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Research Article

Implementation of Digitalized Technologies for Fashion Industry 4.0: Opportunities and Challenges

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The Sustainable Development Goals of the United Nations prioritize sustainability by 2030. The fashion industry is one most substantial manufacturing industries that generate an economy of 3 trillion dollars and contributes to 2% of the world's gross domestic product. In addition to this, the fashion industry must focus on social and environmental concerns, where it should create fashionable products to promote sustainable consumption and production. Sustainable consumption and production can be achieved with the establishment of resilient infrastructure with innovation. The resilient infrastructure with innovation is realized by the integration of digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, augmented reality (AR), and virtual reality (VR). With this motivation, this study explored the different studies that implemented these technologies in the fashion industry for smart cloth (health), supply chain, circular economy, dress recommendation system, fashion trend forecasting, health prediction, and virtual and augmented based shopping experience. Along with the progress of these technologies in the fashion industry, the study also discussed limitations and provided recommendations such as wide adoption of blockchain in fashion supply chain; advancement in energy storage for smart cloth; integration of IoT, AI, and edge computing; and smart clothing-based framework for rescue operation for future enhancement.

1. Introduction

The fashion industry is one most significant manufacturing industries that generate an economy of 3 trillion dollars and contributes to 2% of world gross domestic product (GDP) [1]. The fashion industry plays a crucial role in the design, manufacturing, and selling of clothes and garments. Moreover, the industry encompasses diverse sectors, including fabrication of raw materials, manufacture of fashion clothes and garments by designers, commercialization, and marketing communication [2]. However, according to United Nations, the fashion industry has a lack of concern for social and environmental issues [3] as it produces 8–10% of the global CO_2 emissions [4, 5], consumes 79 trillion liters of water per year, contributes to 35% of microplastic pollution, and generates >92 million tonnes of textiles waste per year [6]. The fashion industry is also a contributor to the United Nations sustainable development goals (SDGs) for social, economic, and environmental sustainability [7], and it needs to achieve the following major SDGs: *goal 9: build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation* [8]; *goal 12: ensure* *sustainable consumption and production patterns* [9]; and *goal 13: take urgent action to combat climate change and its impacts* [9].

As part of goal 9, the fashion sector must foster innovation and build intelligent infrastructure using digitalized technologies such as IoT, AI, blockchain, AR, and VR. These emerging technologies are capable of establishing sustainable industrialization through their unique and intelligent features. The European Commission report concluded that, in the future, the utilization of clothing with smart garments will be on a large scale [10]. For the same, innovative garments, fabrics, and clothes need to be fashionable, flexible, reliable, and smart. This can be achieved due to the availability of miniature electronic chips and sensors and also due to the availability of energy-efficient connectivity protocols. Fundamentally, fashion is a type of self-expression through clothing, footwear, lifestyle, garment, makeup, hair, and body posture in a specific time and place and a specific environment [11]. So, it concluded that, in fashion along with clothes, the development of smart garments and footwear is also part of it.

Smart clothing and smart garments have a significant contribution to health and well-being and quality of life through the integration of IoT along with AI. In terms of health status, physical activities, and daily activities, these two technologies will strengthen and enhance real-time monitoring of the actions of athletes, patients, babies, and the elderly [12]. AI can be utilized for fashion trend forecasting, dress recommendation based on environmental parameters and health prediction, and so on. Furthermore, the combination of IoT and blockchain allows for effective real-time tracking and tracing of fashion activities, which helps envision the quantity of material consumed and produced, and for the establishment of a circular economy in fashion [13, 14]. To experience the product in terms of fitting, size, and color selection is possible with AR technology, and this technology assists in experiencing the product from any location in the world through mobile [15]. VR technology assists in the product development of an individual and fosters retail experience through the virtual world [16]. As per the observation in the previous studies, it has been identified that limited studies have discussed the significance of all digital technologies implementation in the fashion industry. In a few studies, the researchers have discussed the implementation of digital technologies separately, but no study addressed all the digital technologies such as IoT, AI, blockchain, and AR/VR under one umbrella. It has been observed that leveraging digital technologies could significantly contribute to achieving the SDGs. Technological breakthroughs have significantly impacted how economies function and how people, society, and the environment interact. The ability to sense, analyze, interact with, and alter their physical environment with minimal human intervention is a critical innovation in the fashion industry.

1.1. Contribution and Structure of the Study. With motivation from prior remarks, we present this review to prioritize the significance and application of digitalized technologies' impact in the fashion industry with advanced connectivity. The contribution of the study is as follows:

(i) The basic concepts and significance of digitalization in the fashion industry are discussed in detail concerning sustainability

(ii) We discuss the progress of individual digitalized technologies in the fashion industry for smart clothing, forecasting of fashion trends, dress recommendation based on environmental conditions, prediction of health, real-time supply chain, and fashion and shopping experience

(iii) We discuss the limitations of the previous studies that implemented these technologies in the fashion industry and also suggested recommendations for future work

The structure of the study is shown in Figure 1, and it is also as follows: Section 3 discusses the digitalization in the fashion industry; Section 4 discusses the IoT in the fashion industry; Section 5 presents the AI in the fashion industry; Section 6 covers the blockchain implementation in the fashion industry; Section 7 covers the AR and VR implementation in the fashion industry; Section 8 covers the discussion and recommendations. The study concludes in the final section.

2. Methodology of the Study

This section shows the methodology followed in conducting the analysis regarding the progress and significance of digitalization in the fashion industry. As a part of this, we have obtained the articles from the Web of Science (WoS), Scopus, and IEEE Xplore. The articles are selected on the basis of inclusion and exclusion criteria. In the following, we have discussed criteria that are implemented to exclude the articles:

(i) Nonpeer-reviewed research articles are not examined, as the significance of research content in it is low

(ii) The articles that lack the abstracts are also not examined

(iii) The research articles that consider similar methodologies/techniques for the same problem statement are also not considered

(iv) Thesis and dissertation works of the postgraduation and graduation are also not examined

Figure 2 illustrates the distribution of the articles yearwise; it has been observed that the major paper portions of the paper considered in this study are 24% (2017) and 26% (2020). Sustainable Production and Consumption, Pattern Recognition Letters, Computer in Industry, Journal of King Saud University, Information and Sciences, Journal of Manufacturing Systems, Electronics, IEEE Communication Magazine, IEEE Systems Journal, IEEE Access, IEEE Sensors, Journal, IEEE Transactions on Consumer Electronics, Waste Management, Sensors, Applied Sciences, Computers in Human Behavior, Journal of Manufacturing Technology

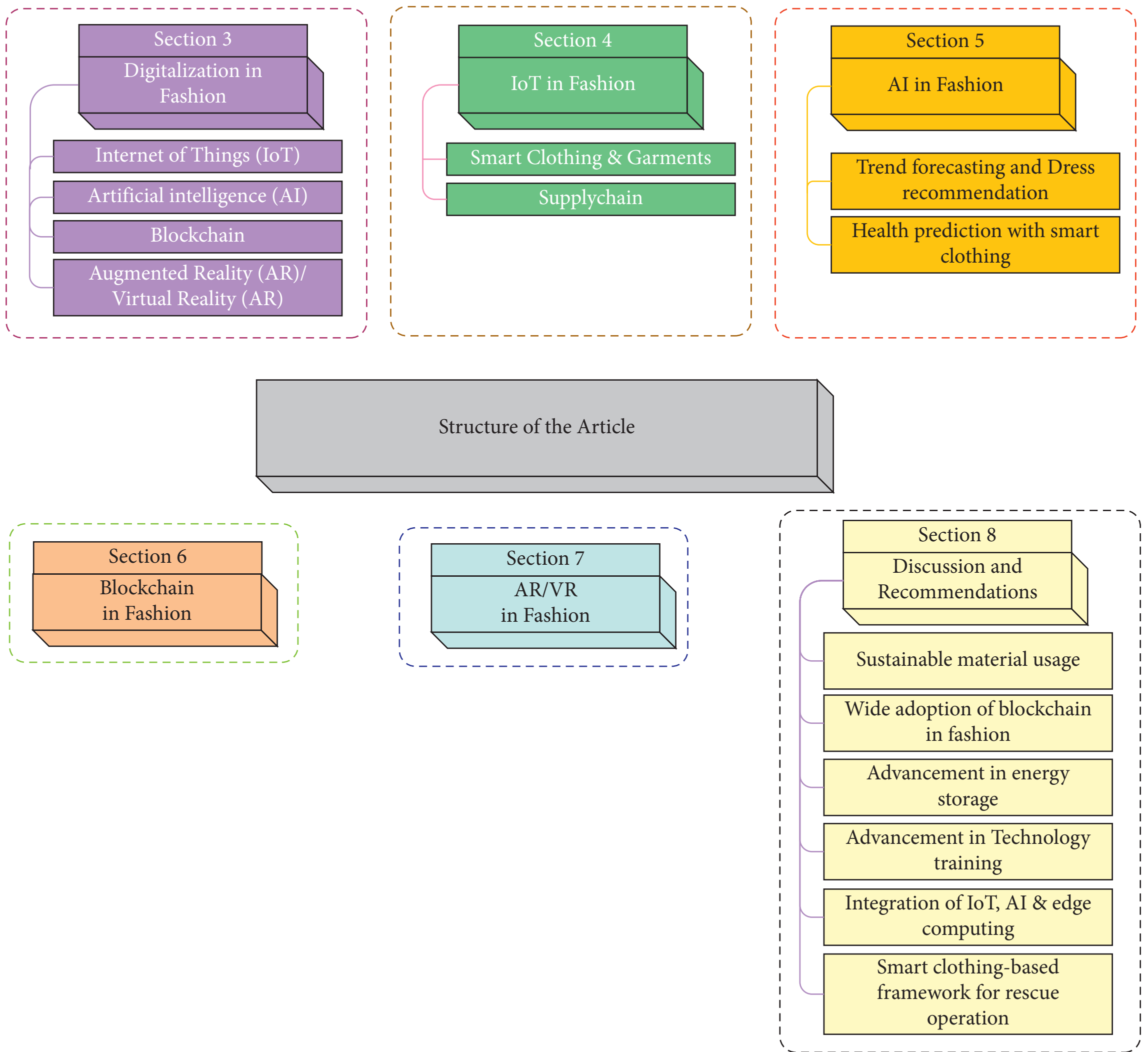


Figure 1: Structure of the paper.

Management, Computers and Industrial Engineering, Journal of Intelligent Manufacturing, Journal of Sustainability, and International Journal of Innovative Computing and Applications are the journals that have been considered in this study.

3. Digitalization in Fashion

According to a Nielsen survey [17], 73 percent of Millennials demand sustainable clothing that is both socioeconomically and environmentally sustainable. Digitalization in fashion boosts the implementation of robust, innovative, sustainable, and real-time infrastructure that is tailored to the requirements of the customer concerning comfortability, flexibility, and reliability in a sustainable manner. It has been discovered that utilizing digital technology can greatly assist in accomplishing sustainability. The digitalization empowers to visualize the real-time information of smart cloth and other garments on the virtual network. This indeed assists in analyzing the data and applying different analytics methods to obtain the needful insights from it. Moreover, Figure 3 illustrates the areas in which the digitalization of fashion can be implemented:

(i) *IoT*. IoT refers to physical things that are equipped with sensors, computing power, and programming to communicate with other devices and systems through the Internet or wireless communication networks [18]. With the assistance of IoT, real-time monitoring of fashion industry activities (product tracking and feedback system), health monitoring of individuals (athletics, patients, elder, and babies) through IoT-enabled clothing and wearables, and implementation of the security system through smart clothing and wearables can be achieved.

(ii) *AI*. Artificial intelligence uses computers and machines to replicate the human mind's problem-solving and decision-making abilities [19]. IoT technology generates a huge amount of data through the sensors embedded in clothing and other wearable devices. In the 21st century, data is a

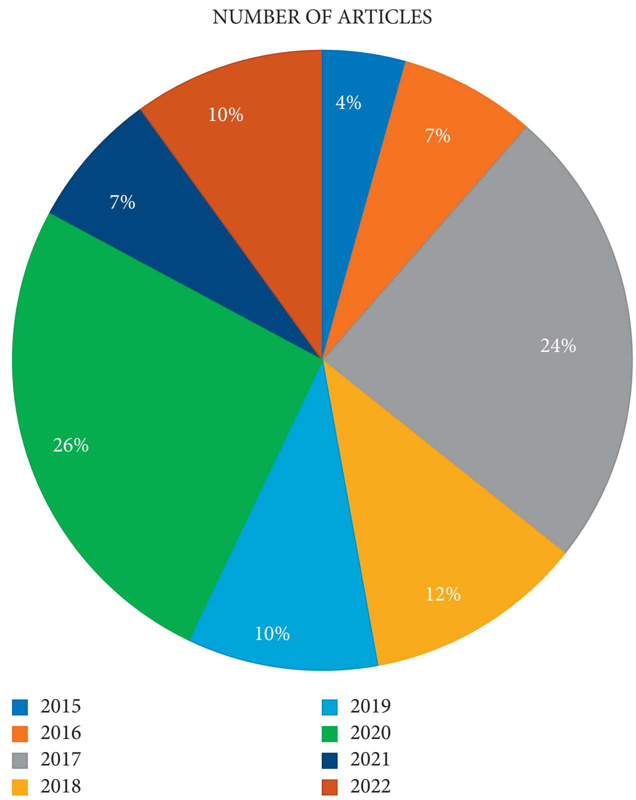


Figure 2: Distribution of articles.

significant resource for performing analytics for obtaining insightful results. In addition to this, AI can be utilized to predict the health status of the elder, athletes, patients, and babies based on real-time sensor data [20]. Furthermore, AI is useful for recommending dresses based on environmental conditions and also for forecasting trends of customers.

(iii) *Blockchain*. Blockchain is distributed ledger technology that has shown a significant impact on various applications to boost transparency, security, and immutability [21]. Blockchain in the fashion supply chain resolves the concerns like information asymmetry, visibility, credibility, and traceability. Blockchain empowers to implement the circular economy in which discarded clothes are used as raw material for the production of new clothes [22].

(iv) *AR and VR*. AR is a technologically upgraded version of the real world that is created through the integration of digital visual elements, music, or other types of sensory stimulation [23]. VR employs computer modeling and simulation to allow a person to engage with a simulated three-dimensional (3D) visual or another sensory world [24]. AR in the fashion industry is utilized for the customer to experience the product that is developed, whereas VR is utilized for the development of the product based on customer needs.

4. IoT in Fashion

4.1. Smart Clothing and Garments. The rapid fusion of textiles and electronics presently permits the smooth and widespread integration of sensors into textiles, as well as the production of conductive yarn. Smart fabrics, which can interface with smartphones to process biometric data such as temperature, respiration, heart rate, stress, movement, or even hormone levels, have the potential to bring in a new era in retail [25]. Modern medicine, from prevention to sophisticated therapies, is built on earlier, accurate, and real diagnoses, supported by robust monitoring of the treatments. Smart clothing is capable of providing real-time sensor data with accuracy and reliability [26]. Smart clothing is crafted by integrating smart wearables into garments, and it is a significant prospect for the future interface between the physical and digital worlds, replacing or extending smartphones and other portable connected gadgets [27, 28].

The role of wearable devices in smart clothing is critical; currently, in smart clothing, wearable 2.0 is adapted to connect to numerous devices and utilize cloud services to improve user life experience [29, 30]. Wearable 2.0 with smart clothing is efficient in terms of accuracy, comfort, usability, washability, and real-time monitoring assistance, which enhances the quality of service (QoS) and quality of experience (QoE). Figure 4 illustrates the concept of wearable 2.0 with smart clothing, where the different activities can be implemented through smart clothing. Smart clothing with wearable 2.0 can be utilized to monitor chronic disease, train auxiliary athletes, and provide emotional care:

(i) *Monitoring Chronic Disease*. Patients with chronic diseases wear smart clothes in their everyday life to acquire noninvasive physiological data. This physiological data is logged in the cloud server to process and analyze health conditions. The system provides customers with individualized healthcare services in a variety of ways based on their diagnosed health state.

(ii) *Training of Auxiliary Athletes*. The effective monitoring of athletes during rigorous training plays a crucial role, as smart clothing with sensory system assists in detecting fatigue in any area of the body. Three-axis acceleration, gyroscope, and electromyography (EMG) sensors are crucial to detecting movement and muscle strain of athletes.

(iii) *Providing Emotional Care*. Emotional care is especially beneficial for single parents, long-distance truck drivers, and people suffering from mental illnesses. The system can deliver emotional care based on physiological data connected to the user's emotions. When the system detects a user in a negative mood, it provides emotional feedback such as voice reminders, tuning appropriate music, or playing selected video content.

Figure 5 illustrates the architecture of smart clothing for healthcare applications with cloud services. The front-end system comprises hardware and communication subsystem

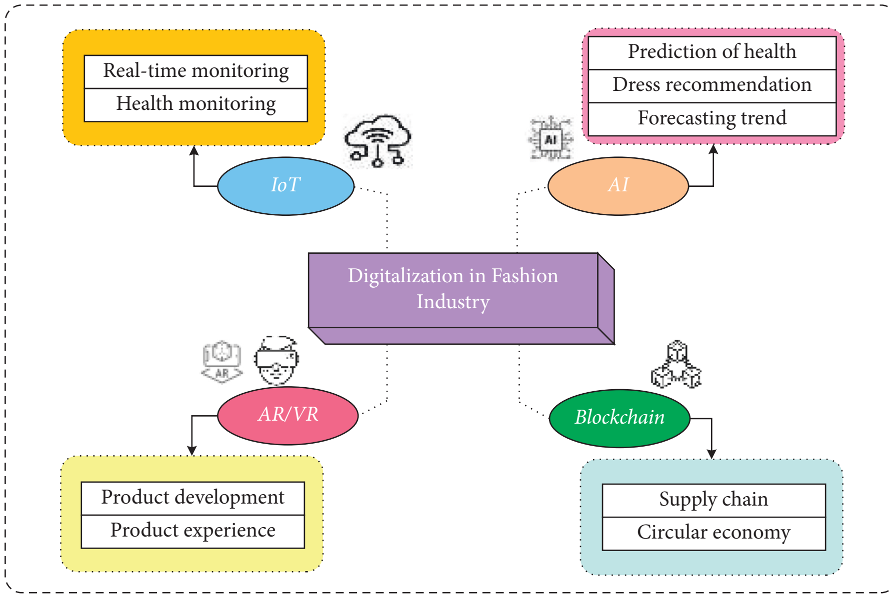


Figure 3: Digitalization in the fashion industry.

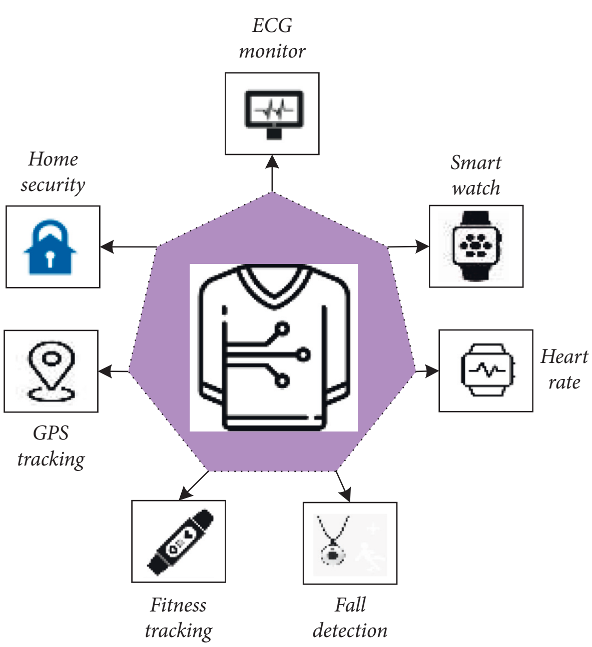


Figure 4: Smart clothing with wearable 2.0.

(sensors, communication protocol, and signal collection components). The user interface of high experience only presents in the front-end to update the health and emotional status of an individual to the family members and local health providers through communication protocol (Wi-Fi; BLE). In addition, the real-time health data from the front-end is logged on the cloud server through the communication gateway. The updated data on the cloud data center can be accessed by the medical advisor and family members and can avail emergency and medical aid in case it is an emergency.

The designing of smart clothing with sensors, electrodes, and communication protocol is presented as follows: the materials that are specifically utilized to build smart clothing with flexibility, comfortability, and durability. A study [31] has presented the raw material that is specifically utilized to develop smart clothing. The textile material is chosen for designing smart clothing as it is flexible, soft, and curable according to the body [32]. The nanowire growth and device fabrication are clearly shown in Figure 6. All the sensors in the smart clothing are enclosed and shielded with textile clothes, and the electrodes are covered under clothing. In addition, these sensors are charged with a small-scale battery to obtain physical sensor data, and opportunistic contacts allow the acquisition of the sensor data during the movement. The only limitations till now in smart clothing are completely washable and flexible electronics that can be fit into the textile materials. The idea of developing a resultant membrane-like substance that acts as sensors and feels like the skin is a novel approach to developing biosensors [33]. The invention of a Gecko-based dry adhesive with conductive capability offers favorable outcomes for monitoring biosignals from the wearer's skin in real time through high-activity periods [34]. Table 1 illustrates the different smart cloth products that are designed and marketed by different brands for various applications. The smart cloth is designed to sense heart rate variability (HRV), step count, sleeping assessment, calories burned, ECG, respiratory rate, skin temperature, blood oxygen saturation, temperature, respiratory, and body position. The different wireless communication protocols like Bluetooth, 3G, 4G, and Wi-Fi are majorly integrated into smart cloth to transmit the biological parameters of the human.

The connectivity is crucial in the context of IoT for guaranteeing reliable and robust communication between nodes and cloud servers. In smart clothing, the wireless communication protocol that consumes low power and works on a low-frequency band is preferred for minimizing the effects on humans. Table 2 illustrates the four different

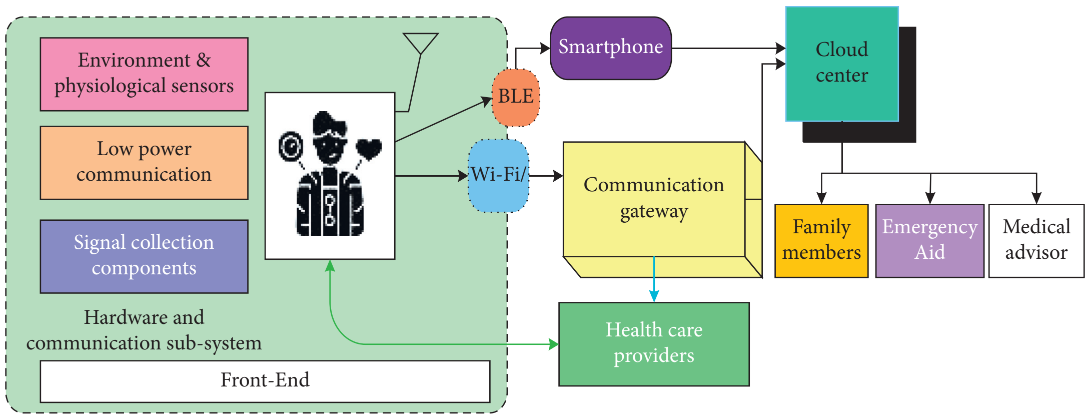
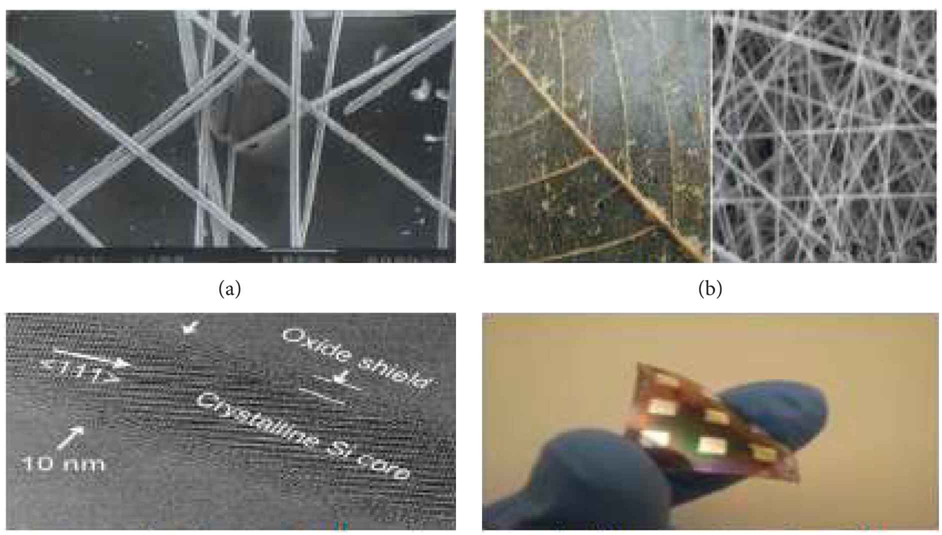


Figure 5: Smart clothing-based healthcare system.



(a) (b) (c) (d)

Figure 6: Raw material for smart clothing [31]. (a) Stainless steel fiber: 1/10 size of human hair. (b) Flexible solar/battery nanotextile. (c) Nanowire (NW) growth and device fabrication. (d) Flexible organic solar cells (https://feel.ece.ubc.ca/content/research-projects).

wireless communication protocol that works in the Industrial, Scientific, and Medical (ISM) band. Long Range (LoRa), IEEE 802.15.4, 6LoWPAN, and BLE are the wireless communication that is feasible in smart clothing for data transmission. As in smart clothing, the amount of data that needs to be transmitted is the low bit rate, so this communication protocol is suitable for these applications.

4.2. Supply Chain. In the fashion industry, the supply chain plays a crucial role, as it provides the flow of goods and services that are required to transform raw materials into the final product. The real-time monitoring and tracking of the supply chain are required in the fashion, as it empowers to visualize the activities that are carried out from beginning to end. Figure 7 illustrates the IoT-assisted traceability architecture that is proposed by [34] for the fashion supply chain; this architecture comprises the following six stages: create, read, communicate, aggregate, consult/trace, and analyze. Under create a stage, the production of textile goods along with the integration of sensors and tags allows to trace in the supply chain. In the read stage, the sensors and tag data are read by the reader, including geographical location and environmental information that is sensed during tracking. In the communicate stage, the traced information is transmitted to the respective authority through the communication protocol embedded in it.

The communication protocol is chosen concerning the size of data and transmission range. In the aggregate stage, the multiple data from various sources are reconciled into one database like a time-series database or data warehouse. Business operations management integrates visibility procedures, supply chain, monitoring, manufacture, and associated human resource activities with a consult/trace stage focus. Data is consumed and interpreted utilizing analytics blocks in this stage to quantify maximum information metrics and indicators that can be used with enhanced visual analytics strategies to evaluate business procedures and produce revenue in the business framework with an emphasis on business methods.

Table 1: Different smart clothing products that are available in the market.

Reference	Product	Dress type	Fabric structure	Data transfer	Sensing	Features
[35]	Hexoskin	Vest	Knitted (27% elastane; 73% micropolyamide)	Bluetooth	HR, HRV, step count, sleeping assessment, and calories burned	UV protection and quick dry fabric
[36]	Bio Device SA	Vest, T-shirt, and baby suit	Knitted (20% elastane; 80% polyamide)	Bluetooth	HRV, HR, ECG, and movement	Disposable electrode
[37]	Healthwatch	Vest	Knitted	Wi-Fi, 3G, and 4G	Heart rate detection, respiratory rate, and skin temperature	Dryable and machine washable
[38]	Emglare	Vest, T-shirt, sports bras, and bra	Knitted (100% polyester)	Bluetooth	ECG and heart rate	ECG sensor, built-in heart rate monitor, and rechargeable
[39]	Neopenda	Baby hat	Knitted	Wireless	Blood oxygen saturation and temperature	Medical grade polymer and silicone
[40]	Bioserenity	Cap and shirt	Knitted	—	—	Detachable e module and washable cap
[41]	Mimo	Baby kimonos	Knitted (cotton and single jersey)	Bluetooth to Lilypad	Respiratory, skin temperature, and body position	Detachable e module and washable
[42]	AiQ Bioman	Vests, T-shirts, and sports bras	Knitted	—	—	Sensors integrated into textiles
[43]	Siren	Socks	Knitted	Bluetooth	Temperature	Dryable and machine washable

Table 2: Wireless communication protocol for IoT in fashion.

Parameters/wireless network	LoRa	6LoWPAN	Bluetooth low energy (BLE)	ZigBee
Standard	802.15.4g	802.15.4	802.15.1	802.15.4
Network	Wide area network	Personal area network	Personal area network	Local area network
Frequency	433 MHz, 868 MHz, and 915 MHz	868/915 MHz and 2.4 GHz	2.4 GHz	868/915 MHz and 2.4 GHz
Standard	802.15.4g	802.15.4	802.15.1	802.15.4
Topology	Star of stars	Star and mesh	Star and bus	Star, P2P, mesh, and tree
Range of transmission	5 km–20 km	10–50 metres	10 metres	10–50 metres
Data rate	50 kb/s	250 kb/s	1 Mb/s	250 kb/s

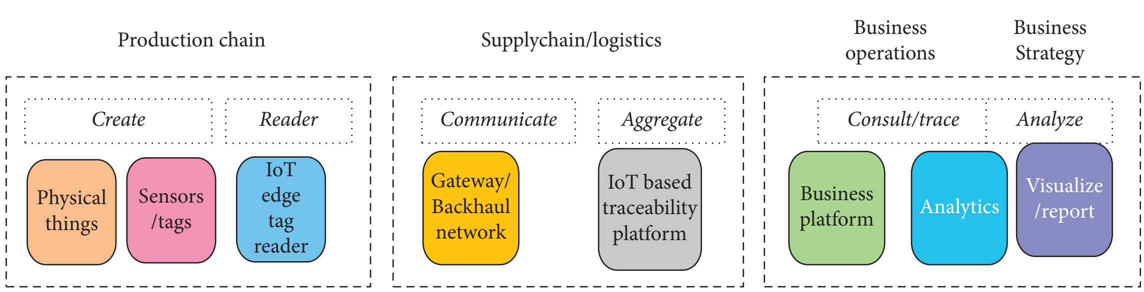


Figure 7: IoT traceability architecture for fashion supply chain.

The traceability technologies that are supported with IoT are barcodes, QR codes, which are better than UPC (Universal Product Code), and EAN (European Article Numbering) [44]. In a few studies, the barcode is integrated with radio frequency identification (RFID) technology to establish a traceable identification system [45]. The advanced version of the barcode is a QR code, which is approved by ISO standards to use a traceability system during the supply chain [46]. IoT traceability technologies, on the other hand, typically comprise NFC, RFID, and Bluetooth low energy (BLE), which are now extensively accessible technologies that have been unified as built-in technologies by various smartphone makers. RFID system comprises two major components, a reader and a small radio frequency transponder (RF tag), which are utilized for the operation [46].

Active RFID Tag Systems and Passive tags are two different types of RFID tags that operate on different frequencies and powers source. An active RFID tag is powered with a battery to communicate with the reader, and it is actively implemented in iLocate for a highly accurate object location solution [47]. NFC is a subset of RFID technology that uses electromagnetic fields to communicate, and it operates at a 13.56 MHz frequency with bandwidth speeds of 424 kbits/s [48].

BLE is a low-latency, low-bandwidth, short-range protocol for IoT applications, its power consumption and latency are 10 times lower and 15 times lower than traditional Bluetooth, and latency is 15 times lower [49]. It has been widely implemented in smart manufacturing and agri-food tracking systems. Along with these technologies, Low Power Wide Area Network (LPWAN) technology has gained wide attention due to its low power consumption for long-range transmission [50]. LoRa, narrow-band IoT (NB-IoT), and Sigfox are categorized as LPWAN technologies [51]. LoRa network is an open-licensed communication protocol that transmits data to the range of 10–15 km.

As a part of traceability, this technology is implemented in cattle tracking [52], and it is concluded that it captures the object traceability effectively in the study of bicycle location tracking and management system [53]. NB-IoT is an LPWAN technology that can collaborate with LTE or GSM under licensed frequency bands for wide area coverage [54]. In [55], NB-IoT is employed to build a smart parking system as part of the smart cities context. Sigfox was a forerunner in the LPWAN market, employing ultranarrow-band modulation on its physical layer while maintaining network protocols private [56]. Sigfox offers a viable solution for integrating LPWAN technology in the recommended agriculture setting, where there is a natural demand for long-lasting battery sensors.

5. AI in Fashion

In this section, we discuss the significance of AI in the fashion industry for multiple applications such as prediction of health-related issues of elders, patients, and children, fashion trend forecasting, and dress recommendation based on environmental parameters.

5.1. Trend Forecasting and Dress Recommendation. Clothing is a type of sign that conveys the wearer's interior perception through the exterior appearance [57]. It can transmit information about the wearer's preferences, faith, personality, occupation, social status, and outlook on life. Predicting fashion and recommending the clothes is possible by analyzing the fashion information available in social networking through images and text [58]. Furthermore, there are several fashion-related forums, such as Chictopia and Loo-book, which are recognized for sharing personal fashion styles. The characteristics and qualities of these clothes photographs shared on social media can reveal more about the wearers' personalities [59]. Although researchers have investigated social media textual content such as post and comment prediction, emotion, and information diffusion [60], research using social media picture analysis is still limited in evaluating fashion styles or trends [61]. Online clothes images from social media and other sources, on the other hand, can be an excellent source for assessing and building online fashion recommendations [62, 63].

Consumer fashion choices are frequently influenced by a variety of elements, including demographic, regional, individual preference, interpersonal influence, age, gender, season, and culture [64, 65]. Effective recommendation systems [66, 67] are critical tools for successfully doing e-commerce operations in the current day. In the case of fashion recommendation, the use of convolutional neural networks (CNN) or deep learning (DL) methods for image analysis, statistical analysis for recommendation system comparison, quantitative or mixed-method based on research design, and the formulation of experimental models for machine learning (ML) application can be an essential integration for creating an efficient fashion recommendation system [68–70]. Reference [64] concentrated on the study of patterns for various consumer groups using finely grained fashion elements. For the initial period, a large-scale fashion trend (FIT) dataset built from Instagram reports and usage statistics was offered, and a Knowledge Enhanced Recurrent Network (KERN) model was developed, which employed deep recurrent neural network capacity to model time-series details.

Reference [71] proposed a data-driven computational abstraction method based on an AI algorithm to improve the reliability of image-based data processing and reduce the cost of fashion image processing. Reference [72] used DL algorithms to investigate fashion styles and trends across different populations based on street fashion photographs gathered from various Internet sources. CNN is a collection of deep neural network machine learning methods that are commonly used by researchers to extract features from large amounts of visual picture data [73, 74]. The statistical data of fashion product visuals, social media participants, and randomized targeted people from image-sharing web pages have been evaluated using different CNN models to analyze and visualize fashion trends based on street style photos [75]. In [74], information was collected from Instagram postal data by using the CNN model to identify the most prominent top fashion accessories in a certain location. This outcome provided a framework for businesses' decision-making awareness, such as examining customer patterns in various locations, product penetration, and finding common products. Reference [76] used the AlexNet CNN architecture for image classification and feature extraction to create a deep user-based efficient recommendation system by comparing the homogeneity of the user vector with the image vector. Reference [77] used deep net theory to determine clothing style and proposed three improvements to deep architectural systems in the distribution of the computational world driven by deep learning's robust classification capacity and ability to process a large data volume in the big data age.

5.2. Health Prediction with Smart Clothing. In the smart cloth, the number of health sensors that are embedded in the cloth assists in obtaining real-time health data of that particular person. The smart cloth can be utilized for real monitoring of health and other activities of the baby, patients, and older persons. In the case of a baby, the sleeping pattern, health conditions, and milk feeding pattern monitoring are crucial to maintaining the health of the baby. In addition, the real-time tracking of babies and their activities is significant to ensure safety and security. In the case of the patients, the biological sensors integrated into the smart cloth of patients keep tracking of pulse rate, body temperature, oxygen intake, and function of neural signals in the real-time scenario. In the case of an older person, health monitoring and real-time tracking of their activities are vital to ensure safety and health. Early fall detection, fall detection alerts, medicine intake remainder, and emergency alerts are the major requirement of smart cloth for older people.

As discussed early, AI has gained wide attention in the prediction of events based on input data available in the form of images and texts. In smart cloth, the real-time sensor data (heart rate, heart rate variability, temperature, oxygen intake, and stress level) obtained from the sensory unit is the input to the AI model for the prediction. DNN has received a lot of interest in AI because it can filter input through a cascade of numerous layers, with each consecutive layer using the output from the preceding one to inform its results. DNN necessitates minimal data preprocessing. Many of the filtering and normalization activities that must be performed by human programmers when utilizing other machine learning approaches are handled by the network itself.

Figure 8 illustrates a framework of smart cloth with DNN and cloud server for detection of health abnormalities and generating emergency alerts. Here, the smart cloth is embedded with a wireless communication protocol to transmit the sensor data based on time interval on the cloud server gateway. The DNN model is applied to the sensor data that is available in the cloud server. Based on the outcome of the DNN model, the necessary further action is represented in Figure 8. In case of health abnormalities, it sends an alert to the personal doctor/health provider, and in case of emergency, it sends alerts to the family members to take immediate action. In addition to the smart cloth, footwear like shoes is also integrated with sensor and communication-based systems to monitor the walking pattern and other health parameters.

6. Blockchain in Fashion

Blockchain was developed for business and supply chain applications as a private blockchain, as it provides privacy and controlled access to approved and identifiable participants. Depending upon the accessibility level, each participant has the right to access the subset of the information. Private blockchain encourages building trust and transparency among the participants in the supply chain. Furthermore, each player can sustain their strategic advantage without exposing all facts and methods to competing organizations. Conversely, the blockchain shall capture all transactional data and provide customized access to supply chain participants while remaining auditable and verifiable [79]. Figure 9 illustrates the participants that are involved in the fashion supply chain, including fiber producers, yarn manufacturing, fabric manufacturing, apparel manufacturing, retailer, and customer.

The private blockchain-based framework of the fashion supply chain is proposed in [80] (Figure 10), where it comprises organization-level and operation levels. The actions engaged at the organizational level include methods for personalized accessibility of records, the configuration of private blockchain infrastructure for the supply chain, and techniques for connecting the blockchain network. The process of recording and storing information connected with various supply chain stages will be detailed at the operational level. For supply chain track and trace application areas, transaction validation mechanisms and smart contracts can also be set up. Maker aspects of the organization-level include channels, applications, ordering services, and membership services.

Channels are network subdivisions used for information segmentation, and it has their blockchain, which is recorded on a distributed shared ledger. A group of upstream suppliers, often trading with a single product, might link up to a single channel or a group of channels, every for a separate kind of operation. Peers are process methods that handle the digital contract, and depending on their functions, they enable the creation, endorsing, and validation of transactions. Only the primary actors of a supply chain must present peer systems based on their roles because it requires capital and system management.

Applications are user-responsive software interfaces that can be leveraged to execute blockchain queries, and to include in the shared ledger, queries can be made to read, update, and authenticate. The blockchain application can be executed on numerous devices with unique access rules from each partner. The ordering facility is often a third-party service that is in charge of network maintenance. Its major purpose is to accumulate a collection of operations complemented by supply chain associates, enroll them on a block, organize them in a rational sequence, and deliver the block for authentication. In a private blockchain network for supply chains, membership services produce and distribute new public key pairs to participants. The key combinations define the kind and scope of exposure to the blockchain network based on the function and ownership of supply chain partners.

At the operational level, the design of a traceability architecture is crucial. The architecture should exhibit operations such as gathering, planning, organizing, and trading traceability data at various stages of the fashion supply chain. Most upstream participants in the fashion supply chain accept raw materials in various types as an entry from providers and execute diverse strategies to create the end product that is forwarded on to the succeeding supply chain associate. This procedure is repeated by multiple supply chain associates until the end product is delivered to the store. It is also critical that the relevant data is gathered and disseminated to comply with local rules and certification bodies' standards. To simplify complexity, the traceability information was divided into four categories: public

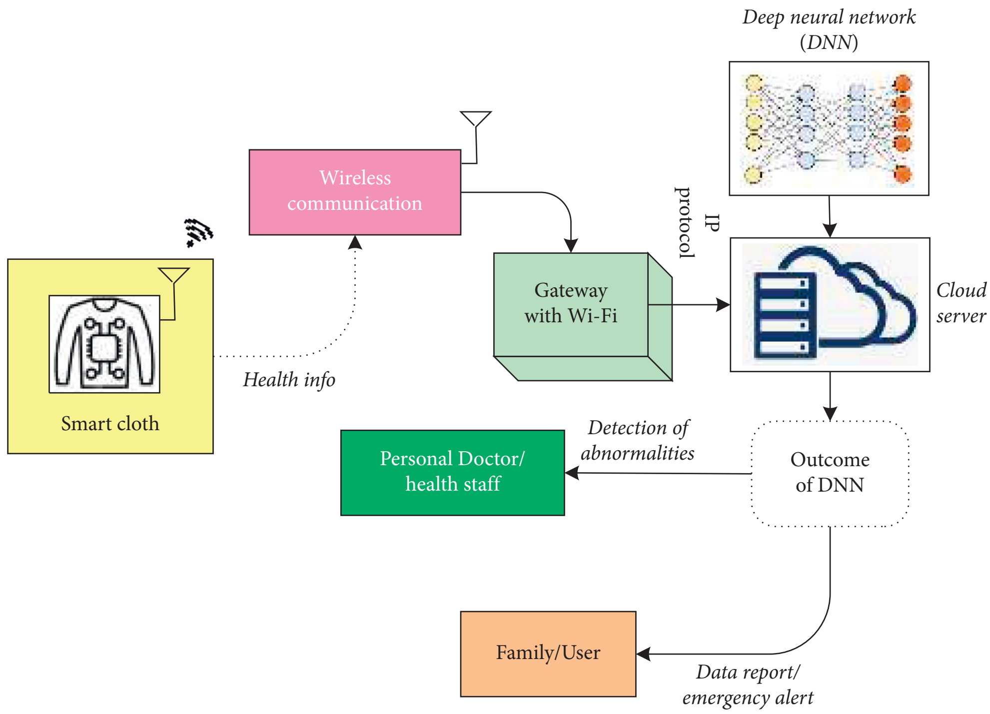


Figure 8: DNN-based smart cloth for health monitoring and prediction of abnormalities [78].

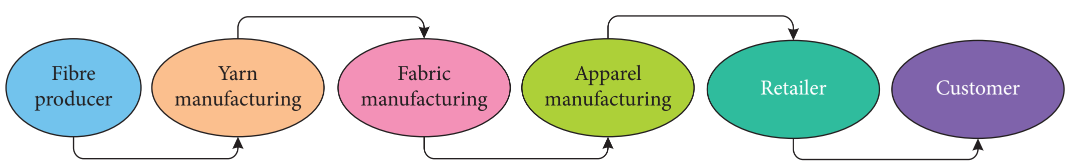


Figure 9: Participants in the fashion supply chain.

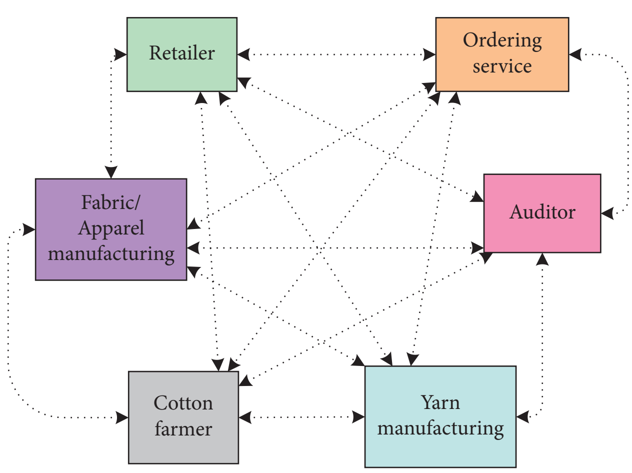


Figure 10: Private blockchain network of fashion supply chain [80].

shareable, private shareable, linkage, and secured information. Public sharable information can be distributed to any third party and customer since it contains critical information that must be captured. The amount to which public shareable information is collected and shared determines the level of transparency of a supply chain for its client.

Private shareable information is a collection of information that is critical for B2B operations, particularly those that are valuable for material processes. When this information is securely exchanged among supply chain partners, it can improve visibility and minimize risk. Secured information is encoded data that can only be accessed by a chosen group of B2B partners. Secured information is sensitive and confidential, and it includes financial data, intellectual property data, and a range of other pieces of information that can be utilized to obtain a significant gain. Linking information is critical to the blockchain's operation, and it is this data that is checked throughout each transaction across the shared ledger managed by the smart contract. This includes four value fields: Transaction Signature, Public Key, Traceability ID, and Asset Value. To validate the transaction, all of these would be checked against the global state of the shared ledger.

7. AR and VR in Fashion

In this section, we discuss the significance of AR and VR in the fashion industry for providing a real-time experience. Here, initially, we discuss AR, and it is followed by VR.

7.1. AR. In fashion commerce and industry, AR comprises virtual try-on that use personalized or noncustomized simulated models to replicate the presence of apparel product patterns on a human form [81]. A recent study proposes a better innovative virtual trial room integrating IoT mirrors to provide customers with a more accurate try-before-you-buy clothes purchasing practice, where AR was employed for skin color identification and outfit suggestion based on skin color [82]. Customers in the fashion industry frequently seek to locate adequate clothing that meets their requirements, and in a few instances, the patterns, colors, and designs elements can make them feel uncomfortable [83]. To overcome these challenges, numerous researchers advised following a user-customization system in which the client can design his or her garment [84]. For that, [85] has suggested using AR to explore textiles with realistic illumination. In their study, they used an AR application to create real-time augmentation on garments by identifying spare cloth in video footage. Research has confirmed that real-time 2D AR on a nongrid object like clothing can monitor a modern circular system and apply the proper radiance and shades to the product.

In mass customization, they created a whole new product mode by combining customized and mass production to provide clients with a variety of brands, draperies, materials, and colors [86]. Scientists are seeking to manufacture footwear with motion detectors rather than modifying t-shirts. Reference [87] established a systematic approach for designing and customizing footwear for youngsters, which supports shoe personalization and pattern development. The design module's functions include color, embroidery, texture, and carving design, with unity3D utilized for color and texture representation and the UVW mapping technique used for mapping. Reference [88] suggested a full-featured garment customization system based on AR, where OpenGL 3D rendering, Azure Kinect somatosensory technology, and a somatosensory virtual fitting room are employed.

The user can apply numerous designs to the cloth and then try virtual fitting, where it encapsulates the deepness data stream of human bones via the Azure Kinect somatosensory technology and does bone-tracking handling as well as 3D clothing virtual try-on in the right location on the human body. Reference [89] conducted research on marker-based AR utilized in a physical clothing marketing ecosystem via AR mobile applications, which cooperate with the consumer by generating data on the product, such as colors available, size, and stock, and visualizing a 2D pattern of the item. Reference [90] offered a mechanism to use the 3D model of a t-shirt by scanning a catalog as an enhanced version of the above approach. Both AR applications were created using the Unity3D and Vuforia AR kits.

7.2. VR. Online shopping has improved dramatically with the growth of the Internet over the past few decades. As a consequence of the pandemic, buying goods and services via Internet platforms has grown commonplace. As a result, it is projected that a new form of shopping environment based on VR would become increasingly prevalent. A VR environment would promote multisensory and physical engagement of fashion-related retail operations, shopping service content to consumers, presenting more precise and realistic products, and facilitating a genuine buying capability. There has yet to be a systematic investigation on the nature of experience supplied to customers while shopping for fashion products using VR. User experience (UX) is a highly complex topic that combines human emotions, usage conditions, and expectations [91, 92]. This physical paradigm allows for the exploration of product events in practically any dimension, including aesthetic, cognitive, and emotional components, as well as sensory aspects [93]. Utility, fun, aesthetics, usability, intention to use, and impairment concerns are among the UX criteria they proposed. Unlike VR games or sports, VR shopping is not a platform that can be enjoyed by a large number of people at the same time. Table 3 illustrates the attributes of UX experience in terms of aesthetics, intention to use, playfulness, usability, and utility.

VR is a computer environment that permits customers to immerse themselves in a virtual world via multiple forms of virtual sensory synthesis response, such as hearing and sight [97]. It refers to cyberspace in which users can experience a sensation of existence and absorption, as if they were physically present in that area, in an intentionally created world of senses. Immersive VR is a method in which a person employs and observes a head-mounted display (HMD) attached to a computer or mobile device [97]. The user's field of view is regulated, the visual stimuli of the actual world are prevented, and the user only receives a 3D image generated by the HMD by putting a distinct device in an immersive VR environment [98, 99]. In this way, it becomes possible to experience a virtual world as if it is the real world, and an intense sense of reality and immersion occurs. However, immersive VR has a few limitations like headache, dizziness, and nausea, and also user's need to buy VR devices negatively impacts customers for product shopping using VR [98, 99]. An empirical experiment was undertaken focusing on the UX rating items created in this manner. UX of immersive and nonimmersive VR is evaluated under the parameters such as telepresence, sharpness intention to use, and playfulness. The immersive type has high UX than the nonimmersive type focused when averages of telepresence, sharpness intention to use, and playfulness are evaluated. It concludes that the fashion product shopping experience in the immersive VR empowers users to experience telepresence, sharpness intention to use, and playfulness parameters effectively.

8. Discussion and Recommendations

According to the UN, the fashion industry needs to meet the following goals: build resilient infrastructure, promote inclusive and sustainable industrialization, foster innovation, ensure sustainable consumption and production patterns, and take urgent action to combat climate change and its impacts. To meet all these goals, the fashion industry needs to incorporate digitalized technologies like IoT, AI,

Table 3: Previous studies determining the elements for UX evaluation.

UX component	[94]	[95]	[96]
Aesthetics	—	Creativity, intuitiveness, and liveness	Aesthetics
Intention to use	Satisfaction	Inspiration	Intention to use
Playfulness	Delightfulness	Entertainment and playfulness	Playful attributes
Usability	Reliability	Accomplishment and efficiency	Usability
Utility	Adjustability	Enhanced awareness	Utility

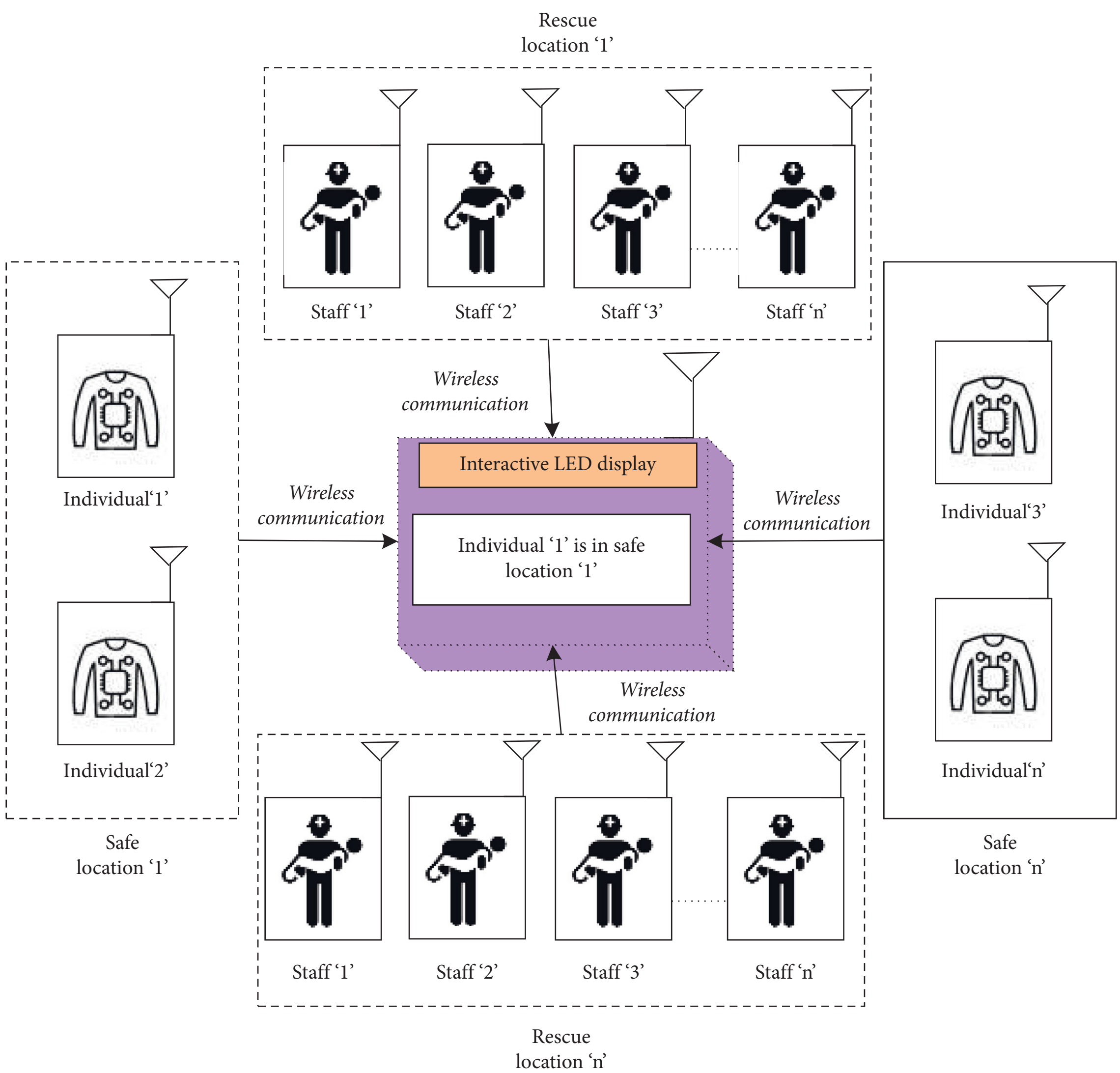


Figure 11: Wireless-based interactive LED display during rescue operations with smart clothing.

blockchain, AR, and VR. With this motivation, this study explored the different studies that implemented these technologies for smart cloth (health), supply chain, circular economy, dress recommendation system, fashion trend forecasting, health prediction, and virtual and augmented based shopping experience. From our exploration, the following findings and suggestions are addressed:

(i) *Sustainable Material Usage*. It is concluded by the United Nations that the fashion industry is also one major sector that contributes to carbon emissions due to its manufacturing practices. The manufacturing unit of the fashion industry needs to adopt 3D printing in designing clothes and garments with sustainable materials. 3D printing has gained attention in the footwear industry to mass customization insole, outsole, and middle sole of shoes [100]. It is encouraged to use 3D printing in the other areas of the fashion industry for the benefit of achieving a sustainable manufacturing environment as it enhances time efficiency, zero-waste production, product customization, and design flexibility [101].

(ii) *Wide Adoption of Blockchain in Fashion*. The fashion industry comprises the supply chain that presents the stage-by-stage production of products from raw material to the final product. The main concern in the fashion supply chain is the protection and privacy of a huge volume of product data that are available with industries. Currently, many industries have effectively implemented the blockchain for their supply chain. So blockchain technology needs to be widely implemented in the fashion industry for better security and transparency [102]. Along with this, blockchain technology achieves an effective circular economy that enhances trading platforms.

(iii) *Advancement in Energy Storage*. In smart clothing, energy storage and energy management play a significant role in the functioning of IoT devices embedded into it. The researchers of material science need to do thorough research on the energy storage devices that can be embedded inside the cloth with flexibility and comfortability [103, 104]. Along with energy storage devices, the communication protocol integrated into the smart cloth should consume low power and have minimum RF effect on the human body.

(iv) *Advancement in Technology Training*. AR and VR have gained wide attention in the fashion industry, as a retailer and manufacturers have implemented these two technologies in terms of virtual fitting, in-store navigation, virtual try-on, and so on [105]. The technology training of the employers through simulation should be effective and have minimum consequences so that they can learn the utilization of these two technologies in real time for different operations.

(v) *Integration of IoT, AI, and Edge Computing*. At present, in this study, we have mainly focused on smart clothing in the health sector; as in the current scenario, health is to be given utmost importance in terms of patients, babies, and older-aged individuals. From the exploration of the previous studies, it is concluded that limited research is carried out on the integration of edge computing, AI, and IoT in smart clothing for the real-time identification of anomalies in health [106].

(vi) *Smart Clothing-Based Framework for Rescue Operation*. In the rescue operation, the location tracking and identification of the precise person to get assistance plays a crucial role. A framework (Figure 11) needs to be designed in such a way that the people can easily identify the respective rescue staff with location on the interactive LED display. Here, people and rescuing staff should wear smart clothing, as the information related to rescued individuals and their location will be wirelessly displayed on the LED display [107]. This indeed enhances the tracking of individuals during the rescue operation, and also this concept can be replicated in other areas for different interactive applications.

9. Conclusion

The fashion industry generates 3 trillion dollars and contributes to 2% of world GDP. In addition to this United Nations concluded that this industry has a lack of concerns for social and environmental issues in terms of generating CO_2 emissions and wastage in material consumption and production. However, the integration of digitalized technology like IoT, AI, blockchain, AR, and VR can achieve the United Nations SDGs relevant to the fashion industry. With the motivation of this, this study explored the progress of digitalized technology in the fashion industry. During the exploration, the study focused on digitalizing technologies in the fashion industry for smart clothing, forecasting fashion trend, dress recommendation on the basis of environmental conditions, prediction of health, real-time supply chain, and fashion and shopping experience. Based on the exploration, this study presented the limitations and suggested recommendations such as wide adoption of blockchain in fashion supply chain; advancement in energy storage for smart cloth; integration of IoT, AI, and edge computing; and smart clothing-based framework for rescue operation for the future enhancement.

Abbreviations

AI: Artificial intelligence
AR: Augmented reality
BLE: Bluetooth low energy
CNN: Convolutional neural networks
DL: Deep learning
EAN: European article numbering
EMG: Electromyography
ECG: Electrocardiogram
GDP: Gross domestic product
HMD: Head-mounted display
HRV: Heart rate variability
IoT: Internet of things
ISM: Industrial, Scientific, and Medical
KERN: Knowledge Enhanced Recurrent Network
LoRa: Long Range
ML: Machine learning
NB-IoT: Narrow-band IoT
RFID: Radio frequency identification
QoE: Quality of experience
QoS: Quality of service
SDGs: Sustainable development goals
UPC: Universal product code
UX: User experience
VR: Virtual reality.

Data Availability

No new data were generated for the study.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

All authors have contributed to the manuscript.

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