibilities of organizations [Duarte et al. 2018].

During each industrial revolution, the textile industry developed. In the first industrial revolution between 1760 and 1830, the textile industry was developed and the first factory was a Boston manufacturing company created in the United States in 1813. The second industrial revolution between 1840 and 1870 was a transition that affected productivity through the introduction of a new source of energy (electricity) in the textile industry. In the third industrial revolution, the focus was on the transition from analog to digital technology. The implementation of electronics and information technology (IT) increased the automation of manufacturing processes, with machines replacing laborers. This revolution was characterized by using microprocessors, CAD (Computer-Aided Design), optical fiber, telecommunication, biogenetics, and laser. Mass customization, in which large quantities of items individualized according to the user are produced, was a challenge for the textile industry. Nowadays, the third revolution is still present but it is smoothly transforming into a new age of industrialization known as the fourth industrial revolution. The fourth industrial revolution, introduced as Industry 4.0, is an interconnected system that connects machines, methods, and products. Smart factories are introduced in this revolution by five key characteristics; they are connected, optimized, transparent, proactive, and agile [Asadollahi-Yazdi et al. 2020, Bartodziej and Bartodziej, 2017].

Like other industries, this fourth revolution affects the textile industry and the term textile 4.0 has appeared these days. Thus, the main objective of this article is to provide an analysis concerning textile 4.0 and its challenges and opportunities.

Therefore, the remainder of this paper is organized as follows. The current situation and future strategies of the textile industry will be presented in the next section. Section 3 is devoted to the challenges and opportunities of the textile and fashion industry. Finally, section 4 concludes with a summary.

2 CURRENT SITUATION AND FUTURE STRATEGIES OF THE TEXTILE INDUSTRY

Each industrial revolution brings technological aspects, which modify the production strategy and methods, as well as societal transition. Industry 4.0 is a type of evolution in terms of developing technologies for a digital production system, which affects the social aspects and human life. In this section, the technological and societal transitions will be discussed. In addition, the global and international markets, as well as second-hand markets as current strategies of the textile industry will be analyzed. Finally, the global strategic vision of different countries in the textile sector will be introduced. These analyses provide a comprehensive industrial vision of the textile sector.

2.1 Technological Transition

Over two centuries and during the industrial revolutions, the focus was on individual production as Craft production. The second industrial revolution permitted mass production through its technological transition. Technological transition in the third revolution targeted market groups such as customization, and nowadays we are coming back to respond to the needs of each customer through personalization, but the difference is that new technologies are developed which allow for technical and personalized products [Asadollahi-Yazdi et al. 2020].

Textile is an industry that originated from humanity and human beings' instinctive desire to dress. Its history is as old as human civilization. As shown in Figure 1, all the clothes are made by hand for each person as hand-made personalized products before the industrial revolutions. During each industrial revolution, different technologies were developed leading to the technological transition. After the first industrial revolution, the first factory in 1813 was constructed as Boston Manufacturing Company in the United States. Ready-made clothing appeared in 1831 as craft production. The second revolution permitted mass production for the textile industry. The third revolution allowed customized production through digital technologies. For example, Tekyn technology is a platform and a short-circuit production model that allows brands to manufacture just the right quantity of clothing in France based on store demand. Nowadays, personalized production is coming and industry 4.0 and its fundamental technologies and aspects permit producing a personalized product with new processes like Additive Manufacturing, smart products, and technical products such as Induo technology, Uniqlo, Gortex, etc. as well as an eco-responsible personalized product like the products fabricated from vegetative leather.

2.2 Societal Transition

Since 2004, GreenFlex, a key partner in the energy, environmental and social transformation of organizations, with the partnership of the Agency for the Environment and Energy Management (ADEME in French) launched a study related to the Responsible Consumption Barometer. This barometer analyzes Citizens' perceptions of the current model of society, their attitudes, and their commitments in favor of more responsible consumption, as well as the relevant levers of action to enable economic actors to understand and integrate the new expectations of their consumers.

According to this study published by [ADEME magazine] in July 2021, in France like other countries, the majority of people aim to change their economic model. 52% of people

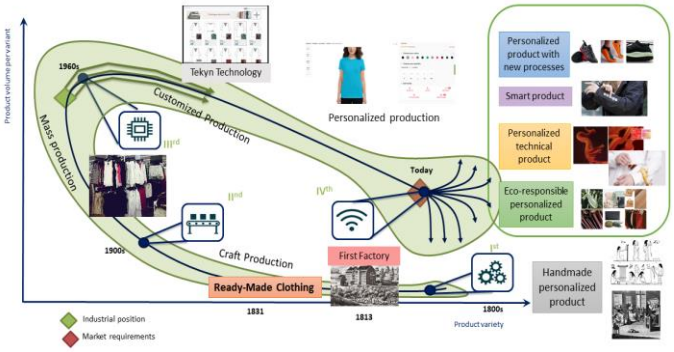

Figure 1. Technological transition

surveyed desire to completely rethink and get out of the infinite growth myth and 82% wish to live in a society where consumption is less important. For 33% of French people, responsible consumption means buying sustainable products (eco-labeled, local, less polluting), 31% of people think about reducing consumption in general and 30% remove the superfluous for responsible consumption. Large-scale distributors, companies, and brands are the leading actors in the development of responsible consumption and 85% of people think that we can achieve responsible consumption by working on their offer to propose healthy, simple, and accessible products, engaging in the reduction of their environmental footprint and on social issues, and making marketing work for more sustainable consumption. According to this societal transition, 67% of people opt for a sustainable product because they have better quality, 72% of people are mobilized in favor of responsible consumption, and 82% of them question whether they need a product before buying it. All these societal transitions illustrate the necessity for a textile industry that is more eco-responsible, durable, and sustainable.

2.3 Global and international market

The textile industry has been also developed in terms of market. The markets are a globalized world. Fashion retailing and consequently the textile industry is global. The internationalization of the fashion industry, particularly the sourcing side of it, has happened over many years and has occurred largely because of increasing offshore production, as companies chase low-cost labor in developing economies [Mccormick et al. 2014].

Globalization increased the internationalization of the production, distribution, and marketing of goods and services. It is the worldwide diffusion of practices, expansion of relations across continents, organization of social life on a global scale, and growth of a shared global consciousness [Levy, 2005].

The development of these new and global markets creates challenges regarding communication, business, logistics, and customers as described as follows [Mccormick et al. 2014]:

- Global consumer markets: These new markets are emerging due to developing economies and some degree of political liberalization. For example, China and India as the fastest-growing consumer markets in the world are attracting many western brands, and changes in political control have made it easier for western companies to do business in these markets.
- Global communication: Nowadays, different advanced technologies create opportunities for customers to be in communication with suppliers across the entire world and for consumers to access information, and for companies to communicate with consumers around the globe, i.e., online fashion platforms.
- Global business: As global trading increases, cooperation

and alliances between countries emerge to facilitate overseas business activities. It is necessary to be agile in terms of business activities in this international market due to the competitiveness between different textile actors.

- Global logistics: Such logistics are more complicated as products will be transformed around the world through different new technologies.
- Global customers: Social and cultural trends, as well as improved communication, have created a generation of global customers. Nowadays, fashion is exposed around the world through music, film, the internet, as well as social networks and some brands are famous all over the world.

Regarding globalization and international markets, different sale channels and networks have emerged. These channels are classified as traditional single-channel, online single-channel, multi-channels, and Omni-channels [Mccormick et al. 2014]. Traditional single channels are brick-and-mortar stores. Some other companies specialized in e-commerce are defined as pure-play retailers, while multi-channel companies develop various disconnected sales channels. Nowadays, companies are aiming for an Omni channel retail process. Regarding these new channels, there is coherence and interdependence between them, which allows the improvement of the customer experience in different sales channels and personalized sales channels. Companies use new technologies to improve the client's experience in both online channels and shops and to combine them. For example, different technologies including digital stores, click-and-collect, orders from the store, e-commerce through social networks, and virtual fitting are now popular among fashion retailers.

2.4 Second-hand market:

Sustainability is a hot topic these days. It is public knowledge that the textile industry is very polluting. It is the 2nd most polluting industry after the petrol industry and it is also the 3rd global consumer of water. To produce one kilo of cotton fabric, on average 9259 liters of water are used [Chapagain et al. 2006]. Under pressure from public opinion, laws, and environmental guidelines, the textile industry must evolve to be more sustainable all along the value chain.

The textile sector is therefore facing many environmental challenges that, if addressed comprehensively, will move the sector from a linear economy, focused on production and sales, to a circular economy concerned with its environmental impact. This impact will be not only on its production system with savings in water, chemicals, and waste but also on the recycling of products from consumers after the sale and from professionals (distributors, sellers) with unsold products.

The young generation is very sensitive to environmental issues and is claiming and screaming for a new Homo Sustainability to assume responsibility and the climate emergency [Marques et al. 2020]. This implies new consumption patterns and promotes waste reduction. Governments also raise the issue as many are making regulations on the second life of products.

The two principles that are important in the circular economy are [Marques et al. 2020]:

1) The value of products, materials, and resources should be retained as long as possible, while the production of waste during the process is minimized.
2) Materials contained in the waste which is already produced can be reused as "new raw material".

Once collected, textile wastes are sorted and then reused (sharing, repair, resale in second-hand markets) or recycled (grinding, defibration, cutting, fraying); incinerated (energy recovery and thermal power generation or without energy recovery) or landfill disposed of [Marques et al. 2020].

The circular economy is not well implemented in the textile industry, it is still a challenge, and most of the clothes sold are not collected. For instance in France, only 38% of the clothes put on the market were collected to be recycled in 2019. The quantity collected by inhabitants almost doubled in 10 years, from 2kg to 3,7kg [Re_fashion, 2020], but it still needs development. The barriers to this implementation of a circular economy can be summarized around the following six points including [Leal Filho et al.2019, Rossi et al.2020, Jia et al, 2020]:

- Viability of the business model: The viability of the economic model depends on the control of the composition of the products. Most of the textile waste recovered is unsuitable for reuse. This is due to the production of many textiles at lower costs and lower quality. Therefore, small-volume reuse is not economically viable, and investors are reluctant to commit to this sector. The costs of recycling plus the costs of transport are high compared to the selling price of the recycled products, as well as the price of some new clothes.
- Material composition: The basic components of many textiles make them unsuitable for recycling. The presences of plastics and metals together are a real obstacle during separation operations such as shredding. The mixture of different types of polymers with specific mechanical characteristics adds to the difficulty of recycling and results in recycled products of poor quality. In addition, textiles contain chemicals and dyes that can be toxic.
- Lack of availability of textile materials for recycling: The quantity of waste potentially accessible and suitable for recycling is insufficient. This is mainly because the mixtures of fibers within the textile make the processing operations very difficult. Furthermore, this lack of material availability can also be caused by a lack of organization of the logistic network of recovery and treatment and by a lack of consumer awareness among consumers.
- Limited technology: Limited recycling technology is analyzed as potentially problematic. One of the major reasons for the limited quantities of recyclable products is the lack of technology for waste separation operations upstream of the recycling operations. This lack of technology is especially present concerning the separation of dyes and contaminants found in fibers. There is a need for considerable investment in the research and development of both chemical and mechanical sorting technologies. Now, the use of advanced communication and information technologies (Internet, Big data, AI, telephony) would allow the improvement of the whole trade part of these recycled products.
- Lack of information and limited participation: Public awareness has a very important impact on recycling and the quantities recovered. There is a strong correlation between information provided to the public and attitudes towards recycling. An effective policy of information and awareness raising would be favorable at all levels of recycling. It must be targeted on several aspects: the knowledge of the tools and means used for the recovery of products (what type of product is recovered, where and in what form), knowledge of the recycling cycle of the different operations carried out, the possibilities of exploitation and the different environmental and socio-

economic impacts. According to [Jesson et al. 2014], the knowledge barrier (ignorance of what to recycle) and the attitude barrier (non-commitment to recycling ideals) are two of the fundamental barriers to recycling-related consumption.

- Coordination and standards to be improved: One of the sensitive points of coordination is the recovery of the products to be recycled. It is called the inbound logistics of this recycling process because it strongly influences the number of products to be recycled. This coordination must be global on the whole process, on the ecosystem, as well as on the whole territory and even beyond. A review and inspiration on the methods of organization, coordination, and standardization of some sectors such as the automotive industry can only be beneficial.

Therefore, to achieve a more responsible and technical textile, each country needs to provide the programs and preconditions toward a more developed textile industry as described in the following:

2.5 Global Strategic visions

As mentioned, each industrial revolution creates a technological transition that affects all industries including textiles. Nowadays in the age of industry 4.0, countries aim to evolve the factories, as well as mode and garment industries toward a textile 4.0. On the other hand, global warming and ecological aspects are the significant factors that modify the entire industrial world. In the following, the future visions and plans for the textile industry in different countries are mentioned:

2.5.1 EURATEX Plan

EURATEX, [European Apparel, and Textile Confederation, 2020] presented their strategies for the future in Europe. In 2020 within the covid-19 crisis, the European textile and clothing industry is ready to transform this crisis into an opportunity and become more digital, sustainable, and agile. EURATEX's plan requires considerable resources and a coherent set of measures, both on a short-term and a structural basis. Therefore, they developed five flagship initiatives in June 2020 as follow:

- The impact of the Covid-19 crisis necessitated organizing guaranteed supplies and building a resilient value chain for critical PPE (Personal Protective Equipment) and other textile products.
- The necessity of educating and attracting well-qualified young workers and professionals as the textile and clothing workforce is growing older, as 35% of it is over 50 years old. SMEs (Small and Medium-Sized Enterprises) should upskill the existing workforce to transform the textile industry toward textile 4.0.
- The need to invest in innovative and sustainable textiles through dedicated Public-Private Partnership (PPP) at the EU (European Union) level. The focus must be on research innovation, pilot testing, and demonstration in critical areas to provide a digital fabrication and digital supply chain.
- Euratex aims to establish five recycling hubs to fabricate raw materials. These hubs make raw materials by collecting, sorting, processing, and recycling post-production, as well as post-consumption textile wastes.
- The need to ensure free and fair trade for the companies. In the future, goods being blocked by national authorities at the borders should not happen.
- All textile products placed on the EU market must be sustainable, repairable, and recyclable.
- It is necessary to provide the cost-effective reuse and repair services widely available in Europe.

2.5.2 Textile 2030: German vision

[Fromhold-Eisebith et al. 2021] proposed a vision of the textile industry in the future of Germany. They proposed their plan based on four themes including:

- World of textile labor: The local labor market implications of digitized textile production dominate the debate. Nowadays, Germany aims to relocate the digital textile production sites based on flexible automation to solve qualified labor shortage problems through continued rationalization and to better combine the interests of employers and employees. The modern textile site provides working conditions including tasks that are more sophisticated to its workforce, but there is a risk related to the loss of jobs and increased work pressure due to increased national and international competition.
- New business models: New business models focus on the issues, in which novel manufacturing and service opportunities emerge from digitalization, in addition to existing technical textile production. Today by addressing digitalization and environmental concerns, industries aim to develop ecological and sustainable formats. For this purpose, localization, known as "Made locally" products, is the German vision for the future of textiles. Different fields like Additive manufacturing, big data analysis, and predictive maintenance and their effects on the textile value chain create different opportunities for the digital textile economy. Customer-centricity is also an approach for production, which focuses on customer demand in the textile industry, in line with novel trends towards smart textiles, smart wearables, and mass-customized, intelligent apparel for private consumers. In this field, there is a risk related to data security in smart and digital textile sites.
- Smart factory: Smart factories are formed by internal coordination, networking requirements, and communications between machines developed by digitalization. Artificial intelligence can also be used to optimize the process to enhance the quality level of products, as well as enhance the coordination between suppliers and clients. In this smart textile industry, textile jobs are more attractive for qualified employees and data science experts.
- Standards and legislation: Smart textile production requires the standards and legislation necessary to implement vertical and horizontal linkage. It is also necessary to define the standard data for the entire value chain of textiles. Shared standards must be agreed upon for all production parameters, which are coordinated digitally. There are also risks related to data security.

2.5.3 Textile 2025: India's vision

India is one of the strongest countries in the textile industry. It is the second-largest producer of polyester in the world, and it is a key player in technical textiles. India's strengths have already been demonstrated in traditional textiles and natural fibers globally. For India, the textile of the future can be summarized as technical textile, ecolabel, and digital textile

hubs, as well as standard textiles, explained as follows [Sharma et al. 2020]:

- Facing the increase of the technical textile demand: Technical textiles have seen an upward trend globally in recent years due to improving economic conditions and it is forecasted that the demand for technical textiles will be augmented by 2025. Technological advancements, increase in end-use applications, cost-effectiveness, durability, user-friendliness, and eco-friendliness of technical textiles have led to an upsurge in their demand in the global market.
- Importation of specialty fiber: Such characteristics as lightweight, durability, and thermal stability have led to an increase in the overall demand for such composite materials as specialty fibers, but the lack of requisite technologies and the absence of an R&D ecosystem are the obstacles to technical textiles. Technical textiles contain different special fibers like meta-aramid, para-aramid, glass fiber, high-tenacity nylon fiber, etc.
- Creation of mega Textile Park: It is planned to develop the mega textile park in India regarding eco-responsibility and digitalization. These textile parks contain a technology-driven ecosystem with R&D, start-up incubation, forward linkage with logistics parks and market access systems, and backward linkage with the creation of textile standards.
- National policy toward textile 4.0: Industry 4.0 and its fundamental aspects and potentials permit the reconstruction of the entire value chain.
- Research and development (R&D): It is planned to integrate the textile industry with recent research and development to enhance the performance of textile industries.
- Standards and norms: It is essential to define the standards regarding export capacity, technical testing, trade barriers, and international cooperation as was the case of the standard textile industry.
- Skilling, Professional training, and education: Special funds are devoted to R&D in technical textiles to develop R&D ecosystems. Different engineering and master's programs are organized to focus on technical textiles.
- Machinery procurement: The manufacture of textile machinery in the country will prove beneficial to redress the entire value chain and fill existing gaps.
- The road ahead: Useful physical properties such as durability, elasticity, and versatility make technical textiles even more useful in times of changing climate, global warming, and complex industrial processes. The presence of large, global, and domestic players has influenced the growth in technical textiles and has helped build sector prominence

2.5.4 Textile 2024: American vision

The textile industry in North America is estimated to grow at a CAGR (Compound Annual Growth Rate) of 3.21% over the forecast period of 2019-2024. The US is a major market in the North American textile industry. The focuses are on the market dynamics, technological trends, and insights into various material, application, and process types. Moreover, it analyzes the major players and the competitive landscape in the North American textile industry. Five principal axes are planned for development as follows [Ljungkvist et al.2018]:

1) The market for technical textiles: The largest market for technical textiles is mainly non-woven fabrics.
2) Disposable and durable markets: The final consumer markets for non-woven textiles are the disposable and durable markets. The disposable end-use markets are made up of product categories, such as absorbent hygiene, wipes, filtration, medical and surgical, and protective apparel, while the durable end-use markets are comprised of geo-synthetics, home and office furnishings, transportation, building construction, and other durables.
3) Lighter and long-lasting non-woven fabric: Nonwoven is being used to make products lighter, more efficient, and cost-effective. They can be used in a variety of fields like packaging and autos.
4) Specialty and industrial fabrics: The specialty fabric business has continued to advance quickly. The base fabric is used in road construction, erosion control, and spoil containment in landfills. Automotive textiles represent the most valuable world market for industrial textiles.
5) Medical textiles: Medical textiles are one of the most significant fields in technical textiles. Nowadays, the medical textile industry aims to develop in terms of existing products and create new ones regarding new materials and innovative designs. These new products are being designed for less invasive surgical procedures, infection control, and accelerated healing.

2.5.5 Textile 2025: Swedish vision

Sweden plans to develop systems to improve statistics on the collection, reuse, and recycling of used textiles, and to follow up on amounts and quality levels of collected used textiles. They aim to provide economic support to collectors and/or sorters running transparent and environmentally appropriate operations, to enable increased collection and sorting capacity [Ljungkvist et al. 2018]. Automated sorting for recycling must be regional for getting sufficient volumes and economies of scale. Local reuse and remanufacturing have the potential to increase from current low levels if customers adopt more resource-efficient trends and lifestyles. Some export for reuse outside the EU would probably still happen. The waste are coming from municipal collectors, charity collectors, and retailer collectors. After automated recycling, this recycling contains mechanical recycling, chemical recycling, and waste incineration. To develop this value chain, it is necessary to remove the administrative barriers and utilize the regulation related to the collection, storage, and shipment of used textiles. Moreover, it is necessary to support fiber-to-fiber recycling of textiles by funding development and the establishment of automated textile sorting. This would create a market pull for recycled fibers and increase the economic viability of collecting non-reusable textiles. To summarize, the future of textiles in Swedish is developments in global used textile markets and implications for reuse and recycling.

2.5.6 Plan 2021-2025: China's vision

Recently, China National Textile and Apparel Council (CNTAC) released the 14th five-year plan for the textile industry. This plan details the development objectives, growth strategies, and priority tasks for China’s textile and apparel sector from 2021 to 2025. According to this plan, some trends are worth watching regarding the future of China’s textile and apparel industry [Lu,2021]:

1) China’s textile industry is facing more uncertainties regarding economic and non-economic factors.
2) “Growing bigger” in the textile industry will no longer be a priority for China. Their objective is to keep the actual capacity (50% of the world's market).
3) China aims to create a more sophisticated and high-tech-

driven textile, as well as a more value-added function in the supply chain.

4) Nowadays, the export market is deteriorating. Therefore, China plans to rely more heavily on its domestic market to support the textile and apparel industry's growth.
5) Going global overseas is still China's strategy in the textile and apparel industry through the "Belt and Road Initiative" strategy.
6) Toward a greener and more sustainable textile and apparel industry: their objective is to develop a sustainability-led growth model that focuses on a circular economy and creating new value-added products based on recycled material.

Regarding these trends, 12 indicators are defined to be developed. These indicators are including the annual growth rate of industry value-added, textile fiber manufacturing size, fiber end-use ratio, annual labor productivity growth, exports, R&D spending as a percentage of revenue, number of enterprises with more than $1.5 billion annual sale revenue, energy consumption per unit of industrial value-added, CO2 emission per unit of industrial value-added, water consumption per unit of industrial value-added, emission of major pollutants, manufacturing of recycled textile fiber, as well as newly mentioned buzzwords and areas like dual circulation, supply chain, technological innovation, etc. [Lu,2021].

Therefore, China's textile industry's strategic development is toward a technical, high-tech-driven, and eco-responsible textile taking account of recycling and the circular economy by continuing to be global and improve the domestic market simultaneously.

2.5.7 "France Relance": Vision 2020-2030

[France Relance, 2020] will mobilize nearly 35 billion euros for industry, in particular, to promote the relocation of several strategic sectors of activity. During this plan, France launched 37 industrial projects in the textile industry based on three main components including ecology, cohesion, and competitiveness. The main objectives of these projects are including Relocation, Digitalization of sites with the modernization of tools, Ultra-modern and eco-responsible building, Recruitment, Development of fibers, Expanding the workshops for online sales, Infinite recycling - the circular economy, Renewable and BioSource color, Increase in production capacity, Eco-design, Mass production through 3D printing.

In conclusion, different countries aim to develop their textile industry towards technical, intelligent, durable, standard, and knowledge-based textiles as well-made local textiles. To achieve these developments the focus must be on the workplace, the business model, the smart factory, and the standards and legislation. The relocation of textile production and the digitalization of the supply chain are plans for the world. Regarding the business model, countries are looking for a textile industry with an environmentally sustainable and regionalized format, customer-centricity, and respect for social and environmental responsibility, with a resilient supply chain. In addition, we see the need for collaborative platforms to optimize performances.

The smart factory is a major issue in the textile world, allowing internal coordination and networking, communication between machines improved by digital technology, and the use of artificial intelligence can contribute to process optimization.

Today, it is essential to comply with certain standards and legislation, such as standardized data throughout the value chain, common standards for all parameters of digitally coordinated production, and standards and legislation on vertical and horizontal links in intelligent textile production.

3 THE CHALLENGES AND ISSUES OF THE TEXTILE AND FASHION INDUSTRY

The emergence of industry 4.0 requires tackling different trends and challenges, including increasing product variety, shorter life cycles, shorter lot sizes, non-stable demand, more complex manufacturing tasks, network modernization, and intensification, as well as responsibility and sensibilization due to social and environmental aspects [Asadollahi-Yazdi et al. 2020]. Textile and garment industries like other industries must be agile and aware due to these trends and challenges coming from Industry 4.0 and digitalization.

The textile sector is therefore facing many environmental challenges that, if addressed comprehensively, will move the sector from a linear economy focused on production and sales to a circular economy concerned with its environmental impact. This impact will be not only on its production system with savings in water, chemicals, and waste but also on the recycling of products from consumers after the sale and from professionals (distributors, sellers) with unsold products.

Nowadays, five issues and challenges can be mentioned in the industrial world including Digitalization, Traceability, Automation, Decision support, automated decision-making, as well as Social and Environmental Responsibility (SER).

3.1 Digitalization

As mentioned by [Ganzalo et al. 2020] in McKinsey& Company "some apparel, fashion, and luxury companies will not survive the current crisis; others will emerge better positioned for the future. Much will depend on their digital and analytics capabilities." Digitalization is one of the current issues in the textile industry and companies must be aware of their digitalization capabilities.

This digitalization can be applied to the entire value chain of the textile industry. This digitalization will allow the implementation of efficient information systems based on a data acquisition network at all levels of the recycling process, from the recovery of products to their reuse, and at the different levels of decision-making. Figure 2 shows the different parts of the value chain in the apparel industry and a list of AI-based software for each one that helps digitalize the different stages of the value chain. The concept is the first part and incorporates research, briefing, mood boarding, and sketching.

The AI-based software related to this part includes trend forecasting and generative design. The second part of the value chain is the materials that concern the natural, manmade fibers and textile production like woven, knitted, etc. The AI, used at this stage, helps with both production and quality control. Robotics is used for manufacturing in the production phase, while in the logistics and distribution part that includes warehousing and inventory, domestic and export distribution,

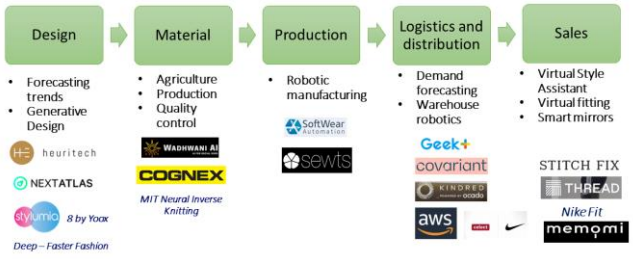

Figure 2. The efficient software in the textile and fashion industry

AI-based solutions incorporate supply chain robots as well as demand forecasting. Finally, the sales part concerns retail, which includes brick-and-mortar and e-commerce. AI is applied in different ways like virtual style assistants, virtual try-on, conversational commerce, as well as brick-and-mortar stores, with smart mirrors.

3.2 Traceability

The traceability of the textile product over its entire life cycle is an important point that allows the constitution of big data and then promotes their exploitation and improvement of the process. The knowledge of users would make it possible to refine and optimize the entire process from the design of the product to its reuse, passing through all the other stages such as its production, transport, storage, use, collection, sorting, and recycling. This traceability is difficult, especially with disassembly operations where each fraction must be identified.

3.3 Automation

The automation of recycling operations is associated with the understanding of flow management. The recovery flows are still processed manually or with very little automation. The workforce used for these operations is often poorly qualified and the operations are physically difficult, which leads to absences and sick leave. The recycling industry suffers from an image of being a very underdeveloped industry. This automation must be concentrated in priority on the operations of sorting, chemical, and mechanical recycling, and fiber preparation.

3.4 Decision-making tools

Analytics techniques allow the firm to reduce operational costs, increase agility, and transform reactive traditional supply chains into reactive supply chains. Analytics is defined by INFORMS as "the scientific process of transforming data into insight for making better decisions" [Gonzalo et al. 2020]. Data sources have increased and diversified. Indeed, new technologies such as radio-frequency identification (RFID), and industrial IoT enable the collection of production data, and technologies such as social media, and consumer and supplier data, enable to have customer insight. Analytics techniques can be categorized as descriptive, predictive, and prescriptive analytics [Davenport and Harris, 2017]:

1) Descriptive analytics relies on a large amount of data to identify the pattern and illustrate past behavior, to answer the question: "What has to happen?"
2) Predictive analytics aims at informing decision-makers by predicting future scenarios, it is summarized by the question: "What is going to happen?"
3) Prescriptive analytics aims at providing decision support and decision automation for the purpose to answer, "What should we do?"

Decision support systems have evolved thanks to new tools. As illustrated in Figure 3, first data analysis was considered as operational support for decision-making, then it was considered as an aid for decision-making, then decision-making was driven by data analysis and now it is possible to have automatic and real-time decision-making [Lueth et al. 2016]

3.5 Social and Environmental Responsibility (SER)

Nowadays, Social and Environmental Responsibility (SER) includes monitoring chemical substances and environmental emissions, circular economy, sustainable design, and recycling are all subjects and issues on which we are making progress. To encounter these issues, all the companies play a key role to optimize the life cycle of products put on the market, promote reuse, extend the life of products, improve collection (only 50% of packaging has a sorting deposit), integrating a minimum rate of recycled material in products, prefer a donation to destruction, no more throwing away, no more wasting. Moreover, it is also better to inform the consumer, to enable him to become an actor by making the right consumption choices, and adopting the right reflex [UIT - union des industries textile, 2021]. This concept can be

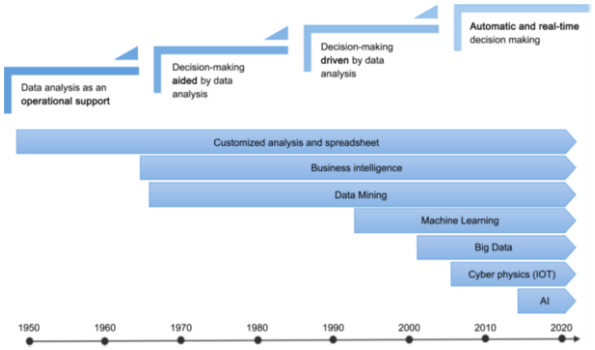

Figure 3. Decision support tools evolution

analyzed based on three visions including customers, company (industry), and civil society:

- Consumers are looking for greater transparency on environmental and societal aspects of the origin and delivery cycle of products. Consumers want the ability to choose and personalize their products, as well as a guarantee of reliability and speed of delivery.
- For the company, it is important to have intelligent management of resources to maximize production. It is also important to increase revenues and decrease production and transportation costs. It is also important to be able to adapt in case of disruption and ensure survival in the era of digital transformation.
- It is imperative to address the civil society that seeks to ensure socially responsible practices, create jobs, and increase the flows destined for the markets.

4 CONCLUSION

Nowadays, the textile industry like other industries aims to fulfill the industry 4.0 aspects and characteristics. This paper provides an overview and analysis of the textile industry in the industrial and research world. Today, textile, like other industries, encountered the current trends and challenges including digitalization, traceability, automation, and decision-making tools, as well as Social and Environmental Responsibility (SER). From the outcome of our investigation, it is possible to conclude that:

- Different countries provided developed their strategic plans to achieve a technical, intelligent, durable, standard, and knowledge-based textile, as well as locally made textiles.
- From the research that has been carried out, it can be concluded that further research will be required to provide the decision-making tools, as a current trend and necessity in the textile industry. These decision-making tools help enterprises to reduce operational costs, increase agility, and transform reactive traditional supply chains into reactive supply chains.
- Further study of the SER issue, as one of the main challenges for industries including textile, as the second pollutant industry of the world, is still required. It can be helpful to benefit from Industry 4.0 technologies to

consider the sustainable aspects and RSE factors in the textile industry. These technologies must be employed in terms of CO2 reduction, decarbonizing transport, taking into account social responsibility, and the second-hand market as well as recycling.

- Smart data is a factor that must be considered in the textile industry to achieve a digital transformation that facilitates the development of integrated and connected smart textile factories and platforms, intelligent digital decision-making tools, as well as flexible, modular, replicable, and scalable systems in textile 4.0.
- To be competitive in the textile world and remain economically viable, it is imperative to have a sustainable and resilient supply chain. Regarding sustainability, the consumption pattern has changed, and there is a strong demand for sustainable products. The customer tends to be a responsible consumer and the demand for customized products is growing. With the strong demand for guarantees on the origin of products, fair trade, and ecological and ethical guarantees of the product delivery cycle, supply chains must be more transparent. The supply chain needs to be resilient because of possible disruptions, as evidenced by the Covid-19 crisis or the increase in raw material prices and the increase in natural disasters. In addition, the diversification of sales channels makes the supply chain more and more complex. Therefore, further research into a sustainable and resilient supply chain in the textile industry is desirable.
- Regarding the business model, countries are looking for a textile industry with an environmentally sustainable and regionalized format, customer centricity, and respect for social and environmental responsibility, with a resilient supply chain.

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5 REFERENCES

Duarte, A. Y. S., Sanches, R. A., & Dedini, F. G. (2018). Assessment and technological forecasting in the textile industry: From first industrial revolution to the Industry 4.0. Strategic Design Research Journal, 11(3), 193.

Asadollahi-Yazdi, E., Couzon, P., Nguyen, N. Q., Ouazene, Y., & Yalaoui, F. (2020). Industry 4.0: Revolution or Evolution?. American Journal of Operations Research,

Bartodziej, C. J., & Bartodziej, C. J. (2017). The concept industry 4.0 (pp. 27-50). Springer Fachmedien Wiesbaden.

"ademe magazine n° 147 / juillet-aout 2021, la mode fait sa revolution," la librairie ademe.

McCormick, H., Cartwright, J., Perry, P., Barnes, L., Lynch, S., & Ball, G. (2014). Fashion retailing–past, present and future. Textile Progress, 46(3), 227-321.

Levy, D. L. (2005). Offshoring in the new global political economy. *Journal of Management Studies*, *42*(3), 685-693.

Chapagain, A. K., Hoekstra, A. Y., Savenije, H. H., & Gautam, R. (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological economics, 60(1), 186-203.

Marques, A. D., Marques, A., & Ferreira, F. (2020). Homo Sustentabilis: Circular economy and new business models in fashion industry. SN Applied Sciences, 2, 1-5.

Re_fashion - annual report 2020.

Rossi, E., Bertassini, A. C., dos Santos Ferreira, C., do Amaral, W. A. N., & Ometto, A. R. (2020). Circular economy indicators for organizations considering sustainability and business models: Plastic, textile and electro-electronic cases. Journal of Cleaner Production, 247, 119137.

Jia, F., Yin, S., Chen, L., & Chen, X. (2020). The circular economy in the textile and apparel industry: A systematic literature review. Journal of Cleaner Production, 259, 120728.

Leal Filho, W., Ellams, D., Han, S., Tyler, D., Boiten, V. J., Paço, A.. & Balogun, A. L. (2019). A review of the socio-economic advantages of textile recycling. Journal of cleaner production, 218, 10-20.

Jesson, J., Pocock, R., & Stone, I. (2014). Barriers to recycling: A review of evidence since 2008. The Waste & Resources Action Programme: Banbury, UK.

The european textile and clothing industry presents its strategy for the future," euratex, jun. 26, 2020.

Fromhold-Eisebith, M., Marschall, P., Peters, R., & Thomes, P. (2021). Torn between digitized future and context dependent past–How implementing 'Industry 4.0'production technologies could transform the German textile industry. Technological Forecasting and Social Change, 166, 120620.

Sharma. A, Mishika.N, and Remya.I, "technical textiles: the future of textiles," strategic investment research unit, invest india, august 2020.

Ljungkvist, H., Watson, D., & Elander, M. (2018). Developments in global markets for used textiles and implications for reuse and recycling. Mistra Future Fashion, IVL Swedish Environmental Research Institute PO Box, 210, 60.

Lu a. S, "outlook for china's textile and apparel industry (2021-2025)," fash455 global apparel & textile trade and sourcing, jun. 25, 2021. Https://shenglufashion.com/2021/06/25/outlook-for-chinas-textile-and-apparel-industry-2021-2025/ (accessed oct. 04, 2021).

France-Relance, "industrie textile habillement: point sur les projets soutenus par france relance 2020-21," mode in textile, jul. 12, 2021.

Gonzalo, A., Harreis, H., Altable, C. S., & Villepelet, C. (2020). Fashion's digital transformation: Now or never. McKinsey & Company.

Davenport, T., & Harris, J. (2017). Competing on analytics: Updated, with a new introduction: The new science of winning. Harvard Business Press.

Lueth, L., Patsioura, C., & Williams, D. (2016). The current state of data analytics usage in industrial companies. Industrial analytics, digital analytics association germany, 38-49 ;

Uit - union des industries textile, "loi relative à la lutte contre le gaspillage et à l'économie circulaire, l'essentiel tlc économie circulaire, textile d'habillement, linge de maison & chaussure." March2020.