



Smart Fashion A Comprehensive Review of Smart Technologies and Their Applications

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ARTICLE INFO

Received:

April 16, 2026

Revised:

May 04, 2026

Accepted:

May 29, 2026

Available Online:

June 20, 2026

Keywords:

Smart textiles; Wearable technology; Artificial Intelligence (AI); Internet of Things (IoT); Nanotechnology; Flexible electronics; Sustainable fashion.

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ABSTRACT

Smart technology in the fashion world resulted in smart wearable textiles becoming a new addition to the traditional textile industry, which brings functional aesthetics by combining smart into fashion. This survey aims to publish the development and main advances of smart fashion focusing mainly on the key advanced materials, nano technology, Ai, IoT and flexible electronics which bring the revolution to the textile by turning it into a smart and interactive garment. Smart textiles can be used for healthcare (checking health in real-time), wearable fitness trackers or in the military and fashion which can monitor the environment or takes adaptive responses. The research investigates the influence of AI-influenced tools, 3D printing and technology communication systems (5G, edge computing) on the future innovations in smart fashion. The problems of high cost of production, scalability and privacy and sustainability requirements, while rapid innovation challenges remain in its way. This review discusses the role of novel materials to overcome these challenges, as well as energy-efficient techniques coupled with secure IoT infrastructures. With its potential to bridge the gap between innovation and mass-adoption and transform clothes into a medium for technology near-physiological collaboration in a more sustainable and intelligent manner.

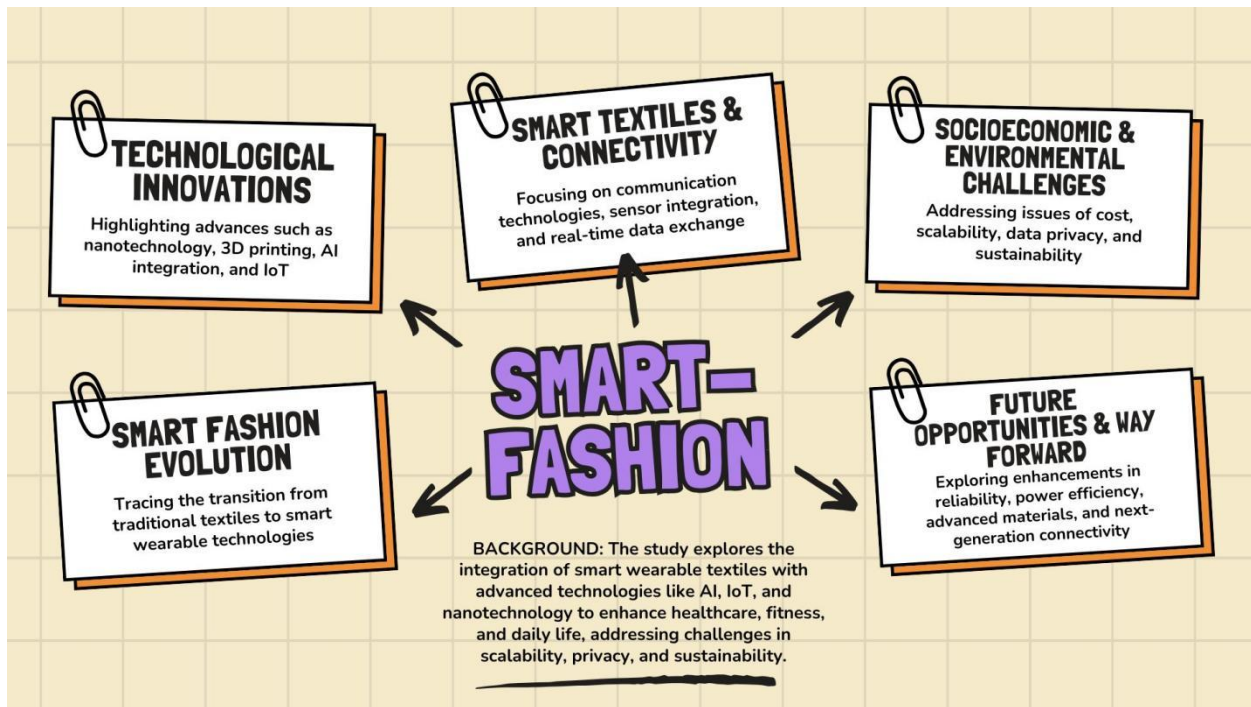


Figure 1: Overview of Smart Fashion

Introduction

It is investigated how the concept of “fashion” shall be reworked in the wearable textiles which are smart technologies and consequently in a new “breed” of “textiles and technologies” interaction and cause effect. It's accompanied by newly developed conductive fibres and nanotechnology, as well as new sensor and actuator technologies that allow health monitoring, sensing environment and adapting to user needs etc. A key enabler of this transformation is data exchange technologies and the Internet of Things (IoT) that allows exchanging real-time data, connective capabilities, applications, etc. Smart textiles are now at the forefront of health care, fitness and lifestyle requirements. The report describes the important characteristics of this process and in doing so, depicts IoT and wearable technologies in an interplay along the scope of endeavor as well as what it takes to integrate smart textiles into daily life. This present report tries to accomplish one interconnected image of the future possible challenges experienced by intelligent wearable textiles in a demonstration of design and innovation. The aim of the review is to provide overview of this unexplored field where traditional textiles evolved as smart and wearable technologies leading on one hand where we interfacing with advanced materials – focusing primarily on communication systems and IoT structures. Thus, an advancement in research work as to the fashion, technology and functionality that certain issues are discussed about this study is focused directly but widening knowledge about what motivates these changes and their use of data, such as health, fitness and lifestyle.

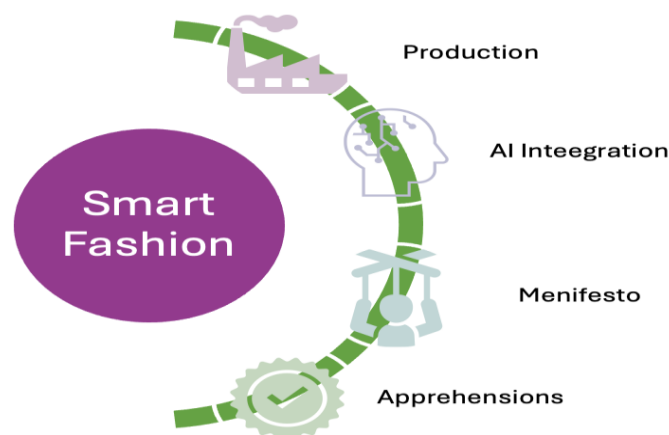


Figure 2: This paper Smart Fashion Review Domains

Contemporary Lifestyle trends – Historical Review of Fashion

The traditional textiles have experienced a fascinating development that reflects the cultural, historical and technological development of societies over time. These fabrics reflect the local customs, colors, and weaving methods, and are an integral part of the regional culture and heritage. Traditional textiles were woven by hand, using natural fibers such as cotton, wool, silk, and flax, which were shaped and designed by the resources available and the skills of the craftsmen. Over time, the exchange of ideas through trade, exploration and colonization led to the introduction of new materials and methods, such as the use of synthetic dyes and mechanized looms during the Industrial Revolution[1]. This was not an improvement in production efficiency, but it made testing and designing easier. Modernization may have come with novel solutions, but it is this very modernization that attempts to challenge the validity of practicing an Ishmirdyo and/or traditions. Today the discourses of revival and preservation of traditional textiles frequently focus on ecological sustainability, functionality and local stories[2].

Nanoparticles

Fashion changes have almost always depended on the changes in lifestyles, so in the past 50 years, advances in modern technology have greatly intertwined with those involved in technology [5]. Nanotechnology thus introduced over the last 50 years functionalities into textiles, which went beyond merely aesthetics. Textiles have been endowed with properties like UV protection, antibacterial resistance and self-cleaning because of the introduction of nanoparticles like silver and gold and zinc oxide. Besides, there are wearables that can harvest energy, a field that has just arrived in the world of smart textiles, fabrics that can be extended and even solar powered garments, which are, or rather are emerging, into being. They enhance comfort and durability, and reflect a growing trend toward multi-functional clothing that enables people to live active, technology-driven lives [2]. This is how the theories indicate that there's a new fashion era-one where the clothing expresses individual personalities and embarks on a journey of potentials in furthering technology [11]. Therefore, nanotechnologies have an important place in the fashion industry and fashion is becoming future-oriented. Thus, nanotechnology has a crucial role in the future of fashion, and fashion is becoming future oriented, as a medium of expression and an instrument of innovation [11].

Smart materials, sensors, conductive fibers, and combination of responsive materials have led to a transition in the textile industry to develop functional fabrics which are not only visually attractive but also mostly functional [11] & [12]. The market for functional wearable textiles has expanded rapidly due to increasing demand for health monitoring devices and growing prevalence of fitness or lifestyle products[12]. Industry statistics show that the world market of wearable technology will reach \$150 billion by 2027, a significant part of which is provided by wearable textiles.

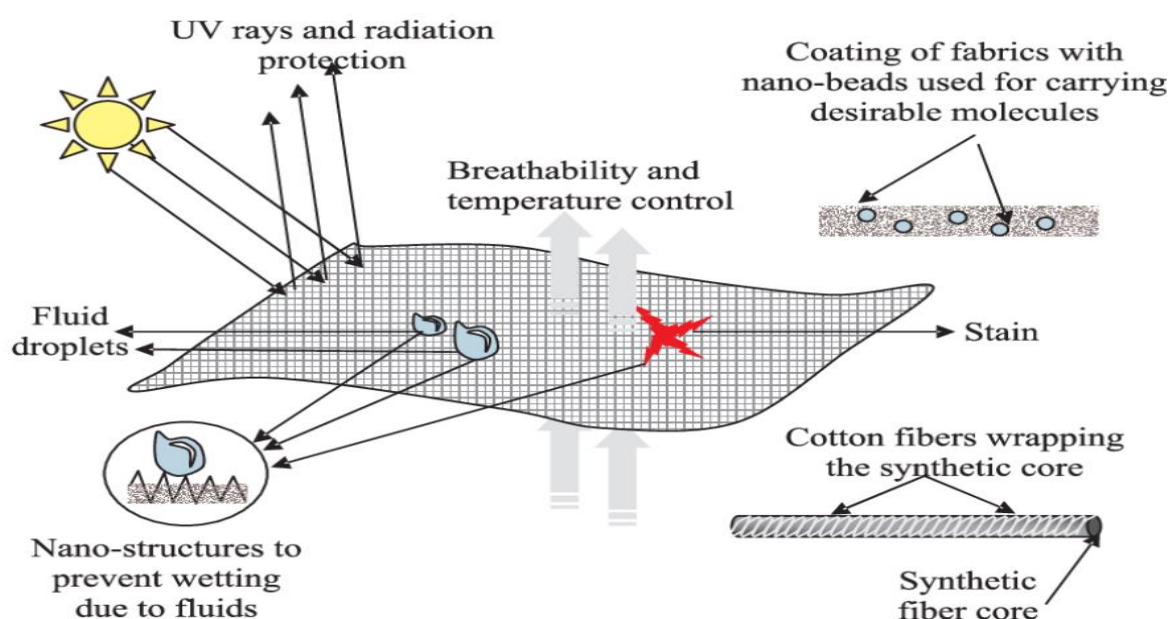


Figure 3: Nano-Clothing

Wearable textiles with functions have been applied to the fields of healthcare, sports, military and fashion. Wearable textiles with embedded biosensors in the healthcare sector track real-time vital sign signals, such as recording heart rate, body

temperature and level of oxygen for enhanced remote patient management[13]. In the sports arena, these fabrics can provide performance feedback to athletes enabling them to optimise and modify training programs while limiting the potential for injury. Beyond the military uses, ornamentations also play a significant role in how one can dress military uniform either for camouflage and whatnot, other reasons such as temperature regulation are also heavily exploited to create revenue even communication skills being potentially used[14]. Nanotechnology, flexible electronics and 3D-printing are the some of our emerging techniques/technologies. As another example, nanofibers[5] were used for lightweight and tough conductive and insulating fabrics. But the challenge for them is on the cost of production, durability and environmental impact of its plastic-based materials; Thus, others are working on green materials and others are optimizing the scalability of their manufacturing processes[15]. Functional wearable textiles are the offspring of style and utility that will therefore replumb the boundaries through fashion and technology. These textiles would be prepared to take on the demands of present-day society, from health monitoring to environmental sustainability, as these fields expand [16].

Smart Fashion's key milestones

The movement from traditional vogue to sensible fashion could be a key trailblazer of the move that is created by a lot of technological innovation and all-new shopper demands round-lapped. Traditional fashion was centered around beauty, culture, craftsmanship and natural fibres while mechanised production introduced by the Industrial Revolution enabled the mass production of textiles from synthetic materials that could be produced cheaply and quickly.

That evolution eventually resulted in the incorporation of electronics and smart materials into fabrics so-called smart fashion. Smart fashion is different from the ordinary clothing items since it creates a balance between appearance and functionality, such as health assessment, adjustable fitting, and interaction with the user-device [17]. The global smart textiles market is forecast to over USD 13.3 billion by 2027 at a CAGR of more than 31.4% from 2020 to 2027 [18].

These are primarily because of the progress in flexible electronics, growing interest in wearables (health monitoring devices) and AI technologies in fashion products. They are utilized in healthcare and sports industries as well as military purposes, where higher flexibility and lower weight of textiles make them unique for many applications such as monitoring athletic performance, supporting preventive care and developing uniforms that can regulate the body temperature or have stealth functions [19].

However, issues like e-waste, scaling and manufacturing costs are the drawbacks of the “smart fashion” industry. Future development of smart fashion technology in the context of nanotechnology, machine learning, etc., needs to be continued to further develop the technology and to allow for new applications.

3D printing in Smart Fashion

The combination of smart fabrics and 3D printing represents a major step towards the rethinking of clothing production, design and use. Many times, smart textiles with responsive materials to the environment are combined with 3D Printing technologies for creating futuristic and sustainable fashion. These breakthroughs have opened the door to the creation of remarkable and innovative clothing items that can change color based on temperature, maintain a specific temperature range, or even monitor health conditions. The smart textile market is projected to grow 31.4% CAGR to reach \$13.3 billion by 2027, according to a new study, which attributes this growth to wearable technology's rising application across various industries including healthcare, sports, and military. Meanwhile, the 3D printing market in the fashion industry has also seen a significant rise in value from \$1.5 billion in 2022 to an expected CAGR of 21.5% by 2030. 3D printing will enable precision manufacturing, reduce material waste and increase design flexibility (which will be especially useful in the fashion industry), and enable the designer to develop complex geometries that would not otherwise be possible by traditional manufacturing methods. As a result, for example, additive manufacturing methods have been employed to create garments and accessories with unique features to curb overproduction in the fast fashion industry and its associated negative impacts on the environment. Furthermore, it's the combination of additive manufacturing and the smart materials that pave the way to the developments such as self-healing fabrics and garments, capable of self-assembly or disassembly as needed by the user.

Although these developments have taken place there are still problems that need to be solved, such as the cost of smart materials, the limited scalability of 3D printing, and the environmental impact of non-biodegradable 3D printing materials in the filament. Scientists are working on sustainable solutions, including the use of biodegradable polymers and energy-efficient printing methods, to alleviate these concerns. This blend of smart materials and 3D printing technology not only represents a key turning point in the fashion industry's push towards sustainability but also opens the door to a new realm of customization and functionality, paving the way for a new chapter in wearable technology and fashion design[4].

Smart Fashion innovations with AI

Traditional fashion was distinguished by its manual approach in crafting and designing fashion, whereas the industrial era marked the beginning of mass production, thus making fashion across the globe. [5] The shift towards smart fashion, though, marks a shift towards the incorporation of AI-driven features such as virtual try-ons, which enable fashion synthesis, and personalized recommendations. As per the recent statistics, the global smart fashion market is expected to experience a compound annual growth rate of 28.5% and is projected to reach a value of \$13.6 billion by 2026 thanks to AI driven tool stick which is computer vision and deep learning have revolutionized the fashion industry by enabling hyper realistic virtual try-ons to help consumers visualize how fashion items will look on their digital avatars before making a purchase[6].

Another important part of this change is growing use of AI virtual fitting rooms, which not only reduce the number of physical fittings but also lower product returns. Another is generative adversarial networks scans, which brings the fashion synthesis process to the next level by creating innovative designs by mimicking fabric patterns and styles digitally. Another example of smart fashion is for clothing to be equipped with a sensor for health or fitness monitoring in the real world [2].

Despite such advances, more challenges remain – including the privacy implications of data collection, high development costs and environmental footprints of digital infrastructures for smart fashion technologies. Even with these advances, a range of concerns must be overcome – from data privacy issues surrounding the researching and collection processes to the environmental footprint that stems from the technologies needed to enable smart clothing and fashion, including technological adoption costs which researchers are working on through embedding principles of ethics and sustainable energy solutions in both technologies integrated into garments; and fabrics themselves.

Smart Fashion & Health

Traditional elements of fashion have been transformed into smart fashion, where the technological advancement and high customer expectations are all crucial factors, is one of these. Wearing specific clothes is a signifier for social stratification; craftsmanship and design had always been the main areas of focus from traditional fashion, industrialisation was only introduced mechanised processes making it easy to mass produce whilst globalisation permitted access to capital resources worldwide. One of the key thresholds in this shift is attire using wearable sensors for monitoring physiological parameters like heart rate, temperature and movement [31]. This implanted technology will be probably used in the field of sports, fitness and health to improve users' performance and also health.

The high public awareness coupled with any advancement in AI and Internet of Things (IoT) will be the tipping point. AI Tools (e. g., virtual fitting room, personalized fashion) changed the shopping experience through convenience and reduction in product returns [28] further hacking of recycled IP IoT garments which are wirelessly embedded giving a more intelligent relationship to the user where Integrated connectivity with mobile phones and devices provides another level of interactivity and functionality[32] As per accumulation from Statista, Smart clothing market will reach \$11.5 billion by end-2026 estimation wise globally wearable technologies are proliferating across industries at 30.4% CAGR in 2018–2026 period appraise [43].

However, data privacy dilemma a exceedingly excessive manufacturing rate and how do environmental sustainability still exist the bottleneck obstacles. scientists are investigating environmentally friendly and humane AI Applications, to overcome them. Art, science and utility with modern style, manufacturing and interacting with garments that never stops are traditional to smart fashion.

Smart fashion manifesto and implications

Smart clothing and Wearable Textiles Engaging both technology and high fashion with aesthetics in clothing materials also affecting functionalitydynamic interaction with the environmentsmart clothesmore info The futuristic textiles are material and electronic parts: filled with sophisticated sensors, actuators, conductive threads that give it everything from health monitoring to environmental sensing. Janette M Rani; et al, PhD thesis Copy Download Report. Smart fabric is a special type involving a net connection that can be broadly categorised into passive active or ultrasmart textiles[17] and it was published in *Advances in Smart Wearable Textiles* (2020).

passive textiles do have some functionality – basically heat retaining and UV protecting. Active by Textiles integrates functionality, including temperature control or biofeedback, through the inclusion of sensors and actuators. AI+IoT deployed ultra-smart textiles are adaptive autonomously to various environmental scenarios or physiologic needs of user with a little parcel of intelligence.

textile out of these has greater application w.r.t its uses like it catered to diversified applications [3]. For example, fitting of a wearable with biometric sensor scan provides accurate levels such as heart rate hydration level glucose level providing vital signs in real time [14]. The smart textiles market is therefore expanding rapidly, projected to exceed USD 5 bn (against progress in material science and miniaturized electronic components) between the end of 2018-2026 with growing consumer interest for wearable technology [31] sportswear incorporated with embedded motion sensors to assess posture movement improves athletic performance accordingly [12].

The advantages of smart fashion wearable textiles were followed up by addressing the challenges of durability, comfort washability and ethical data security on how to mitigate such challenges through numerous research endeavours for tackling sustainability and recyclability issues in smart textiles that are global environmental goals puts an amalgam between functionality and aesthetics discussing a way beyond conventional approach considering a futuristic idea about clothing styling for decorative propose mixed with day to day fine tuning life aspect from what it really means wearing clothes. Theme Updates per week.

Smart Wearable Textiles – Smart Fashion: It is a futuristic line of textile engineering & sensor technology. Smart materials comprise alternative electronic components—other than sensor actuator communication devices, embedded into the textile frameworks of materials—that allow for integrated purposes in the areas presented within this research article on smart textiles sensors. **Smart Textiles - Sensors.** All wearables provide at a real-time health monitoring of physiological and environmental parameters through advanced sensor systems to gather personal data that is going to be available to the wearer like cardiac frequency, hydration or stress indicators.

The results of Fiber Optic Sensors, piezoelectric materials and nanotechnology have revolutionised smart textiles, with precise measurements of strain, pressure and temperature are embedded within the clothes to provide lightweight flexible comfort; for instance wearable textiles possess capacitive and resistive sensors that plays a part in sport and healthcare systems concerning detecting human motion along With biological signals as well as temperature sensing fibres which modify the properties of clothing being worn based on its surroundings find great potential in enhancing energy efficiency also added with overall comfort levels.

Statistics show that with healthcare and sportswear applications driving growth, the global market of smart textiles is expected to exceed 30% CAGR in the next decade. The surge in acceptance is attributed to the advent of micro electronic components, low power communication module and increasing appeal towards consumers' want for wellness technologies.

On the other hand, durable washability and environmental sustainability aspects of smart fashion wearable textiles remain challenging for more researchers as biodegradable and energy harvesting materials have been explored to achieve compatibility with environment in terms of consumerism alongwith long durability across a range of applications; yet, the confluence of artificial intelligence (AI) and Internet-of-things (IoT) promises to afford unprecedented opportunities that will revolutionize human interactivity with technology in our daily lives.

The ability to sense and react to the needs of their users is the key contribution made by new inter-disciplinary technologies considered in an earlier chapter on smart textiles and wearables for flexible electronics, advanced polymers and smart materials; these have been produced into garments that enable health care, sports and daily life applications (see Chapter 3).

Tac, such as shape memory alloys and conductive polymers, which enables garments to respond to external stimuli (light, heat or moisture); (2) unknowns, such as piezoelectric fibers and triboelectric nanogenerators that harvest mechanical energy to generate electricity and have recently made it possible a self-powered system consisting of an energy harvester embedded in the jacket which charges a smartphone with kinetic energy from human movement.

These technologies are moving from promise to reality including the \$10 billion global market for smart textiles by 2025 as they have penetrated the military sector with adaptive camouflage and biological monitoring that are crucial in practice, intelligent coding approaches can increase their durability and functionality addressing wear and wash concerns.

Smart textiles are steadily integrating into the revolution of wearables and even more connected to machine learning and Internet of Things (IoT). Wearables will, thus continue to be an integral part of human-tech interface with smart enough connecting directly with grand smart ecosystems like real time data analytics, personalised user experiences, and so on.

Table 1: Overview of smart fashion technologies and its applications

Technology	Description	Application	Key Features
AI	Machine learning & Dee learning Algo	Virtual try-Ons, personalized recommendations.[9]	Data driven insights, enhanced design.[10]
IoT	Connectivity Through sensors and wireless networks[11]	Realtime health monitoring and smart home integration.[12]	Seamless data exchange and connectivity [8]
Nanotechnology	Use of nano particles to enhance fabric properties.[3]	UV protection, antibacterial textiles and energy harvesting. [13]	Enhanced functionality[14]
Flexible electronics	Integration of miniaturized electronics withing fabrics	Sensor-embedded clothing and wearable devices	Lightweight Adaptable Comfort-focused
3D printing	Additive manufacturing for customer textile production.[15]	Customized design and sustainable production.[16]	Precision and reduced material waste.[17]

Smart textiles communication technologies

Smart textiles are able to include communication technologies e.g. bluetooth, nfc & iot and eventually reprogram traditional fabrics so that they dynamically interact[33]. Such innovations have the fabrics communicating with IoT ecosystems[34] allowing them to function a variety of functions beyond health metrics monitoring; contactless payments. Bluetooth technology and smart textiles support seamless data transmission between devices over short distances enabling real time interactions like fitness tracking or medical monitoring FC with its high speed secure data exchange capability finds applications in authentication and payment systems embedded in textiles meanwhile IO T extends the sea capabilities by connecting smart textiles to broader networks allowing for advanced applications like remote diagnostics or predictive maintenance in industrial settings however the adoption of these technologies is constrained by several challenges including the complexity of integration power consumption and ensuring reliability and varied environmental conditions furthermore ensuring cyber security and addressing privacy concerns are crucial to prevent misuse or unauthorized access to the sensitive data generated by these textiles despite these hurdles advancements in low power electronics and flexible circuits suggest a promising future for smart textiles in sectors ranging from healthcare to fashion provided the ecosystem addresses scalability and interoperability across devices and platforms Badawi 2024 advancements in sensor technologies nanotechnologies embedded systems and wireless communication have greatly expanded the scope of smart textiles enabling them to monitor detect and respond to various stimuli these textiles incorporate phase change materials that enhance thermal regulation by absorbing storing Andre leasing heat is needed providing superior comfort during physical activity or fluctuating environmental conditions for example sportswear embedded with such materials adapts dynamically to the wearer's body temperature and activity level improving performance and comfort furthermore the integration of photochromic and thermochromic color and sats a functional and aesthetic dimension to textiles photochromic textiles respond to light intensity by changing color making them suitable for applications like UV protection or fashion while thermochromic materials alter their hue with temperature changes providing visual indicators of environmental or body heat levels these functionalities combined with the ability to incorporate sensors for activity monitoring health diagnostics and environmental sensing exemplify the transformative potential the smart textiles however challenges persist in scalability durability under repeated usage and energy management for embedded components which are critical for broader adoption in industries like healthcare sports and fashion overcoming these obstacles will rely on interdisciplinary collaboration to ensure these textiles deliver sustainable reliable and user-friendly solutions integrating communication technologies into smart textiles has led to the development of flexible textile based antennas that facilitate wireless data transmission these antennas crafted from conductive fibers or coatings enable seamless communication between the textile and external devices supporting applications such as health monitoring and activity tracking for instance graphene based soft wearable antennas have been explored for their potential in creating ecofriendly and sustainable communication interfaces within textiles Ibanez labia no at all 2020 additionally the incorporation of conductive materials into textiles has enabled the development of flexible and breathable E textile components including sensors energy harvesters batteries and antennas these components enhance the functionality of clothing and convenient and unobtrusive ways supporting applications ranging from fashion to healthcare do at all 2022 however challenges remain in ensuring the durability washability and user comfort of these integrated systems ongoing research focuses on developing materials and fabrication techniques that maintain the textiles inherent properties while providing reliable electronic functionality addressing these challenges is crucial for the widespread adoption of smart textiles in everyday applications.

Smart Textiles: Significance in everyday life

Technologies plus fashion equals smart clothes and smart textiles, where aesthetics and functionality are merging to create smart garments, where wearer and environment will have a dynamic interaction. The futuristic materials in these fabrics are rich in high-tech material and electronic components – sensors, actuators, conductive threads that give this fabric advanced functions in health monitoring, sensing environmental conditions, and so much more. (M. Rani; et al); PhD thesis. Published in the book called *Advances in Smart Wearable Textiles* (2020), smart fabric are broadly categorised as passive active and ultrasmart textiles [17].

Passive textiles provide a few functions: to retain heat, and to provide UV protection. Textiles make use of active by incorporating sensors and actuators which perform functionality like temperature control or biofeedback. ultra-smart textiles (AI+IoT) are adaptive autonomously to different environmental situations or physiologic needs of the user, with some level of intelligence.

The Potential of Wearable Textiles: one of these textiles has its significant uses as it were adapted for a wide range of applications including healthcare, sports defence and fashion, for instance, a smart textile with embedded motion sensors that monitor the athlete's vital signs in real-time, enhancing their overall athletic performance [12] thus, the market for smart textiles is expanding rapidly, with estimates placing its value over USD 5 bn by the end of 2026, driven by advancements in material science, miniaturized electronic components, and the growing consumer interest in wearable technology [31].

though smart fashion wearable textiles is a very huge opportunity challenges on how durable, comfort washable and ethically data secure needs to be addressed for this purpose researchers are trying to tackle the issues of sustainability and recyclability for smart textiles that are aligned with global environmental goals with a mix of smart fabric and usability smart wearable textiles are reconceiving what it means to wear clothes by leveraging a futuristic notion of clothing styling that serves for decoration and also fine tuning your life on a daily basis.

Wearable textiles are smart fashion, cutting edge technology of textile engineering and sensor technology. These smart materials are combinations of other electronic elements besides sensor actuator communication devices, embedded in the material fabrics that provide other functions according to the research article smart textiles sensors. Smart Textiles for Sensors. All wearables are equipped with advanced sensor systems that allow to track physiological and environmental parameters in real-time, and that make available to the users all the personal data related to health, such as heart rate, hydration levels or stress indicators.

Smart textiles that incorporate fiber optic sensors, piezoelectric materials and nanotechnology are now capable of measuring strain pressure and temperature, which has revolutionized the industry allowing for the precise measurements of body movement and vital signs; for example, capacitive and resistive sensors are being used in the sports and healthcare sectors to monitor body motion and vital signs and could be used in garments to change their thermal properties to suit the environment, making them more comfortable and energy efficient, and temperature sensing fibers for example could be used in garments to change in response to the environment[8].

According to statistical data, the smart textiles market is expected to increase more than 30% CAGR over the next 10 years, with the largest growth being in healthcare and sportswear. The increase in consumer demand for wearable technology, low-power communication modules and miniaturized electronic components are driving this growth.

As smart fashion wearable textiles evolve, they are set to transform how people interact with technology in their daily lives, particularly with the integration of AI and IoT, which allows these textiles to connect seamlessly with smart devices and cloud-driven systems, ensuring they serve their purpose beyond the fashion industry.

The integration of interdisciplinary technologies, as described in the introduction of this research chapter on smart textiles and wearables, further enriches the advancement of smart fashion wearable textiles, which are not only expected to monitor physiological parameters, but are also dynamic and responsive to the surrounding environment.

The use of shape memory alloys and conductive polymers, allowing garments to adapt to external stimuli like temperature, light or moisture, is one of the significant advancements in this area, while innovations such as the use of piezoelectric fibers and triboelectric nanogenerators for harvesting mechanical energy from the environment, such as for self-powered electronics like a jacket with embedded piezoelectric fibers to generate power from walking, highlight the practical applications and sustainability of these materials.

The statistics show a significant rise in research investment and industry investments in smart textiles, and the general expectations are for the market to reach \$10 billion by 2025, especially in sectors where adaptive camouflage and biometric

monitoring are essential, such as the military, the growth of such technologies has become more prevalent, and the development of intelligent coding techniques has made these textiles more durable and functional, tackling challenges like wear and wash.

As machine learning and IoT frameworks are taking part in wearable technology, smart textiles is an irreplaceable component of this revolution. Smart enough to connect directly to the grand smart ecosystems, like real-time data analytics and personalised user experience, for instance, will make it wearable electronics an integral part of human-technology interaction in the future.

Table 2: Overview of smart fashion technologies and its applications

Technology	Description	Application	Key Features
AI	Machine learning & Deep learning Algo	Virtual try-Ons, personalized recommendations.[9]	Data driven insights, enhanced design.[10]
IoT	Connectivity Through sensors and wireless networks[11]	Realtime health monitoring and smart home integration.[12]	Seamless data exchange and connectivity [8]
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Sensors can be embedded in fabrics that provide feedback on a physiological parameter such as hydration, body temperature, and muscle performance in real-time, which helps to optimize athlete performance and reduce the risk of injury [38], while other textiles are engineered to actively regulate the body temperature by varying the porosity or phase change [39]. Comfort for high performance sporting activities you can see stuffs that have properties such as self-cleaning and odor reducing fit into lifestyle[18]! In terms of lifestyle, smart textiles are used for most of their benefits in clothing and accessories that directly enhance personal comfort and usefulness, like smart clothes that offer built-in thermal regulation for easy change of seasons [41]. Their innovations in textiles are now no longer restricted to the tv years and have been expanded to incorporate clever applications, like self-healing fabrics and colour-changing garments, which they add durability and personalisation to, taking the significance of wearables to an ever-increasing level in daily attire [19]. Smart textiles represent a crucial innovation for a sustainable, modern lifestyle, with the advent of renewable energy technologies such as wearable solar textiles, which also bring renewable energy into everyday life[3].

Smart textiles communication technologies

Smart textiles are made with embedded communication devices (Bluetooth, NFC and IoT) that enable traditional textiles to communicate directly with digital devices and networks [33]. As per the purpose from health monitoring[31], textiles have now extended their purpose to fitness tracking, medical monitoring, authentication, contactless payment and remote diagnostics and industrial maintenance [34].

Bluetooth is mainly used for short-range real-time data transfer between textiles and devices while NFC, which was introduced specifically to enable secure over-the-air communication in payment and identification systems at the area of two behind close objects. Smart textiles are complemented by IoT because they can be part of wide networks that allow a complex structure for data gathering aimed at deep analyses. But these barriers include integration difficulty, power consumption, durability and reliability issues, security and privacy risks, interoperability problems.

Recently, these abilities have been further improved due to the progress of sensing, nanotechnology, embedded systems and wireless communications (Badawi, 2024). Phase change fabrics are textile materials that absorb, store and release heat for thermal regulation to create better comfort in human movement. Photochromic and thermochromic materials that change color in response to light as well as temperature add even more value.

Flexible textile-based antennas require conductive fibers or coatings; this need is fueled by the rapid growth of communication-enabled smart textiles. Multifunctionality is achieved through wearable antennas and breathable e-textile

components based on graphene, sensors, batteries harvesters (Wang et al. 2019), and antennas enabling applications in the fields of healthcare, sportswear and fashion clothes industrial (Ibañez-Labiano et al., 2020; Do et al. However, there are significant challenges to mass adoption due to issues with washability, comfort, energy use and durability in the long-term.

The implications of smart textiles for market dynamics and customer behavior will be explored. The impacts of smart textiles on the market dynamics and customer behavior will be addressed.

This schema demonstrates the opposing concepts of fast and slow fashion, luxury brand and mass production, new and novel design or the constantly-changing design movement [16]. The mass production of fast-fashion clothes has also low price point and easy access and nature (trend) which appealed to the consumers, but some consumers become conscious about the negative environment side effects of fast fashion [10].

The consumer decision-making comprises need recognition, information search, pre-purchase evaluation, purchase and postpurchase evaluations. This process, however, is influenced by psychological aspects (self-expressiveness) and marketing (influencer marketing, lifestyle brands, digital engagement and personalisation through AI) [20]. Studies reveal more than 70 percent of consumers engage with brands online before a purchase [20] and AI tools are able to increase customer retention by almost 30% [21].

At the same time, conscious consumption is growing and among Millennials and Gen Z, who are more demanding than ever in terms of transparency and sustainability. While as many as 63% of all global shoppers are willing to pay more for sustainable products, the example of brands such as Patagonia's 'Don't Buy This Jacket' shows how ethical brands, authentic stories and good production can improve brand loyalty [4, 23]. Likewise, brands have begun experimenting with the use of AI, AR/VR and other digital elements to personalize the overall shopping experience and improve engagement [9].

The fashion marketing and consumer behavior have been transformed by a strong influence of digital. Social media, mobile marketing, smartphones, wearables and IoT is changing the way consumers interact with brands [23]. The Gen Z consumers are active users of Instagram, Facebook, and YouTube to actively engage with fashion brands and the shopping experience is enhanced through the use of QR codes, geolocation, and smart mirrors in particular [24].

The main criteria that contribute to fast fashion are speed, low cost, design based on the trend and constant availability [25]. On the other hand, slow fashion is the opposite that emphasizes sustainability, a local resource, transparency, timeless pieces (lasting design) and ethical production [27]. Digital touchpoints in the fashion marketing mix are increasingly influencing consumers' decisions, as seen with brands such as Zara and H&M who use technology to constantly capture the consumer's interest, through promotions, new product/collection releases and social contacts.

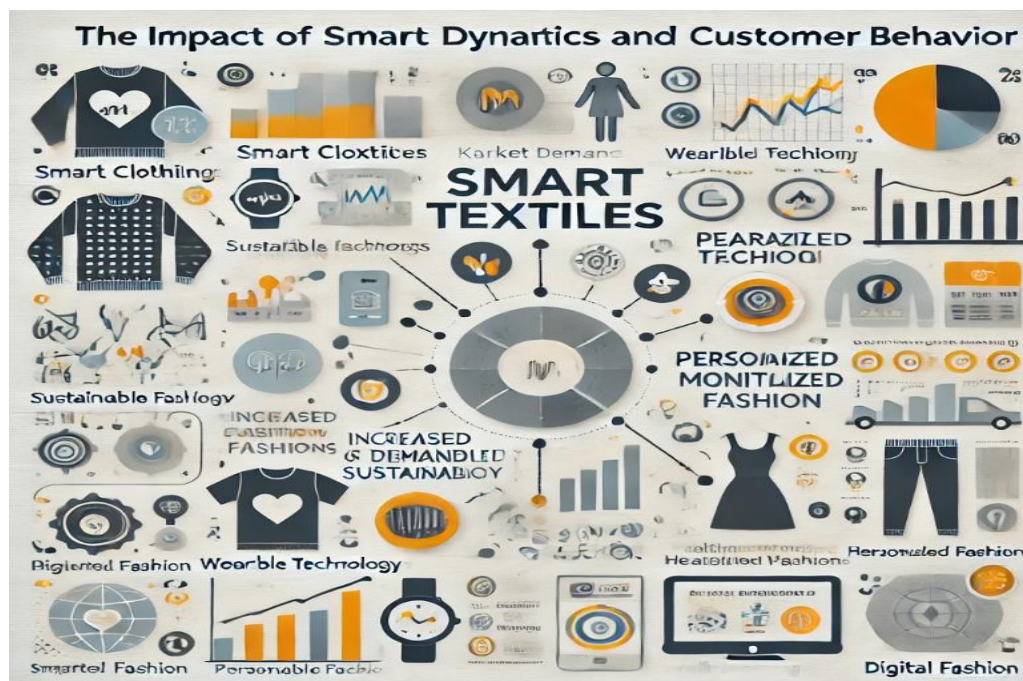


Figure 4: Smart Fashion & Consumers Behaviors

It can be concluded by some researchers though that emotional, authenticity based interactive campaigns succeeds more in altering purchasing behaviour. For instance, campaigns that offer virtual reality or collaboration with influencers as campaigns can resonate with younger consumers who are more interested in experiences than and not only transactions. While on the other hand, the higher level numbers of relevance like subjection from excessive industrialization and decline in high quality grade merchandise can disprove belief as a result of 24% respondents resist heavy branded inputs or low level campaigns that fail to encourage them[29]. Hence the challenge is to balance between innovate marketing[51] and actual substance; providing real authentic experiences that match up to shifting consumer preference? The high-tech innovation and sustainability synergy will be necessary to the fashion industry for overcoming contemporary obstacles[30].

Smart fashion's socioeconomic challenges and concerns

Barriers related to accessibility and cost

The cost and accessibility for smart clothing integration to mainstream fashion is limited [9]. One of the primary concerns cited with affording is a problem for designers and consumers. The high cost is often due to the price of the raw materials and advanced manufacturing processes required to manufacture state-of-the-art garments, such as sensors, batteries and flexible electronics, which make these garments essentially use unavailable, as pointed out by one of the studies, which highlighted the cost-to-consumer barriers, the gap between the cost and the consumer expectations [31].

Further barriers to low cost production include the labour complexity required to embed electronics into textiles in a way that is both low cost and durable in terms of functionality, and looks great[32]; the novelty of these garments will also be perceived as experimental and adds to the high price tag as economies of scale are yet to be reached for affordable smart clothing[33].

These cost concerns or accessibility problems, combined with consumers' lack of awareness and knowledge of the potential benefits of smart clothing, reduce consumers' willingness to invest in the clothes[34]. many consumers have never used or even encountered smart clothing, which effects their willingness to invest in the clothes. There is recognition by designers of missing consumer needs for affordability, usability and integration into everyday life that have been identified as factors that have hindered broad acceptance and accessibility [31][23].

To further complicate matters, the industry is also grappling with the challenge of taking the technical performance into account while keeping the garments and their aesthetics functional and affordable[35]. until this balance can be achieved the fashion industry will continue to be restricted in terms of reaching scale with smart clothing, despite its efforts to develop multifunctional garments[14].

IoT concerns related to privacy and security issues in textiles

The ability of smart textiles to measure various physiological data, communicate wirelessly, and connect to cloud systems also presents substantial challenges in terms of privacy and security. this is because such textiles can record a multitude of sensitive information, such as physiological measurements, location and user behavior, making them susceptible to data breaches, unauthorized access, and misuse of personal information[37].

Over-the-top infrastructure also refers to a critical issue with smart textiles: the lack of adequate encryption and communication systems. For example, since IoT devices are often deployed in a distributed fashion, where the data—for example using BLE and other wireless protocols common in smart textiles—can be intercepted and tampered before it reaches its destination they become vulnerable to man-in-the-middle (MITM) of might attacks[38]. In addition, high deployment of cloud-based systems also puts security features at risk since attackers have a higher chance of exploiting the vulnerability spectra associated with cloud-based infrastructure[39].

However, if such a last if corrected measure is not taken, monitoring health data in real time (from smart textiles to healthcare systems) can be misused. Moreover, the user has no authority over what data are being gathered from him and for what purpose it is shared, which just mitigates aspects of consent and transparency in usage of data.

To address these challenges, the fashion industry needs to implement advanced security measures such as blockchain for authentication, sophisticated encryption methods, and secure IoT solutions. For example, blockchain can help maintain the integrity of data and offer transparency and security so that critical information can only be accessed by the appropriate users. Furthermore, from a consumer POV, even more user-centred privacy policies implemented and regulations such as GDPR respected can foster trust in the use of smart textiles. Last but not least, being mindful of privacy and security is essential to the success of IoT in textiles. Without this consideration, its potential uses in fashion and lifestyle will always be

limited. Collaborative efforts of designers manufacturers and cybersecurity specialists are urgently needed to create a safe and privacy protecting ecosystem for smart fashion.

Calculate the cost of waste and recycling

The textile and fashion industry is one of the biggest and most polluting industries in the world, responsible for eight to 10% of the global carbon emissions and consuming around 79 1,000,000 liters of water annually, it contributes to 35% of microplastic pollution and produces more than 92 million tons of textile waste a year, there is a need to have sustainable practices in the fashion sector.

Textile recycling is part of the steps that can help achieve the goal of sustainability by reusing the material in new products, which are pre and post-consumer processes in the textile waste. For example, technologies such as intelligent sorting stations and data-driven ecosystems have been suggested to increase transparency and deficiency and the recycling of these solutions requires the use of standardized data formats like the circularity ID's, as the information regarding the product comes in detail, including material composition, dye processes and recycling instructions[10].

Moreover, the collaboration of stakeholders in a CE ecosystem has an important role to play with respect to sustainability, for instance, through the use of data-driven approaches that can help optimize the use of resources, and the development of sustainable business models: for example, the implementation of blockchain technology in the supply chain for greater transparency and tracking of materials from the production to the recycling processes[43]. Similarly, using digital technologies such as artificial intelligence and spectroscopy is being explored to find new materials and enhance recycling processes.



Figure 5: Smart Fashion and Environment Sustainability

However, not all of this new trading is smooth sailing as there are several hurdles to be overcome, including the high costs of implementing it, non-standardisation and lack of consumer knowledge about the options are available. This will require multi-level action by policy makers, industry and consumers to put sustainability at the heart of policy, innovation and behavioural change [64]. Dynamic recycling education and repair initiatives are another solution to transition Toward Circular Fashion, through providing education and new incentives for a more sustainable way of consumption.

Smart Fashion and moral data usage implications

The use of data in iot-Enabled textiles and fashion platforms bring critical ethical questions of privacy consent, and transparency [65], [66]. Consumers generally do not know how their data like usage patterns and preferences is collected shared or used (for advertising)[67], [68] Ouch smaller computers often have no serious security to make breaches easier

but bigger platforms have also of course become the subject of ridicule for the data they appropriate [69]. The Event also including biased algorithms needed for requiring to rectify these problems would need consents that are not skewed or accurate and regulatory minded like GDPR, and this will be a sort of consumer education for trust in fashion systems based on data.[27], [43], [44].

Table 3: Challenges and Future prospects in smart fashions.

Challenge	Description	Proposed solutions/opportunities
High production cost	Expensive raw materials and complex manufacturing processes [45]	Economic of scale material innovations governmental incentives [29]
Scalability	Difficulties in transition from prototype to mass production [46]	Standardized process. advanced manufacturing techniques.[35]
Privacy concerns	Vulnerabilities in data security for iot enabled garments [11]	Secure iot framework robust encryption[47] blockchain integration[48]
Integration and usability	Balancing advanced functionality with comfort and aesthetics. [49]	User centered design Self healing[50] Adaptive materials

Opportunities of Advancement in Smart Fashion: Way forward

Improving smart fashion's reliability and usability

Smart clothes are often washed in the smartest ways and subjected to a stretch and abrasion during handling after which the clothes are brittle because the electronic components (eg sensors, conductive threads) are broken. Comfort: Proper fit and user friendly interfaces must be ensured especially for garments used in extreme environments or situations such as sports use and health innovations (12), and flexible batteries conductive inks as well as self-healing materials are used to address these issues using a user centred design process with a focus on feedback [72]. Others, including flexible batteries, conductive inks, and self-healing materials to address these problems and user-centered design paradigms to incorporate feedback [91] are also proposed. Scalability at low cost and interpretability of textiles with electronics are still barriers though which need further research and development to be enabled[46].

Improving of Smart fashion Power efficiency

Smart Fashion – power consumption is an important consideration, as the energy consumed by the embedded sensors/processors [34]. for flexible batteries energy harvesting textiles that are flexible solar panels Piezoelectric materials and extreme-low-power microprocessors despite the fact that they have solved these problems so far. [51]. The garments power generation capabilities can be further enhanced with energy harvesting techniques, in which the fabrics harness sunlight motion or temperature differentials to obtain energy [52]. Scaling these technologies and making them affordable, compact and long lasting, however, is still an important challenge that needs to be explored further.

Data security and consumer protection policies

The industry standards for consumer privacy and data security, such as encryption methods, secure communication protocols and regular audits, can help prevent data breaches and unauthorized access, promoting trust in smart textile technologies[55]. consumer awareness and compliance with these regulations are essential for establishing trust in smart textile technologies[56].

From innovation to mass adoption

In the smart fashion context – new technologies, pooling of actors, policies and researchers could contribute to widening better access to and more consumer trust in smart textiles [58] [59] [60]. These can be lowered by offering subsidies and incentives, and by standardizing manufacturing processes, it can be enhanced, respectively, for smart textiles [61]. Educating stakeholders on the benefits of using smart textiles, e.g., on the functionality and the sustainability, appears to be a more consensual task via draft campaigns [62].

AI and machine learning integration

In the last decade, the fashion industry witnessed several developments, especially in the field of artificial intelligence and machine learning, which has significantly contributed to the operational efficiency, customer experience, and data-driven insights. The industry has come a long way in improving the precision of different tasks like feature extraction, classification, detection, virtual try-on, and garment 3D modeling, with some methods reaching an accuracy of up to 97.1% in attribute recognition [18] the research spanned the period from 2010 to 2020, and had 86 public fashion datasets for training and validation, to make the solutions more robust and comprehensive.

Importance of 5G and Edge Computing and Improving connectivity.

Smart textiles are even more connected with the integration of 5G and edge computing, enabling real-time data transfer and communication between devices[66]. Together with edge computing, 5G technology brings a variety of advanced capabilities to the smart fashion market: AR-based fashion items, user-centric experience, and optimized supply chain management – all of these are crucial to the next generation of smart textiles, enabling faster data analytics, enhanced responsiveness and scalability[46].

Advanced materials and conductive fibers and nanotechnology

The birth and incorporation of new materials like conductive fibers, optical fibers, shape memory materials like nickel titanium alloys and phase change materials (PCM's) have revolutionized the development of smart textiles, leading to a huge range of applications in various sectors of healthcare, military, fashion, sportswear, and more.

Opportunities and challenges for IoT ecosystem in the case of ‘smarter textiles’ applications.

The transformative potential of smart textiles in IoT is obvious as it combines technological advancements with comfort and aesthetics, enabling new applications in the fields of healthcare, fitness and lifestyle[75]. challenges include the development of efficient energy harvesting mechanisms like triboelectric and piezoelectric generators to maintain fabric devices, designing an autonomic system for managing the heterogeneous devices, and addressing privacy concerns by avoiding the collection of sensitive identity related data[7374].

Conclusion

The study shows how fashion has come from traditional textiles to smart wearable gadgets using the concept of material communication system (MCS) and IoT. It has functions like measuring health, and sensing the environment, all these by developing conductive fibers, nanotechnology applications and implementing non-chip sensing systems. In addition, the fields of IoT and communication technologies, like 5G and edge computing, have also had a significant impact on data transmission, as they enable seamless connectivity and support real-time data collection, thereby shaping the user experience and solving current problems in various sectors, such as healthcare, sports, and lifestyle[76]. The power of IoT is only going to take this to the next level if it is complemented by developments in advanced communication technologies such as edge-computing powered by 5G and low-power wide-area communication protocols that will enable ultra-reliable high-speed data transmission, thereby paving the way to real-time applications like health monitoring, and augmented reality fashion experience, and sustainable energy use for all this activity. Moreover, solving the privacy issues by using blockchain based authentication and being able to develop strong cybersecurity protocols will also be crucial in gaining user trust and expanding the market interoperability of IoT enabled smart textiles [7].

Fashion as well as modern technology aligned changing the role of clothes while smart wearable textiles revealed a world of socio technical implications that might meet healthcare needs, improve performance in sports and fashion sustainable solutions for Elvis presley hears something in this new paradigm shift where reusable or transformed[77] appear to fit into an everchanging society. The advancement of technology and the future of smart fashion will be as innovative as they will be able to be integrated as a seamless component of everyday life or as a (cap) solution.

References

1. I. Docherty, G. Marsden, and J. Anable, “The governance of smart mobility,” *Transp. Res. Part A Policy Pract.*, vol. 115, pp. 114–125, Sep. 2018, doi: 10.1016/J.TRA.2017.09.012.
2. E. Rockett, M. Fenwick, P. Jurcys, and P. Jurcys, “Fashion 4.0 and emerging designers: leveraging data and AI to drive creativity, innovation and compliance in global supply chain regulation,” *J. Intellect. Prop. Law Pract.*, vol. 00, no. 00, Dec. 2024, doi: 10.1093/JIPLP/JPAE110.

3. M. N. M. Azlin, K. Z. Hazrati, and K. Z. Hafila, "Biomaterials Based on Plant Fibres: Sustainable for Green Composites," *Emerg. Sustain. Renew. Compos. From Packag. to Electron.*, pp. 225-247, Jan. 2024, doi: 10.1201/9781003408215-12/BIOMATERIALS-BASED-PLANT-FIBRES-SUSTAINABLE-GREEN-COMPOSITES-AZLIN-HAZRATI-HAFILA.
4. A. Ghosal et al., "An Autonomous Robot to Sustain the Pond or Lake Clean and Pollutant Free," *eduzonejournal.com*, vol. ISSN, no. 1, pp. 2319-5045, Accessed: Aug. 01, 2022. [Online]. Available: <http://www.eduzonejournal.com/index.php/eiprmj/article/view/43>
5. X. Gu, Q. Yao, · Xiaojun Gong, and Z. Kuang, "iDesigner: making intelligent fashion designs," *Multimed. Tools Appl.*, vol. 83, pp. 32835-32855, 2024, doi: 10.1007/s11042-023-16780-1.
6. S. F. Yeo, C. L. Tan, A. Kumar, K. H. Tan, and J. K. Wong, "Investigating the impact of AI-powered technologies on Instagrammers' purchase decisions in digitalization era: a study of the fashion and apparel industry," *Technol. Forecast. Soc. Change*, vol. 177, p. 121551, 2022.
7. "Proceedings of the International Conference on AI Research - Google Books." Accessed: Jan. 25, 2025. [Online]. Available: https://books.google.com.pk/books?hl=en&lr=&id=YCI9EQAAQBAJ&oi=fnd&pg=PA75&dq=Ethical+Considerations+in+Data+Use+%2B+smart+fashion&ots=kQGDJbSioL&sig=qkHKybOSFVJpivfkIRWycmFKpsQ&redir_esc=y#v=onepage&q=Ethical+Considerations+in+Data+Use+%2B+smart+fashion&f=false
8. K. Du, R. Lin, L. Yin, J. S. Ho, J. Wang, and C. T. Lim, "Electronic textiles for energy, sensing, and communication," *iScience*, vol. 25, no. 5, p. 104174, May 2022, doi: 10.1016/J.ISCI.2022.104174.
9. S. V. Akram et al., "Implementation of Digitalized Technologies for Fashion Industry 4.0: Opportunities and Challenges," *Sci. Program.*, vol. 2022, no. 1, p. 7523246, Jan. 2022, doi: 10.1155/2022/7523246.
10. T. Semeraro, S. Arzeni, A. Turco, M. Ghoreishi, K. Bhandari, and A. Franconi, "Smart Fashion Economy through a Data-Driven Circular Ecosystem: A Case Study," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1009, no. 1, p. 012012, Apr. 2022, doi: 10.1088/1755-1315/1009/1/012012.
11. M. Z. Talukder, S. S. Towqir, A. R. Remon, and H. U. Zaman, "An IoT based automated traffic control system with real-time update capability," *8th Int. Conf. Comput. Commun. Netw. Technol. ICCCNT 2017*, Dec. 2017, doi: 10.1109/ICCCNT.2017.8204095.
12. H. Manglani, G. L. Hodge, and W. Oxenham, "Application of the Internet of Things in the textile industry," *Text. Prog.*, vol. 51, no. 3, pp. 225-297, Jul. 2019, doi: 10.1080/00405167.2020.1763701.
13. F. Khakpour, Z. Heydari, S. P.-I. journal of food science, and undefined 2024, "Production of alfalfa seed mucilage film with nanoparticles of Smyrnum cordifolium Boiss and milk thistle seed oil and physical and chemical properties," *jfst.modares.ac.ir*, Accessed: Jan. 25, 2025. [Online]. Available: <https://jfst.modares.ac.ir/article-7-71805-en.pdf>
14. A. Nadi, A. Boukhriess, A. Bentis, E. Jabrane, and S. Gmouh, "Evolution in the surface modification of textiles: a review," *Text. Prog.*, vol. 50, no. 2, pp. 67-108, Apr. 2018, doi: 10.1080/00405167.2018.1533659.
15. S. Roshankish and N. Fornara, "Exploration of Norms and Policies in Digital Fashion Domain Using Semantic Web Technologies," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 12781 LNCS, pp. 384-395, 2021, doi: 10.1007/978-3-030-78227-6_28.
16. C. Gyde and L. S. Mcneill, "Fashion Rental: Smart Business or Ethical Folly?," 2021, doi: 10.3390/su13168888.
17. G. Chen, X. Xiao, X. Zhao, T. Tat, M. Bick, and J. Chen, "Electronic Textiles for Wearable Point-of-Care Systems," *Chem. Rev.*, vol. 122, no. 3, pp. 3259-3291, Feb. 2022, doi: 10.1021/ACS.CHEMREV.1C00502/ASSET/IMAGES/MEDIUM/CR1C00502_0010.GIF.
18. J. S. Chase, D. C. Anderson, P. N. Thakar, A. M. Vahdat, and R. P. Doyle, "Managing energy and server resources in hosting centers," pp. 103-116, Oct. 2001, doi: 10.1145/502034.502045.
19. M. S. Sarif Ullah Patwary, "Smart Textiles and Nano-Technology: A General Overview," *J. Text. Sci. Eng.*, vol. 05, no. 01, 2015, doi: 10.4172/2165-8064.1000181.

20. P. Del Vecchio, G. Secundo, Y. Maruccia, and G. Passiante, "A system dynamic approach for the smart mobility of people: Implications in the age of big data," *Technol. Forecast. Soc. Change*, vol. 149, Dec. 2019, doi: 10.1016/J.TECHFORE.2019.119771.
21. J. P. Gouveia, J. Seixas, and G. Giannakidis, "Smart City Energy Planning: Integrating Data and Tools," *WWW 2016 Companion - Proc. 25th Int. Conf. World Wide Web*, pp. 345–350, Apr. 2016, doi: 10.1145/2872518.2888617.
22. Q. Li, Z. Xue, Y. Wu, and X. Zeng, "The Status Quo and Prospect of Sustainable Development of Smart Clothing," *Sustain.* 2022, Vol. 14, Page 990, vol. 14, no. 2, p. 990, Jan. 2022, doi: 10.3390/SU14020990.
23. D. Kaczorowska-Spychalska, "Shaping Consumer Behaviour in the Fashion Industry by Interactive Communication," *Fibres Text. East. Eur.*, vol. Vol. 26, no. 4 (130), pp. 13–19, 2018, doi: 10.5604/01.3001.0012.1307.
24. H. Schneider, F. Mukinda, H. Tabana, and A. George, "Expressions of actor power in implementation: a qualitative case study of a health service intervention in South Africa," *BMC Health Serv. Res.*, vol. 22, no. 1, Dec. 2022, doi: 10.1186/S12913-022-07589-Z.
25. R. Havaragi and C. Bhagoji, "Role of Product Lifecycle Management and Bill of Material in Fashion Industry," pp. 277–303, 2024, doi: 10.1007/978-3-031-71052-0_10.
26. C. Huang, G. Nan, H. Qiu, M. T.- Resources, undefined Conservation, and undefined 2025, "Launching smart circular supply chain practices toward sociotechnological synergy: An integrative influential fast fashion model," *Elsevier*, Accessed: Jan. 26, 2025. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0921344924005287>
27. D. Birnbacher and W. Birnbacher, "Fully Autonomous Driving: Where Technology and Ethics Meet," *IEEE Intell. Syst.*, vol. 32, no. 5, pp. 3–4, Sep. 2017, doi: 10.1109/MIS.2017.3711644.
28. Y. K. Dwivedi, E. Ismagilova, D. L. Hughes, J. Carlson, R. Filieri, and J. Jacobson, "Setting the Future of Digital and Social Media Marketing research: Perspectives and Research Propositions," *Int. J. Inf. Manage.*, vol. 59, no. 1, pp. 1–37, 2021, [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0268401220308082>
29. R. R. Ruckdashel, D. Venkataraman, and J. H. Park, "Smart textiles: A toolkit to fashion the future," *J. Appl. Phys.*, vol. 129, no. 13, p. 130903, Apr. 2021, doi: 10.1063/5.0024006/157391.
30. V. K. Shrotryia, "Human Well-Being Policy and Discussion," pp. 103–137, 2020, doi: 10.1007/978-3-030-33270-9_4.
31. A. Perry, L. Malinin, E. Sanders, Y. Li, and K. Leigh, "Explore consumer needs and design purposes of smart clothing from designers' perspectives," *Int. J. Fash. Des. Technol. Educ.*, vol. 10, no. 3, pp. 372–380, Sep. 2017, doi: 10.1080/17543266.2016.1278465.
32. A. Alam, "Possibilities and Apprehensions in the Landscape of Artificial Intelligence in Education," *2021 Int. Conf. Comput. Intell. Comput. Appl. ICCICA 2021*, 2021, doi: 10.1109/ICCICA52458.2021.9697272.
33. C. Campolo, G. Genovese, A. Molinaro, and B. Pizzimenti, "Digital Twins at the Edge to Track Mobility for MaaS Applications," *Proc. 2020 IEEE/ACM 24th Int. Symp. Distrib. Simul. Real Time Appl. DS-RT 2020*, Sep. 2020, doi: 10.1109/DS-RT50469.2020.9213699.
34. S. Cuc and M. Vidovic, "Environmental Sustainability through Clothing Recycling," *Oper. Supply Chain Manag. An Int. J.*, vol. 4, no. 2, pp. 108–115, Dec. 2014, doi: 10.31387/OSCM0100064.
35. M. Krech, A. Trunk, and P. Groche, "Controlling the sensor properties of smart structures produced by metal forming," *Procedia Eng.*, vol. 207, pp. 1415–1420, 2017, doi: 10.1016/J.PROENG.2017.10.906.
36. M. Coeckelbergh, "Responsibility and the Moral Phenomenology of Using Self-Driving Cars," *Appl. Artif. Intell.*, vol. 30, no. 8, pp. 748–757, Sep. 2016, doi: 10.1080/o8839514.2016.1229759.
37. R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. De Rose, and R. Buyya, "CloudSim: a toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms," *Softw. Pr. Exp.*, vol. 41, no. 1, pp. 23–50, Jan. 2011, doi: 10.1002/spe.995.
38. K. Ren, Q. Wang, C. Wang, Z. Qin, and X. Lin, "The Security of Autonomous Driving: Threats, Defenses, and Future Directions," *Proc. IEEE*, vol. 108, no. 2, pp. 357–372, Feb. 2020, doi: 10.1109/JPROC.2019.2948775.

39. D. Moore and J. Hebel, "Computing in the clouds," *Dr. Dobb's J.*, vol. 34, no. 2, pp. 16–21, Feb. 2009, doi: 10.1145/1327512.1327513.
40. P. Barham et al., "Xen and the art of virtualization," p. 164, 2003, doi: 10.1145/945445.945462.
41. M. R. I. Rana and J. Ha-Brookshire, "New conceptual framework for fashion business ideation, negotiation, and implementation undergraduate curricula for sustainable development," *Int. J. Fash. Des. Technol. Educ.*, vol. 12, no. 2, pp. 140–148, May 2019, doi: 10.1080/17543266.2018.1534003.
42. O. Singh, N. Singh, A. S.-... and I. Security, and undefined 2024, "AI, IoT, and Blockchain in Fashion: Confronting Industry Applications, Challenges with Technological Solutions," [search.proquest.com](https://search.proquest.com/openview/9400c362addeff39239begf35518b947/1?pq-origsite=gscholar&cbl=52057), Accessed: Jan. 26, 2025. [Online]. Available: <https://search.proquest.com/openview/9400c362addeff39239begf35518b947/1?pq-origsite=gscholar&cbl=52057>
43. M. Nguyen, M. T.-J. of E. S. Science, and undefined 2023, "Privacy and Security Implications of Big Data Applications in Consumer Behavior Analysis for Fashion Retail," *publications.dlpress.org*, vol. 7, no. 4, Accessed: Jan. 26, 2025. [Online]. Available: <https://publications.dlpress.org/index.php/jesss/article/view/60>
44. S. Du and C. Xie, "Paradoxes of Artificial Intelligence in Consumer markets: Ethical Challenges and Opportunities," *J. Bus. Res.*, Aug. 2020, [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0148296320305312>
45. A. Nadi, A. Boukhriess, A. Bentis, E. Jabrane, and S. Gmouh, "Evolution in the surface modification of textiles: a review," *Text. Prog.*, vol. 50, no. 2, pp. 67–108, Apr. 2018, doi: 10.1080/00405167.2018.1533659.
46. A. Bucchiarone, "Collective adaptation through multi-agents ensembles: The case of smart urban mobility," *ACM Trans. Auton. Adapt. Syst.*, vol. 14, no. 2, Oct. 2019, doi: 10.1145/3355562.
47. M. A. Ahad, S. Paiva, G. Tripathi, and N. Feroz, "Enabling technologies and sustainable smart cities," *Sustain. Cities Soc.*, vol. 61, Oct. 2020, doi: 10.1016/J.SCS.2020.102301.
48. C. Thorun and J. Diels, "Consumer Protection Technologies: An Investigation Into the Potentials of New Digital Technologies for Consumer Policy," *J. Consum. Policy*, vol. 43, no. 1, pp. 177–191, Mar. 2020, doi: 10.1007/S10603-019-09411-6.
49. S. Park and S. Jayaraman, "The wearables revolution and Big Data: the textile lineage," *J. Text. Inst.*, vol. 108, no. 4, pp. 605–614, Apr. 2017, doi: 10.1080/00405000.2016.1176632.
50. D. Dias and J. P. S. Cunha, "Wearable Health Devices—Vital Sign Monitoring, Systems and Technologies," *Sensors* 2018, Vol. 18, Page 2414, vol. 18, no. 8, p. 2414, Jul. 2018, doi: 10.3390/S18082414.
51. H. Sun, Z. Zhang, R. Q. Hu, and Y. Qian, "Wearable communications in 5g: Challenges and enabling technologies," *IEEE Veh. Technol. Mag.*, vol. 13, no. 3, pp. 100–109, Sep. 2018, doi: 10.1109/MVT.2018.2810317.
52. H. J. Kim, S. K. Ahn, and J. A. Forney, "Shifting paradigms for fashion: from total to global to smart consumer experience," *Fash. Text.*, vol. 1, no. 1, pp. 1–16, Dec. 2014, doi: 10.1186/S40691-014-0015-4/FIGURES/3.
53. C. Thorun, J. D.-J. of C. Policy, and undefined 2020, "Consumer protection technologies: An investigation into the potentials of new digital technologies for consumer policy," *Springer*, Accessed: Jan. 26, 2025. [Online]. Available: https://idp.springer.com/authorize/casa?redirect_uri=https://link.springer.com/article/10.1007/s10603-019-09411-6&casa_token=vrk1P3iM9QYAAAAA:eeBMDt426_9LJlczQpnGL-kpHknjD1ExcJJMJzbGosjDIAf4LQuWMb2-rvObLJx6Ag8XS7OUFoUVbmr8
54. "Policies for Consumer Protection and Data Security... - Google Scholar." Accessed: Jan. 26, 2025. [Online]. Available: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Policies+for+Consumer+Protection+and+Data+Security+%2B+smart+fashion&btnG=
55. M. Baza, M. Nabil, N. Lasla, K. Fidan, M. Mahmoud, and M. Abdallah, "Blockchain-based Firmware Update Scheme Tailored for Autonomous Vehicles," *IEEE Wirel. Commun. Netw. Conf. WCNC*, vol. 2019-April, Apr. 2019, doi: 10.1109/WCNC.2019.8885769.

56. B. Bhushan, A. Khamparia, K. M. Sagayam, S. K. Sharma, M. A. Ahad, and N. C. Debnath, "Blockchain for smart cities: A review of architectures, integration trends and future research directions," *Sustain. Cities Soc.*, vol. 61, Oct. 2020, doi: 10.1016/J.SCS.2020.102360.
57. M. Myers, C. Brace, and L. Carden, *Intelligent Automation: Bridging the Gap Between Business and Academia*. 2023. Accessed: Jan. 26, 2025. [Online]. Available: <https://books.google.com/books?hl=en&lr=&id=8ETZEAAAQBAJ&oi=fnd&pg=PT14&dq=Bridging+the+Gap+Between+Innovation+and+Mass+Adoption+%2B+smart+fashion&ots=rBiI7wqKPc&sig=F99pLM39MX2EGak-UB4pStUa7Jg>
58. A. Vänskä, S. Rauti, T. Heino, R. Carlsson, S. Mickelsson, and N. Särämäkari, "Fair Data is the New Black: Online Shopping, Data Leaks, and Broadening the Understanding of Sustainable Fashion," *Taylor Fr.*, vol. 28, no. 3, pp. 305–333, 2024, doi: 10.1080/1362704X.2024.2339251.
59. G. Z.- Laws and undefined 2020, "Wearable technologies and smart clothes in the fashion business: some issues concerning cybersecurity and data protection," *mdpi.com*, doi: 10.3390/laws9020012.
60. P. Bertola and J. Teunissen, "Fashion 4.0. Innovating fashion industry through digital transformation," *Res. J. Text. Appar.*, vol. 22, no. 4, pp. 352–369, Nov. 2018, doi: 10.1108/RJTA-03-2018-0023/FULL/HTML.
61. S. V. Akram et al., "Implementation of digitalized technologies for fashion industry 4.0: Opportunities and challenges," *Wiley Online Libr.*, vol. 2022, 2022, doi: 10.1155/2022/7523246.
62. B. R. Gordon, K. Jerath, Z. Katona, S. Narayanan, J. Shin, and K. C. Wilbur, "Inefficiencies in Digital Advertising Markets," *J. Mark.*, vol. 85, no. 1, p. 002224292091323, 2020.
63. D. Casciani, O. Chkanikova, R. P.-S. Science, undefined Practice, and undefined 2022, "Exploring the nature of digital transformation in the fashion industry: opportunities for supply chains, business models, and sustainability-oriented innovations," *Taylor Fr.*, vol. 18, no. 1, pp. 773–795, 2022, doi: 10.1080/15487733.2022.2125640.
64. M. Taraba, J. Adamec, M. Danko, and P. Drgona, "Utilization of modern sensors in autonomous vehicles," *12th Int. Conf. ELEKTRO 2018, 2018 ELEKTRO Conf. Proc.*, pp. 1–5, Jun. 2018, doi: 10.1109/ELEKTRO.2018.8398279.
65. R. Luckin and M. Cukurova, "Designing educational technologies in the age of AI: A learning sciences-driven approach," *Br. J. Educ. Technol.*, vol. 50, no. 6, pp. 2824–2838, Nov. 2019, doi: 10.1111/BJET.12861.
66. W. Fu et al., "Intelligent fibers and textiles for wearable biosensors," *Responsive Mater.*, vol. 2, no. 4, p. e20240018, Nov. 2024, doi: 10.1002/RPM.20240018.
67. Y. Yu, · Xiaojian Liao, and W. Feng, "Recent development of elastomer-based smart sensing materials and structures," *Adv. Compos. Hybrid Mater.* 2025 81, vol. 8, no. 1, pp. 1–28, Jan. 2025, doi: 10.1007/S42114-024-01168-Y.
68. E. P. da Cruz et al., "Impact of concentration and aging time of pea starch-based polymeric solutions on the fabrication of electrospun nanofibers," *Polym. Adv. Technol.*, vol. 35, no. 6, Jun. 2024, doi: 10.1002/PAT.6479.
69. X. Hu, T. T. Li, B. Shou, L. Li, H. T. Ren, and C. W. Lou, "Novel personal cooling textiles revolutionizing human thermal management: principles, designs and applications," *Chem. Eng. J.*, vol. 499, p. 155729, Nov. 2024, doi: 10.1016/J.CEJ.2024.155729.
70. Y. Zhang, G. Zhang, Y. Dong, Y. Wu, L. Yu, and Y. Bai, "Interfacial Modulation of Polydopamine–Reduced Graphene Oxide for Achieving Highly Conductive and Strong Graphene/Cotton Composite Yarn Toward Smart Wearable Devices," *Adv. Fiber Mater.*, Dec. 2024, doi: 10.1007/S42765-024-00449-X.
71. M. Chen et al., "Fabric computing: Concepts, opportunities, and challenges," *Innovation*, vol. 3, no. 6, p. 100340, Nov. 2022, doi: 10.1016/J.XINN.2022.100340/ASSET/53E305B9-0C11-4936-A999-1C4AF592E080/MAIN.ASSETS/GR6.JPG.
72. B. P. Pokharel and R. Koju, "Sentiment analysis using Hierarchical Multimodal Fusion (HMF)," *World J. Adv. Res. Rev.*, vol. 2022, no. 03, pp. 296–303, 2022, doi: 10.30574/wjarr.2022.14.3.0549.

73. K. Kuhi, K. Kaare, and O. Koppel, "Ensuring performance measurement integrity in logistics using blockchain," *Proc. 2018 IEEE Int. Conf. Serv. Oper. Logist. Informatics, SOLI 2018*, pp. 256–261, Sep. 2018, doi: 10.1109/SOLI.2018.8476737.
74. B. D. Deebak and F. Al-Turjman, "A smart lightweight privacy preservation scheme for IoT-based UAV communication systems," *Comput. Commun.*, vol. 162, pp. 102–117, Oct. 2020, doi: 10.1016/J.COMCOM.2020.08.016.
75. "IoT Adoption and Application for Smart Healthcare_ A Systematic Review _ Enhanced Reader.pdf."
76. P. Madduru, "ARTIFICIAL INTELLIGENCE AS A SERVICE IN DISTRIBUTED MULTI ACCESS EDGE COMPUTING ON 5G EXTRACTING DATA USING IOT AND INCLUDING AR/VR FOR REAL-TIME REPORTING," *Inf. Technol. Ind.*, vol. 9, no. 1, pp. 912–931, Mar. 2021, doi: 10.17762/ITII.V9I1.220.
77. T. Semeraro, S. Arzeni, A. Turco, M. Ghoreishi, K. Bhandari, and A. Franconi, "Smart Fashion Economy through a Data-Driven Circular Ecosystem: A Case Study," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1009, no. 1, p. 012012, Apr. 2022, doi: 10.1088/1755-1315/1009/1/012012.



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