TEX4.0

Enabling Industry 4.0 Skills in Textile SMEs

Smart Textiles & Fabrics

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1. Introduction

Textiles and fabrics have been an inextricable part of the human evolution. Initially, they were used to satisfy basic needs such as covering our body parts or keeping us warm and would be a domestic task for each individual. Gradually, human vanity led to their evolution from a necessity to an accessory and their production on a big scale became a reality. As societies grew and people began to develop different needs, textiles and fabrics became more sophisticated and grew in variety and the demand for a robust textile industry was vital.

Over the decades, the textile industry has evolved into a ginormous industry that has invested much time and money in the research, design, development and manufacturing of textiles and fabrics that respond to people's demands or needs. It became a global phenomenon and part of its tremendous success is owed to technological advancements in all aspects of the industry. These aspects refer to production, processing, manufacturing and distribution of products.

The textile industry is mainly divided into three categories:

a) Apparel (clothing, fashion design)

b) Home furnishings (think of bedding, linens, curtains etc.)

c) Industrial textiles (fabrics and textiles used in industries for cleaning, filtration etc.)

All three categories share similar characteristics and develop in a radical rhythm. From using raw materials and turning them into basic forms of fabrics such as wool or cotton yarn, the textile industry has evolved into something far more explicit and ready to cover every possible need. The latest development in the industry implicates the use of technology in the creation of textiles and fabrics that do more than cover our bodies or provide warmth and beauty. The so-called "Smart textiles and fabrics" are the latest trend in textile manufacturing and are set to become a necessity shortly.

1.1 Objectives

This course aims to explore the rapidly evolving field of smart textiles and fabrics, with a focus on basic elements; namely, the concept itself, their types, design principles, and their practical applications.

This course is designed to help learners:

- understand the core definition and significance of smart textiles and fabrics,
- explore the various types of smart textiles based on their features and capabilities,
- become familiar with basic design using smart textiles and fabrics,
- examine the practical use and applications of smart textiles
- be informed about the future trends related to the use of smart textiles and fabrics.

2. Overview of smart textiles and fabrics

2.1 Definition and characteristics

The term “smart textiles and fabrics” refers to the textiles and fabrics that consist of technological components with the ability to perform different wearer functions. In more detail, these functions include differentiation in temperature or colour (can heat or cool our bodies, can change their colour). Often called “electronic textiles” or “e-textiles”, they revolutionise how we think about fabrics.

These textiles are materials designed to interact with their environment or user. This is achieved by sensors, actuators and communication systems incorporated into their manufacturing that enable them to respond and adapt to external stimuli. Their key features include:

- **Responsiveness**: the way they react to external stimuli like temperature, body temperature, light etc.
- **Interactivity**: the way they interact with external factors and use this stimulation in combination with apps or devices to process and analyse data.
- **Integration**: the way they can be combined with modern technology (e.g. sensors, actuators) and from a simple traditional fabric/ textile become a smart textile/ fabric.
- **Functionality**: the purpose they serve apart from style and comfort (e.g. the applications they have in healthcare, sports, safety etc.).

Figure 1 - Source: freepik.com

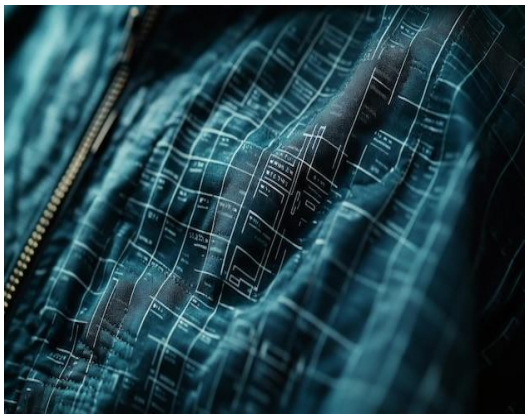


Figure 2 - Source: freepik.com

Smart textiles and fabrics are nowadays being used in almost all aspects of life such as:

- healthcare and medical applications
- sports and fitness
- military and defence
- fashion and entertainment
- sustainability and energy

and serve specific purposes that go way beyond fashion or comfort.

The next generations will probably be the main recipients of smart textiles and fabrics' technology and innovation but the advancements of today in the sector and their application seem to have captured people's interest. More and more manufacturers invest in the research and production of smart textiles and fabrics responding to consumers' demands for innovative solutions in fashion and home furnishing.

2.2 Historical evolution

Early fabrics were manmade from raw materials such as cotton, sisal, and jute. Their functionality was restricted to providing protection and comfort while there were limitations regarding their design. They would be dyed using natural ingredients like plants and the weaving techniques for their making were simple just like the tools used.

This lasted up to the 18th- 19th century when the textile revolution of the Industrial Age took place. The increasing demand for more intriguing designs in garments and textiles and the technological developments of the time led to the need for a mechanized, mass production of fabrics. Textile factories emerged and rapidly grew in numbers as a response to the never-ending demand for fashionable textiles and fabrics of an ever-growing population on a global scale. Additionally, sometime in the late 19th century the sector was introduced to new materials such as rayon and nylon which were artificially made and their use responded well to new needs that emerged due to World War II. More specifically, the strength, elasticity and resistance to mildew that nylon fabric offered was a great alternative to manmade fabrics such as silk and for a fraction of the cost of making. The military troops were able to fight in comfort. The invention of nylon transformed the chemical industry as it opened the way for scientists to engineer many other chemical products based on the manufacturing process of nylon and the research around its potential.

Sometime around the mid-20th century, more synthetic fabrics were developed (e.g. polyester, spandex). Once again, global circumstances led to the development and manufacturing of new textiles and fabrics. World War II had once again influenced the textile industry. New synthetic fibres were produced as a response to the armies' demand for clothing that was water-resistant and flame-retardant.

The emergence of smart textiles took place in 1980-1990. The world had progressed, the World Wars' effects had fainted and societies had already begun to become more focused on consuming goods years in. People now needed fabrics that could make their life comfortable and luxurious not just easy and bearable. Fabrics that provided UV protection or resistance to

moisture were introduced into the market. The first wearable electronics were embedded in fabrics (e.g. heated gloves and textiles that responded to the pressure or change of weight).

By 2000, smart textiles were something common and their applications had expanded to all aspects of life. Their applications expanded both in industrial and domestic use. They were able to sense and react to environmental stimuli, adapt to changes and provide comfort, satisfy complex needs and consumers' vanity all at the same time.

2.3 Current trends and industry insights

The evolution in textiles from a technological aspect has been notable. Advanced textiles are traditionally used fabrics that have been enriched with technology that encompasses five primary functions: sensors, data processing, actuators, storage and communication. The prime objective is to meet basic needs for comfort, durability and resilience in the context of sustainability and the promotion of a circular economy.

Current trends in the sector include:

a) *Promotion of sustainability*

The world's values shift towards fostering eco-friendly approaches in all aspects of life. In the textile industry, this is depicted by:

- The use of renewable energy sources in manufacturing.
- The use of eco-friendly materials such as organic cotton, hemp and wool.
- Adopting low environmental impact techniques for dyeing that minimise water and chemical use (e.g. digital printing)
- The production of fabrics that can be re-used and are themselves a product of recycling
- Turning to local sourcing of materials for production. This means less CO_2 emissions.

b) *Digitalization of the manufacturing process*

AI has infiltrated the sector and its applications are transformative and endless in certain cases. More specifically, digital technology has re-shaped the textile industry by:

- Introducing digital tools that enhance automatic manufacturing procedures and make them less labour-intensive or time-consuming.
- Allowing the production of textiles and fabrics that are customizable and on-demand.
- Providing stakeholders in the sector with the ability to track, evaluate and maximise the procedure of manufacturing and distribution (blockchain).
- Enhancing research in the field eventually leading to the development of new products.

c) *Highlight of traditional textile craftsmanship*

Even though textiles and fabrics manufacturing has sky-rocketed over the past decade and fast fashion has become an affordable consumer trend, there is a shift in people's thinking. More and more consumers seek apparel and textiles for domestic use that are hand-made and ethically sourced. This is a trend that is not convenient for the textile sector in terms of mass production or profit maximization. Regardless, a small proportion of the sector has embraced expertise in craftmanship and has moved on to the production of a limited series of textiles and fabrics made using traditional dyeing and weaving techniques. These pieces are considered high-end and are often very expensive.

d) *Production of fabrics with technological elements (smart textiles)*

AI and VR are part of our everyday lives now and the need for accessories and products that enhance their application is essential. Man-made and synthetic fibres are enriched with technology such as sensors or actuators that expand their potential and transform them into super textiles/ fabrics that can interact with the stimulation they receive from their surrounding environment. These textiles and fabrics can be used both in the domestic and industrial sectors. The trends in the sector point towards the direction of continuous technological development in textiles and methods used for their production. If the textile sector aims to keep up with the constantly changing world it ought to dedicate all efforts towards sustainability and embrace the circular economy model.

The "*EU Strategy for Sustainable and Circular Textiles*" was developed to help the sector work towards this direction. It implements the commitments of the European Green Deal (*The European Green Deal* 2020) the Circular Economy Action Plan (*Circular Economy Action Plan: The European Green Deal* 2020) and the European Industrial Strategy (*European Industrial Strategy*). The key objectives of these Actions focus on strengthening the textile sector and making it resilient to global shocks (e.g. wars, pandemics, natural disasters) while promoting its transition to "greener" techniques. These objectives will be achieved by the implementation of a sector-specific regulatory context for industries to adopt and use as a guide. This means that the textile sector will carry on with its progress but will minimise its environmental footprint by:

- Designing and producing textiles that are more durable and easy to recycle.
- Addressing the issue of waste management in the industry.
- Maximising the use of AI especially in the field of research, allowing innovative products and production methods to emerge.

In conclusion, the future for the textile sector seems bright as long as it manages to balance sustainability demands with consumer demands.

3. Classification of smart textiles and fabrics

Classifying smart textiles and fabrics is essential in many senses. First of all, it allows consumers to better understand their sourcing and application in everyday circumstances. Secondly, it makes it easier for manufacturers to communicate and enhances product design and development. Moreover, it is a great way for researchers to conduct extended research on specific types and maximise their potential. Last, but not least, it is a necessity when it comes to market analysis as it enables marketers to foresee future trends.

3.1 Broad categories

Smart textiles and fabrics are classified into three main categories based on their functionality:

A) Passive Smart Textiles

This category is the "primal" version of smart textiles. Such fabrics and textiles are characterised by their ability to detect and react to environmental conditions and do not require an external power source. As mentioned before such fabrics were introduced sometime around 1980-1990. Examples of this type of textiles are UV-protecting clothing, waterproof fabrics, anti-microbial fabrics, plasma-treated clothing (fabrics and textiles coated with a specialized layer that has varying characteristics like making the fabric/ textile more durable, water-resistant etc.) and conductive fibres (fibres capable of conducting electricity to ground).

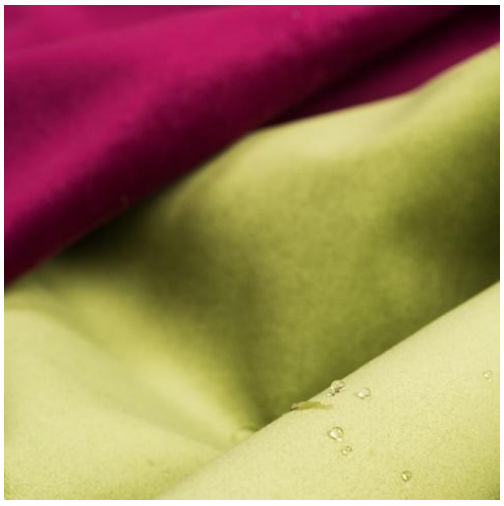


Figure 3 - Source: freepik.com

B) Active Smart Textiles

In contrast to the above category, active smart textiles are fabrics that can adapt to the wearer's changing conditions. They can respond to external stimuli via incorporated sensors, actuators and microcontrollers and perform various actions depending on the custom need each time. They can change colour, monitor physiological signs and adjust their thermal properties responding to environmental changes each time. Their applications and possibilities are still being explored by the sector's stakeholders but they are already being widely used in several sectors of daily life like healthcare, sports, and fashion.

C) Ultra-Smart Textiles

This category is the most advanced one in terms of technology. Ultra-smart textiles and fabrics, just like active smart fabrics, use sensors, actuators and microcontrollers but to a different

extent: they don't just react to changes in their environment. They use this technology to interact with the stimuli they receive by communicating and processing data. Although this category is not yet widely spread or affordable to the typical consumer, it has been a great assistance to certain areas of technological advancements. Think of NASA and the spacesuits that astronauts wear or high-end robotics where the use of wearable computers is becoming a necessity. As the world marks rapid progress towards a future that is characterised by technology, this smart textile category is expected to be the dominant one for the time to come.

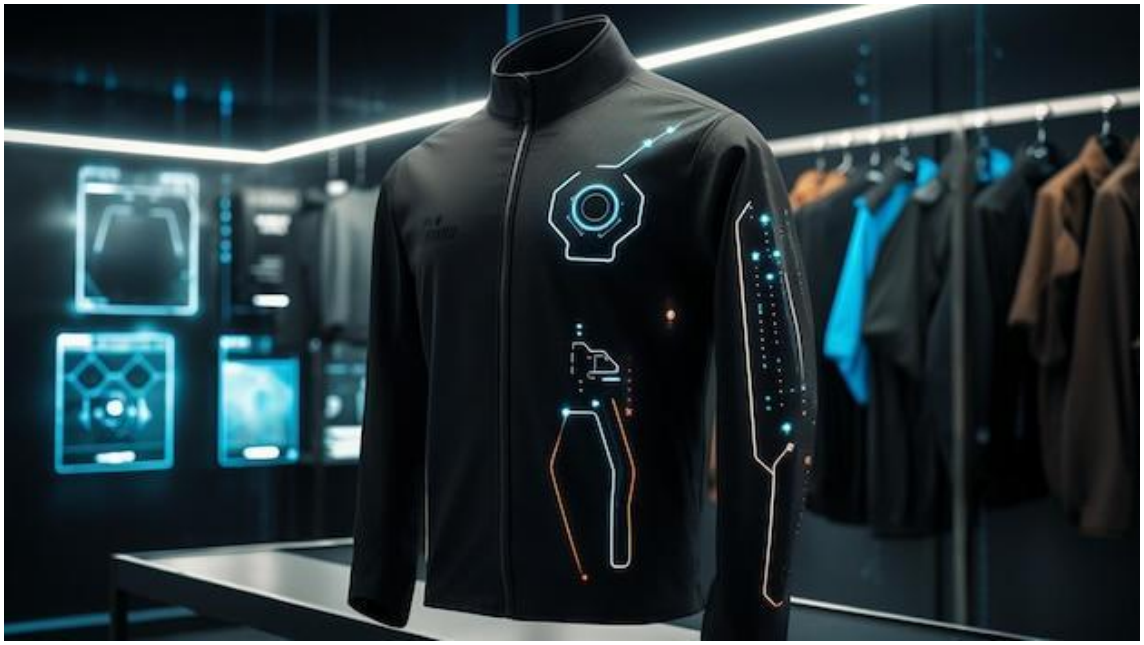


Figure 4 - Source: freepik.com

3.2 Materials used and characteristics

The ability of smart textiles to react and interact with external stimuli is what distinguishes them from ordinary fabrics. This is due to a variety of materials used in their making some of which are presented below.

MATERIALS USED IN SMART TEXTILES		
1.	CONDUCTIVE MATERIALS	
	METALS	Silver, gold, copper, aluminium
	POLYMERS	Polyaniline (PANI), Polypyrrole (PPy), Polythiopene derivate poly (3,4- ethylene dioxythiophene): Poly (styrene sulfonate) (PEDOT:PSS)
	CARBON- BASED	Graphene, carbon nanotube (CNT), carbon black (CB)

2.	THERMO- RESPONSIVE MATERIALS	
	SHAPE MEMORY ALLOYS (SMAs)	Nickel-titanium (NiTi), Copper-aluminium-nickel
	PHASE- CHANGE MATERIALS (PCMs)	Organic (paraffins, non-paraffins), Inorganic (salt hydrates, metallic alloys), Eutectic (combination of organic-inorganic)
3.	OPTICAL & LIGHT-RESPONSIVE MATERIALS	
	OPTICAL FIBERS	When integrated into fabrics they can illuminate or transmit light
	SLIM SOLAR PANELS	Solar power harvesters
4.	SENSORS	
	MOISTURE	Hydrogels, Hygroscopic polymers
	HUMIDITY	Conductive materials
5.	PIEZOELECTRIC MATERIALS	
	MECHANICAL STRESS/VIBRATIONS	Polyvinyl chloride (PVC)/Titanium Oxide (TiO_2)/Potassium carbonate (K_2CO_3)
6.	ELASTOMERIC MATERIALS	
	ELASTICITY/FLEXIBILITY	Natural rubber, polyurethane, polybutadiene, neoprene, silicone
7.	ANTIMICROBIALS	
	BIOCIDES	Silver nanoparticles, metallic salts, metal-organic complexes (e.g. zinc pyrithione)

The materials presented above serve different purposes when integrated into textiles depending on the need they need to fill. As mentioned earlier, the key features they transfuse to the textiles/ fabrics are responsiveness, interactivity, integration and functionality. Let's have a look now at the main characteristics that define them and how these serve the specific purpose they are being used for:

A) Flexibility

Flexibility or elasticity in the fabric means that the fibres can be stretched to a great extent without the fabric losing its original shape. Such textiles have a wide range of applications in everyday life from sports garments to industrial use.

B) Breathability

Breathability in fabrics refers to the fibre's ability to allow airflow and thus regulate moisture levels. This is also an extremely common category of smart textiles that have a broad spectrum of applications in everyday life.

C) Durability

The term “durability” in the textile sector refers to the fabric's ability to retain shape and performance when undergoing long-term usage and mechanical stress. The most common textile that fulfils these properties and is used almost by every human being on the planet is denim. Used for the first time in the 17th century, denim became popular rapidly and became the main workwear fabric choice for farmers, industrial workers and miners due to its durability.

D) Lightweight feeling

Especially for fashion textiles and fabrics, it is important that they feel lightweight on our bodies to ensure comfort. The materials integrated into smart textiles fulfil this expectation even though sometimes they can be very heavyweight when used for different purposes.

E) Washability

All fabrics, smart or traditional ones, must fulfil an important condition: to have the ability to retain their characteristics and functionality during regular cleaning cycles. This ensures that they remain hygienic.

When we manage to use these materials in a way that maximizes their characteristics, not only have we achieved the production of smart textiles and fabrics but we have ensured their longevity. In the long run, this is yet another way of promoting sustainability as it means that the same piece of fabric can be used for an extended period before we decide to acquire a new one. Less consumption means less production but this condition also means that the textile sector is being encouraged to work towards the production of sustainable fabrics in that sense.

3.3 Fabrication methods

Smart textile functionalities are being integrated into the final product by putting into use one of the following three methods:

a) By integrating some electronic or other technological, mechanical etc component to the original textile (e.g. sensors).

b) By integrating a component into the textile after fabrication.

c) By using a hybrid approach that involves both the above options.

In the first method, conductive textile yarns are incorporated into smart textiles by weaving, knitting, stitching, embroidery and lamination. The application that the smart textile is destined to have and the nature of the material being used plays a crucial role in the technique that will be chosen for the conductive textile yarn to be integrated into the smart textile. For example, sensors' properties can be maximized when they are incorporated into the textile as interconnecting lines.

The second method uses weaving and knitting. In the weaving process, weft and warp form a 2D textile allowing space for the conductive textile yarn to be integrated.

The third method is a combination of the two previous ones. The weaving process takes place, and the conductive material is integrated a the beginning or end of the process. Afterwards, electronic devices are incorporated into the textile that enables lines inside the textile to interconnect.

4. Key design principles with smart textiles and fabrics

Textile design involves combining knowledge and skills to create a fabric that responds well to its intended use and at the same time has an attractive interface (colours, patterns, shapes). In smart textiles and fabric design, the factor of integrating technology must be also considered. Smart textile and fabric design is a joint effort between specialists in the sector such as textile engineers, material scientists and IT and electronics engineers.

4.1 Interdisciplinary approach

When designing with smart textiles and fabrics an interdisciplinary approach is essential due to the complexity of the factors implicated: textiles, technological components, engineering skills and fulfilment of specific needs. The key elements to keep in mind are as follows.

Textile and material engineering

In-depth knowledge of the properties of the materials used and the way these can be used/combined successfully.

Technology engineering

Skills and knowledge of the way each material will be integrated into the fabric and specifically technological components such as sensors, actuators and electrical circuits.

Design

The end products that are made of smart textiles and fabrics must have a certain design that responds to the purpose it aims to satisfy. For example, in sports clothing, the design must provide comfort, flexibility in movement and breathability. Moreover, it needs to be appealing and pleasing to the eye, especially when we refer to fashion textiles.

Environmental science

The materials used and the manufacturing process when using smart textiles and fabrics must be in line with sustainability efforts and principles. This is essential not only in the sense of eco-friendly production but also from the aspect of the consumers' well-being.

As we can understand, when creating or using smart textiles there are different areas of expertise that need to work together to achieve the best results. By blending these perspectives textile designers manage to create fabrics that are characterised by innovation and functionality and address complex challenges.

4.2 Key design factors

Traditional textiles and fabrics share four basic elements in the design: fibre, structure, colour and decoration. When it comes to smart textiles and fabrics things are a little bit more complicated which is to be expected as the technology behind smart textile and fabric design is complex itself.

We have already made references to the key design factors in smart textiles but let's have a closer look at their properties:

Functionality*:* The smart fabric needs to serve the specific purpose it was intended for, the embedded technology must be integrated in a way that doesn't affect its performance or aesthetics and must continue to respond well to its intended purpose regardless of the diverse conditions it's being exposed to.

Interactivity: This term refers to the smart fabrics' ability to react or interact with external factors rapidly and in a way that doesn't affect the user. This ability is expected to have multiple applications and extensions rather than be static and of minimal functionality.

Comfort*:* The materials used should consist of three main characteristics: be flexible, breathable and lightweight.

Aesthetics**:** It applies to all areas of textile usage but holds an extra weight in fashion. The fabric's design must have the ability to please the eye and at the same time retain its functionality. If its design allows customization that's an extra bonus.

Durability: The textile needs to sustain hard use without losing any of its original properties. By hard use, we refer to longevity, resistance to environmental conditions exposure and washability.

***Sustainability*:** The materials used in the textiles and fabrics production should be recyclable, biodegradable and ethically sourced. In other words, they need to be eco-friendly. The manufacturing process must also be in line with sustainable practices and the end products be receptive to repairs, upcycling and recycling.

Health and safety: Smart textiles should be skin-friendly, safe in terms of electricity (short circuits, overheating, electrical leakage) and in line with personal data protection guidelines (specifically for their applications in the healthcare sector).

Cost-effectiveness: Smart textiles and fabrics can be very expensive due to the extended amount of research required for their production and the sophisticated components/ materials used. If textile sector stakeholders manage to balance innovation with cost-effectiveness then smart textiles will be accessible to a wider audience.

4.3 Challenges in design

As mentioned, smart fabric design is a complex procedure combining many different factors. As one would expect such a task comes with challenges. Following are some of the hurdles in smart textile design.

Material compatibility

Seamlessly integrating electronic components in textiles while maintaining their functionality is not easy. Certain mechanical and electronic materials used in textile and fabric design require careful consideration in manufacturing as they can be damaged or lose their utility if integrated in the wrong way or the wrong combination. For example, electric circuits must have the same flexibility as the textile they are being integrated into to prevent detachment or failure. Compatibility of the materials used in textile design refers to:

- Electronic/ Electrical components' compatibility
- Mechanical components' compatibility
- Thermal compatibility
- Chemical compatibility.

Complexity of fabrication

This refers to the difficulty of integrating a variety of processes, materials and techniques in textile design to achieve positive aesthetic outcomes without compromising functionality or performance. More specifically, the things to keep in mind are:

- Selection of the most suitable materials for the purpose
- In-depth knowledge and skills in handling advanced technology
- The balance between aesthetics and functionality
- Sustainability in the manufacturing process
- Cost-effectiveness.

Management of energy/ Sustainability

In a sector such as textile manufacturing that is constantly developing and growing in numbers and technological advancements, managing energy and producing within the frame of sustainability can be very challenging. The main obstacles in textile design in relation to energy management and sustainability are:

- Constraints in energy storage components: must be lightweight and flexible so that they can be integrated into the textiles easily without affecting their functionalities.
- Trouble in maximizing the use of eco-friendly energy materials: components that harvest solar, kinetic or wind energy can not produce sufficient amounts of power for high-end devices.
- Materials durability/ recyclability: materials and components used in textile design must be durable and wearable, they must allow textiles to last for a long time. This way their design can be sustainable. Moreover, the materials used should be bio-degradable, non-toxic and recyclable.

Mass production management

In the textile sector demand for goods is constantly growing. Sometimes, textile design sacrifices quality over quantity to satisfy this growing demand. Effective textile design calls for planning in mass production, the use of market trends and data, investment in technology, up-to-date machinery and upskilling of the sector's labour force skills.

Balance aesthetics with functionality

The complexity of the smart textiles' design often poses a hurdle to the stakeholders involved. The fabric's design must satisfy the wearer from the point of functionality and aesthetics. The electronic components should be integrated into the textile in a way that they are not visible but remain functional, the weaving of fabric must respond each time to the intended purpose and integrate all materials used effortlessly.

Cost-effectiveness

Materials used in smart textile design are often quite expensive and so is the manufacturing process as it requires extensive research and expert skilled workers. As a result, the end products are expensive which in some cases limits the audience they appeal to.

Interdisciplinary collaboration and communication

As mentioned before, smart textiles take place after several areas of the sector collaborate. Due to the complexity of the process and materials used this collaboration often seems to lack proper communication and thus becomes difficult and less effective than what one would expect and hope for.

Lack of regulation on smart textiles

The regulatory frame around smart textiles is not clear due to the fact that it uses technology and technology is always adapting and changing. Additionally, the sector has been rapidly growing over the last decades and there was not enough time for the regulatory bodies to respond and create the context in the boundaries of which the sector has to operate. Certain efforts have been made but there's still progress to be made on this.

5. Practical applications of smart textiles and fabrics

Smart textiles and fabrics offer non-conventional textile applications in many different sectors. Many other industries have benefited from the progress made in the textile sector, especially by the innovation that smart textiles offer. Their practical applications cover all aspects of human life as we know it. Following, are the main areas that smart textiles have contributed the greatest to.

5.1 Healthcare and medical applications

The healthcare sector has benefited to a great extent from smart textile design and the progress made in the textile sector in general. Some of the ways this took place are:

- Creation of fabrics that use sensors to monitor vital signs and are being used in everyday life (think of garments that can monitor blood pressure, body temperature, heart rate, respiration).
- Use of smart textiles in healthcare machines such as heart rate monitors in electrocardiography, blankets with incorporated sensors that monitor patient's body temperature etc.
- Design of smart textiles that have the ability to act as a means of therapy for the wearer. Think of garments designed for and used by people who suffer from arthritis or multiple sclerosis and can relieve pain by regulating body temperature or variation in compression.
- Invention of fabrics that can release doses of medication in a regulated way via nanofibers.

5.2 Sports and fitness

This sector has benefited from textile design to a whole new level. Active people have never had it easier in their fitness course. The use of smart fabrics in the production of athletic garments has taken sports apparel to the top. Nowadays, in the market, one can find sports and leisure clothing that offer:

- Body temperature regulation (dry-fit garments that allow the air to flow and regulate sweat discharge, heat gear that provides thermal insulation in extreme weather conditions).
- Tracking of performance (wearable technology such as smart watches, smart patches and clothing that monitor movement, burning of calories and heart rate to allow the wearer to evaluate their performance and athletic condition).
- Prevention of injuries by wearable textiles with integrated sensors and mechanical materials that use data sourcing to allow rapid risk management and prevent the wearer from getting hurt (think of posture, gait and support guards).

5.3 Fashion and entertainment

Smart fabrics have revolutionised fashion and entertainment to an extent that none could have predicted. Smart textiles in fashion clothing use all sorts of technology (nanotechnology, wireless sensors, polymer development) in materials and the manufacturing process (3D printing, AI in research and development, IoT) maximising functionality without compromising style. High-end fashion clothing that has been created with the use of smart fabrics is probably not affordable yet to all but there is a great number of fashionable garments created using smart textiles that even the average consumer can afford. Such examples are:

- Apparel with integrated LEDs (e.g. colour changing, changing of display).
- Touch-sensitive garments that allow interaction and data processing with smart devices (gloves that are being used with smartphones, VR wearables that maximise interaction).

Such advancements in fashion have an implicit effect on the entertainment industry. From grande shows where the main character of entertainment delivery wears colour-changing apparel to in-house leisure where the wearer is an average person wearing VR gloves and glasses and plays an online interactive game, the entertainment sector has developed to a great extent thanks to the progress marked in fashion due to smart textiles.

5.4 Military and defence

What we used to watch in futuristic movies in the past is now a reality thanks to smart textiles. The perfect soldier of today is the military man who is of course well- trained but his performance is outlined by the sense of safety and comfort he feels in his clothes. Smart textiles have led to the creation of more interactive military uniforms that provide the wearer with body temperature regulation, maximise their safety, allow them to collect data from the surrounding environment and react to the changes efficiently, allow them to collect data and use it for processing and thus contribute to research or development of military strategies. These functions are being achieved by sensors in military uniforms such as solar and energy-harvesting micro-panels, mechanical components and materials that act as bullet repellents and micro-sensors that process data and are interconnected to high-end computers for data sourcing and processing. All the above, offer an extended sense of safety and greatness to the military sector which enhances the desired effects that the textile sector is expected to have on it.

5.5 Sustainability

Smart textile design is in line with efforts for sustainability. In the market, one can find textiles that:

- Are capable of harvesting solar, kinetic and wind energy to generate power for their functionality. This is being achieved by micro-motor sensors, micro solar panels and air-flow design in weaving. Such technology in textiles has wide applications in the industrial sector where such fabrics have been incorporated into the manufacturing process, thus making it more sustainable.
- Use their properties for purifying energy sources such as air or water. This is being done with nano-filters embedded in the textiles. This type of smart fabric is being used in a variety of sectors whether we are referring to everyday life or industrial areas. Think of how much it can impact places on earth where hygiene is of a minimum level and water purification is essential for further development. It can be a simple piece of cloth with purifying properties or an advanced form of textile with integrated materials that can purify air or water on a larger scale (e.g. air filters in industries, water filters in the water supply system of a city).
- Are biodegradable, recyclable or made from recyclable materials. Synthetic fibres have an extended environmental impact but research in the textile sector has led to the discovery of ways that these can be reused or decomposed in an eco-friendly way.
- Have self-cleaning properties. The most common example of such smart textiles is the hydrophobic fabrics (or water-resistant/ repellent). Their ability to not absorb moisture

leads to them being less frequently washed and thus saving in energy consumption from the use of washing machines.

Moreover, the sustainability that occurs from smart textiles refers not only to the above properties but also to the advanced technology and methods used in their production, an effort achieved via continuous research in the sector.

6. The future of smart textiles and fabrics

The wide use of textiles and fabrics expands from the clothes we wear to the fabrics used in the production of goods needed on rare occasions (e.g. the wearable equipment used by astronauts). How would our life be if all the fabrics used in every aspect of life were smart textiles? Scientists and the majority of the people on Earth seem to believe that life would be easier, less complicated and more advanced in terms of technology. In the future, smart textiles will infiltrate fashion to an extent that the importance of a variation in designs and patterns will not be as great as the importance of functionality meaning that designers will focus on creating garments that act as a technologically advanced second skin on the human body.

6.1 Emerging innovations

The amount of time and money spent by textile stakeholders in research on the innovations of smart textiles and fabrics is expected to pay off in the future. More specifically, the sector hopes that in the years to come smart textiles will:

- Be used in everyday life by a wider range of consumers and help them regulate day-to-day activities (from monitoring their vital signs to using their technology towards more creative activities in their leisure time). It is happening already, but the cost of certain materials used in textile design makes it hard for the average consumer to possess high-end pieces of smart textile design.
- Be a source for re-discovering the abilities of the human body. Imagine people using hats with embedded mico-sensors that will interact with visual stimuli and allow the wearer to process data in a faster and more efficient way that will allow them to function on a higher level of mental abilities. Seems like a fiction movie but it is something that will eventually become reality as it seems to be a necessity due to the expansion of VR in more aspects of life.

- Be used in healthcare to an extensive degree via applications such as administrating microdoses of prescribed medication through wearable textiles or as a means for self-healing. People would no longer need to wear clothes with pockets which they would use to store for example an insulin shot. The future garments will have the technology to detect differentiation in insulin levels and automatically administrate the correct dosage to prevent seizures.
- Need minimum washing as they will have properties that will allow them to perform self-cleaning actions or at least repel moisture and dirt to an ultimate extent. As mentioned before, this is an excellent way to support sustainability.
- Need minimum repair as their durability will be increased. This will lead to long-term purchases and will probably battle the fast fashion trend that has emerged so radically over the last years. As a consequence, the money spent by consumers on clothing will be minimised in the long run and the amount of textile waste that ends up in the landfills will be reduced.
- Be manufactured using innovative technologies such as 3D printing. This technology already has applications in the textile sector but the convenience it provides and its endless limitations in design expect to feature it as a regular means of smart fabric production.

In response to the modern world's demand for innovations in the textile sector and the emerging use of smart fabrics several technologically advanced products have appeared.

Loomia Electronic Layer (LEL) is a flexible and thin circuit system that can be easily and seamlessly integrated into textiles by sewing, laminating or peeling and sticking on. Its flexibility and advanced electronic sensors enhance certain applications such as lighting, pressure sensing and more. This technology can be used in various sectors (robotics, production of electronic goods, healthcare, health and safety, entertainment, fashion etc).

Bolt Threads' Mylo is a bio-based leather alternative that provides textile softness and durability. It is an eco-friendly solution as it derives from mycelium (fungi's roots) and can grow in a matter of weeks compared to animal leather which takes years.

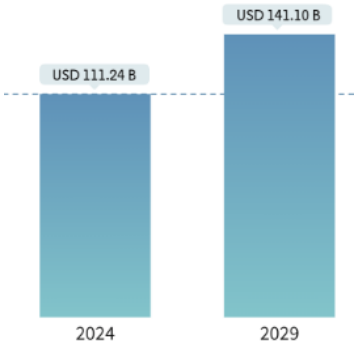
HeiQ Xreflex is a technology used in textile design that allows the creation of fabrics that are lighter, thinner and warmer at the same time. These textiles use graphene-based technology. This type of technology allows excellent heat retention and requires minimum insulation which means less volume of the garments used for protecting ourselves from cold weather. In the future, this technology will be used in more than just clothing and could lead to minimisation of energy use for heating.

Hexoskin Smart Textiles are the epitome of smart fabrics that use sensors to monitor vital signs. Their ability to perform more complex functions like processing and analysing the data they collect makes them a future necessity.

These are some of the emerging innovations in the textile sector specifically in regards to smart textiles and fabrics. As technology progresses in the blink of an eye, we need to always look out for new innovative solutions.

6.2 Market growth projections

The textile sector is the cornerstone of the manufacturing workforce in Europe. All data show robust growth in terms of profit, innovation and market expansion.



Study Period	2020-2029
Base Year for Estimation	2023
Market Size (2024)	USD 111.24 Billion
Market Size (2029)	USD 141.10 Billion
Market Size in USD Billion	4.87%

As shown in the above graphics and table, the EU textile market size (estimated in USD) is expected to grow by 4.87% in the period between 2024 and 2029. This growth is something expected if we think of the technological advancements and their incorporation into the manufacturing procedure within the sector.

The emphasis given by European textile stakeholders on research and development in combination with the integration of AI and IoT across the sector guarantees a rapid and steady growth of the textile market. The sectors that will see enhanced development in the use of smart textiles design are more likely to be healthcare, sports, fashion and military.

The increasing demand for smart textile solutions will lead to the development of technological innovations in the sector, as suggested in the previous sub-chapter.

The regulatory frame around smart textile design and manufacturing will allow the drastic expansion of the market always in line with sustainability measures adopted by the European nations. In the next sub-chapter, we will present you with the challenges that come with the textile market's growth.

6.3 Challenges and ethical considerations

Although the fact that the textile market will present growth in the future is undeniable based on the data provided, there are several challenges that it will have to overcome to allow a smooth expansion and development.

Sustainability challenges

The more the textile market grows the more energy will be required for manufacturing. This entails a high demand for energy sources and raw materials which will have to be harnessed in an eco-friendly way. This is automatically a new challenge as the technology required for sustainable methods of energy and material sourcing can be very expensive and time-consuming as extensive research is required. Moreover, in the face of environmentally- friendly market growth, the textile sector will have to minimize its waste management. Data shows that in Europe 82% of textile waste came from consumers and the rest from unsold textile products or wrongful applications in the manufacturing process.

Social Concerns

The fast-fashion phenomenon leads to the uncontrollable use of the labour workforce. Textile sector workers experience substandard working conditions, gender discrimination and violation of their labour rights by being forced to work long hours without getting paid sufficiently, being excluded from essential training that could up-skill them and experiencing low health and safety measures in their workplace. In addition, the automation of the manufacturing process using top-tier technology means that there is a growing reduction in the number of human workers within the sector. This leads progressively to faster rates of unemployment and consequently to an increasing deterioration of the gap between household incomes within the European population. In the long run, this leads to societal differences and possible turmoil in social stability.

Personal data concerns

Yes, technological progress is essential, and it can be very beneficial to the sector's growth. But what are the limits to it? Ethical concerns regarding technological use within the textile sector have been rising in direct progress to its development. Smart textiles incorporate materials that can source personal data. Is there a satisfactory regulatory context regarding the use of this data? People are concerned that personal information like medical conditions or their reactions to external stimuli can be subject to misuse by companies that incorporate e-textile technology in their fabrics. Specifically in the military and healthcare sectors, such data leakage could be extremely inconvenient or even dangerous.

Gaps in regulation

In relation to the previous challenge, there seem to be gaps in the regulatory framework of the textile sector. More specifically, there is no global framework available but what's more troubling is the fact that there is no defined accountability for failures resulting from misuse of technology in textiles. This translates to the existence of no legal framework in relation to who is responsible in the event of e-textile malfunction or misuse. Think of a scenario where an e-garment designed to monitor the vital signs of the wearer provides false data due to malfunction and causes a health issue. Who is responsible? The manufacturing company of the electronic component integrated into the textile or the textile company that took on its integration?

6.4 Potential for collaboration

The future of the smart textiles and fabrics sector is doubtful without effective communication among its stakeholders and external ones. Earlier, we presented the level of collaboration required across several sectors of the industry (researchers, designers, workers etc) for the design process to take place in an effective way. Let's have a look now at potential collaborations that can further promote the sector's market growth and development.

Partnerships with academic institutions

By reaching out to universities and academic institutions in general whose research focuses on sustainability, industrial applications, development of technologically advanced and eco-friendly manufacturing methods and innovations in the textile sector, there could be tremendous progress marked. Academic institutions have long experience in performing research which means that the textile sector researchers cut down their time consumed towards this direction in half and can focus on the application of the findings to the sector's needs.

Data exchange with competitors

Sometimes, innovation takes place in the most unexpected circumstances. Positive competition could be beneficial as by sharing experience and information amongst the sector's companies lots of new data and ideas can emerge. The competitiveness remains active as the way this data will be used by each is a challenge for each one of them to overcome and prevail.

Collaboration on an international level

The exchange of information, innovative technology and experience of the textile sector's procedures on an international level can be extremely beneficial to the sector as a whole. Different demographics, social, economic and environmental circumstances that populations in nations face depending on their geographical position on the planet can be a rich source of inspiration for future innovation. As Kofi Annan said, "Knowledge is power. Information is

liberating. Education is the premise of progress, in every society, in every family". This applies in our case too.

Partnerships with the public sector

This refers to the collaboration of the sector's stakeholders with public bodies in the direction of promoting innovation hubs and contributing to the development of the textile industry through grants and financing. This will accelerate the progress marked and will allow others to show further interest in the sector's development.

Collaboration with consumers

Due to the fact that consumers are the end-users of the textile sector's products, it only makes sense that their points of view should be taken into consideration. Usually, a form of collaboration between the industry's stakeholders and consumers takes place during the market research phase or when a new product is being launched. By sourcing data from consumers on a constant basis and by incorporating their points of view in a way that shows obvious respect towards the power of their opinions, the textile sector can ensure their loyalty and dedication. This is a principle embedded in the art of marketing and could be beneficial in the textile sector as well as any other industry.

7. Conclusion

The field of smart textiles and fabrics is a dynamic combination of different areas of expertise such as technology, design, elements of functionality and adaptation in changing circumstances. The historical course of textiles throughout the different periods of time in human history evolved the knowledge surrounding their manufacturing from basic to technologically advanced. From using textiles simply for modesty reasons (to cover our body parts), or the satisfaction of basic human needs (keep us warm), fabrics evolved into a luxury necessity and eventually nowadays into a combination of all the above. Textiles today are fashionable, leave room for customization, are functional and durable, can provide health and safety in a specific context and are due to become our second skin in the future- a smart second skin that will take on all challenges from external stimuli and respond to it effectively and fast. The components integrated into the textiles that convert them from traditional simple fabrics to e-textiles are various and include mechanical, electrical/ electronic, metallic and other types of material. They are distinguished into three main categories (passive smart, active smart and ultra-active smart textiles) and their production involves different methods of fabrication.

Smart textiles or e-textiles as they are often referred to, have applications in industries and all areas of daily life: fashion, sports and fitness, entertainment and leisure, healthcare, military and

defence. Their application in all these sectors comes along with a series of challenges that refer to cost-efficiency, sustainability, lack of proper technological expertise and lack of relevant regulatory framework.

Looking ahead, the future of the textile sector shines bright as the innovations taking place guarantee its further development. For this to happen though, the sector needs to overcome existing barriers related to social, economic and environmental challenges. Collaboration on different levels would be a tremendous help for the sector to overcome existing and future challenges.

Overall, the textile sector is characterised by rapid growth and has a substantially great potential to become a sector that grows in a sustainable, ethical and technologically advanced manner.

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