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Digital Transformation in Textile & Apparel: Leveraging Martech Strategies within Industry 4.0

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Abstract

The fashion sector is at the forefront of digital transformation, propelled by a change in consumer preferences that favours supra-functionality over mere economic functionality. This paper aims to highlight the significance of new age marketing strategies in the field textile & apparel sector. The increasing digitalization in fashion aligns with the emergence of digital fashion, which effectively addresses the swift changes in consumer demands. Cloud-based digital fashion platforms embody a comprehensive omnichannel strategy, uniting all participants & offering real-time insights into their operations.

The digitalization process presents both advantages & challenges for the sector, influencing its opportunities & potential obstacles. Strategies for digital transformation, encompassing Artificial Intelligence, cloud computing, blockchain, big data analytics, Internet of Things (IoT), Radio Frequency Identification (RFID), & 3D printing, enable the clothing industry to adopt the industry 4.0 paradigm. Considering that the fashion industry is the second largest contributor to environmental pollution, it is essential to adopt proactive strategies aimed at achieving business sustainability through the implementation of smart factories & digital apparel.

Keywords: Textile & Apparel; Industry 4.0; Digital Transformation; Cloud Computing; Digital Fashion; Sustainability.

Introduction

The emergence of Industry 4.0 took place in the year 2010.The concept of Industry 4.0, also known as I4, was initially presented by the German government through the "High-Tech Strategy 2020 Action Plan," which advocates for the digitalization of manufacturing processes (Drath and Horch, 2014). Digitalization, or the transformation of an economy through digital means, is a term frequently encountered in contemporary discussions (Innolytics, 2020). The emergence of the term Retail 4.0 in the retail sector can be attributed to the implementation of Industry 4.0 technologies such as Artificial Intelligence, the Internet of Things, Cloud Computing, Augmented Reality & Big Data Analytics.

The evolution of information & communication technology (ICT) has further propelled these digital innovations within the sector. The transformation is being propelled by technologies including cyber-physical systems, the Internet of Things, personalization, customization, artificial intelligence, & high-performance computing. Additionally, augmented reality & virtual reality are increasingly utilized to enhance the shopping experience in a simulated environment prior to purchase.

Retail 4.0 is often known as the Omnichannel, integrates various technological platforms to deliver a cohesive purchasing experience for consumers. It relies on internet connectivity through designated information sensing devices & protocols to facilitate the exchange of information & communication. The evolution of digital solutions, driven by the digital economy, has notably hastened the transformation of the conventional fashion industry (Lucian et al., 2023). Within this digital landscape, the conventional fashion sector is positioned at the forefront of global transformative changes (Lucian et al., 2023), which contribute to its volatility, speed, diversity, complexity, & dynamism, thereby necessitating the adoption of digital solutions. The current socio-economic landscape, particularly the rise of a non-contact society during the pandemic, has prompted the fashion industry

to undergo digital transformation (Simon et al., 2010). This transformation is characterized as "The industry's transition to the digital realm" (Gary Gereffi, 2014),

During the recent years, the fashion industry has undergone a significant transformation, moving away from traditional retailer-led manufacturing towards a contemporary model characterized by fast fashion & consumer-driven production. This sector is recognized for its volatile demand & supply dynamics, extended production lead times, brief fashion cycles, selection of raw materials, seasonal fluctuations, & diversity (Huang and Rust 2020). Current industrial trends, including fast fashion & mass customization in the fashion sector, are heavily reliant on rapid response times & swift delivery.

Review Of Literature

The fashion & apparel industry has evolved into a high-tech sector on a global scale. To address this demand, the industry can leverage a variety of digital technologies, including cutting-edge computational platforms such as virtual reality (VR), augmented reality (AR), & mixed reality (MR) (Nunes et al., 2017). Industrial enzymes find applications across multiple sectors, including leather, tanning, & textiles (Li et al., 2012; Sarmiento et al., 2015; Rahman et al., 2019). It is estimated that around 10 percent of industrial enzymes are utilized in processing of textiles (Silva et al., 2010).According to the findings of Sun and Zhao (2021), The fashion sector is witnessing considerable expansion as a result of progress in digital technologies, such as artificial intelligence, robotics, agile manufacturing, on-demand production, virtual fitting rooms, e-commerce platforms, & social media.

Digitalization refers to the integration or enhancement of digital technologies that influence the economy, society, & culture, facilitating a change in business operations, functions, models, processes, & activities (Brennen and Kreiss 2016). In contrast, digitization is characterized as the tangible process of converting, interpreting, storing, & transmitting analog information streams, including images, video, & text, into a digital format (Negronponte 1995; Brennen and Kreiss 2016).

The technological components of Industry 4.0 comprise cyber-physical systems (CPS), cloud computing (CC), big data, the Internet of Things (IoT), & the process of additive manufacturing, which is widely recognized as 3D printing (Alcacer and Cruz-Machado, 2019; Ardito et al., 2019). The concept of Industry 4.0 includes various technological innovations that influence both products & processes, enabling the creation of smart products through the integration of digital & physical environments (Schmidt et al., 2015).

The elements of technology serve an essential function in assessing the technological capabilities within an organization (Susihono, 2014). The significance of Industry 4.0 technologies has been widely recognized in academic literature (Nunes et al., 2017; Kusiak, 2018). The elevated labour costs in developed nations have led to a preference for the production of textile & apparel goods in developing countries (Rahman and Mendy, 2019) & hence developing nations need to upskill their technical knowledge.

The concepts of smart factories, smart products, & smart services is garnering significant interest from both researchers & industry professionals, particularly regarding their impact on emerging & transformative business models for the upcoming era (Kusiak, 2018) & the incorporation of supply chain information in the development of models & business networks (Garay-Rondero et al., 2019).The inclination towards customization is, in fact, amplified by the social media communication preferences of modern users, thereby broadening the design boundaries to incorporate participatory processes (Noor Al-Deen Hana and Hendricks, 2012; Flichy, 2007; Bollier and Racine, 2005).

Cyber Physical Systems (CPS) are automated frameworks that facilitate the amalgamation of physical processes with computational & communication networks. In contrast to conventional embedded systems that function as independent units, Cyber-Physical Systems (CPS) emphasize the interconnection of multiple devices. The advent of Industry 4.0 will significantly impact manufacturers & their workforce, as well as the firms that provide manufacturing systems.

The integration of Industry 4.0 technologies within the fashion industry is instigating significant & disruptive transformations across both the backend & frontend of the value chain. These transformations are driving the advancement of innovative processes, products, services, & business models that are marked by greater speed, intelligence, & efficiency. (Bertola and Teunissen 2018; Kalbaska and Cantoni 2019).

The integration of digital technologies within the fashion industry has historically been in a phase of exploration, hindered by various obstacles that impede the speed of implementation, such as financial limitations, lack of expertise, & resistance to change. However, the pandemic has accelerated a transition towards digitalization in the fashion sector, promising to promote innovation & sustainability in all dimensions of the industry (Brydges, Retamal, and Hanlon 2020; Gonzalo et al. 2020).

The fashion industry is recognized as an area recognized for its profound cultural impact (Bertola et al. 2016; Martin and Vacca 2018). The emergence of digital technologies has enabled the digitalization & digitization of information & processes, leading to a digital transformation that alters value-creation methods & brings forth new products & services. This transformation involves managing the structural changes & obstacles encountered during the process (Vial 2019).

The ongoing digital transformation in the fashion sector influences the complete value chain, causing considerable modifications in customer interactions & supply chain processes due to the integration of 3DVD (3D Dimensional Virtual & Digital) technology (Arribas and Alfaro 2018). The utilization of 3DVD technological systems, which employ computer generated images of garments or accessories throughout various phases of production & distribution, affects customer experiences & behaviours while providing opportunities for the dematerialization of the fashion sector.

The 3DVD design processes enable collaboration across various disciplinary fields, fostering transdisciplinary knowledge & hybrid design approaches that promote creativity & innovation (Marshall and Pengelly 2006). The open-source philosophy inherent in digital fashion provides enhanced access to educational resources shared within the digital apparel community (Sarmakari 2021). The emergence of interactive, digitally oriented platforms is hastening the speed & techniques of fashion communication & distribution, compelling fashion companies to evolve & enhance their functions within the realm of fashion media (Cantoni et al. 2020). Digital platforms that support mass customization & production on demand facilitate personalization in aspects such as style, colour, size, & other preferences, involving co-design processes among customers, retailers, & manufacturers (Maldini 2017).

3DVD technologies facilitate the digital transformation of "fast fashion" within the virtual realm, offering avenues to positively impact the environment & promote individual self-expression on social media platforms. Nonetheless, there are apprehensions that this may adversely affect the shift towards more sustainable consumer practices, particularly in relation to overconsumption behaviours (Crewe 2017). "Although digitalization is already a significant catalyst for societal change, it has thus far resulted in increased consumption & inequality, remaining linked to the indirect utilization of energy & materials, thereby perpetuating resource-intensive & greenhouse gas-emitting progression patterns at the macroeconomic level" (Wiedmann et al. 2020).

The application of 3D modelling facilitates the integration, optimization, & enhancement of the design & development workflow through comprehensive digitalization & cohesive design processes, including iterative prototyping, fit testing, functional performance simulations (such as thermal analysis), visualization of aesthetic attributes (including colour, pattern, & material), & production specifications (Papachristou and Bilalis 2015). This digital methodology improves the efficiency of material-resource utilization for physical samples, accelerates production timelines, promotes creative design, & lowers expenses (Demarco et al. 2020).

Digital production-on-demand facilitates a reduction in lead times & logistics using eco-friendly, localized, & on-demand small-scale urban micro-factories. These facilities create a more concise supply chain by eliminating excess inventory of unsold products & improving working conditions (Clarke-Sather and Cobb 2019; Ashby 2016). Digital retailing enhances customer experiences by offering innovative services, such as personalization, & by immersing individuals in creative, gamified environments (Silvestri 2020).

The introduction of innovative services & processes, an enhanced focus on customer needs, increased customization, initiatives aimed at shortening lead times, novel marketing & distribution strategies, improved energy efficiency in production, proactive maintenance, automation of an inbound logistics, intelligent data collection, & miniaturization represent pivotal trends that align with the principles of Industry 4.0 (Schmidt et al., 2015).

Methodology

The study delves into the topic of digital transformation from the perspective of textile & apparel industry which can contribute to better comprehend Industry 4.0 from a viewpoint of specific domain. The concept is covered from recent studies from eminent journals & reports globally.

Discussion

The fashion industry is undergoing a shift from mass production based on standardized sizing to a model of personalized manufacturing driven by consumer preferences. Conventional methods of producing & marketing fashion items are facing significant challenges. The primary issues include extended production lead times, disjointed supply chains, delays in market entry, & an increase in the number of fashion seasons characterized by greater volume, variety, & speed. Consequently, the supply systems within the fashion sector, which are influenced by rapid trends, are defined by their need for shorter lead times in responsiveness, production, & high adaptability.

The textile & clothing industries are essential components of the economies in both developed & developing countries (Lalic et al., 2019). To reduce production costs, clothing companies based in developed nations are relocating their manufacturing activities to emerging markets (Dachs et al., 2019). For over two decades, countries including the United Kingdom, & the United States have shifted their clothing manufacturing to more economical locations such as China, India, & Sri Lank (Dachs et al., 2019; Stentoft and Rajkumar, 2020). In recent years, there has been an increasing focus on the relocation of manufacturing, especially with the incorporation of Industry 4.0 technologies (Stentoft and Rajkumar, 2020). The advent of automation & robotics, which often requires minimal or negligible human involvement, is prompting companies to reassess their decisions regarding manufacturing locations (Bertola and Teunissen, 2018).

In rapidly evolving technological landscapes, particularly within high-tech sectors, it is essential for companies to recognize the importance of formulating strategies for the development of new products & process innovations that leverage emerging technologies. The adoption of Industry 4.0 is becoming more prevalent across diverse applications & industries, allowing organizations to achieve a competitive edge embracing digital transformation (Drath and Horch, 2014; Ardito et al., 2019).

As noted by Park and Jayaraman (2017), the amalgamation of electronics & textiles has established the groundwork for wearable sensors, highlighting the significant impact of technology within the textile sector.

Contemporary companies are actively seeking hybrid professionals who possess a blend of expertise in digital technology, fashion, & business (Kalbaska and Cantoni 2019). The emergence of 3D virtual design (3DVD) technologies in the fashion sector has prompted educational institutions to incorporate 3DVD fashion design programs into their curricula (Ftalliance 2020), aiming to equip aspiring professionals for the fashion-tech sector. Research by Maldini et al. (2019) indicates that garments that are collaboratively designed in a digital format & manufactured on demand often enjoy prolonged product lifespans, due to the emotional & practical relationships that users cultivate with them. Furthermore, digital garments enable the replication, conversion, manipulation, & recombination of data, thus promoting a more equitable cultural remix of information & products (Brennen and Kreiss 2016).

The application of digital transformation in textile & apparel can be understood through the below disruptive technologies.

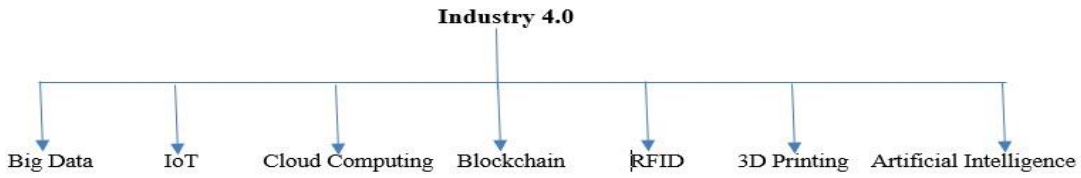

Figure 1: Industry 4.0 technologies

I. Big Data

Big Data Analytics (BDA) refers to the method of assessing the extensive data that an organization has accumulated (Lim et al., 2020). This approach facilitates data-informed decision-making, revenue forecasting, inventory management, improvement of customer relationships, & ultimately, the enhancement of both revenue & profit margins. Additionally, BDA seeks to elucidate the reasons behind certain occurrences & to provide guidance for subsequent actions.

Big data has the potential to assist the textile manufacturing sector in generating innovative concepts, identifying emerging patterns, & developing new shapes & styles, which could contribute to sustainable manufacturing practices (Sharma, 2017). It is acknowledged that although intuition & creativity in design play a crucial role in the fashion & textile manufacturing industries, big data serves to inform & guide the production processes (Williams, 2017). Leveraging big data enables organizations to achieve a "competitive advantage" in the global marketplace by replacing conventional chemical processing techniques. (Ansari and Kant, 2017).

Big data analytics & cloud computing facilitate the storage & analysis of user data, enabling retailers to anticipate consumer preferences & deliver personalized services. Furthermore, these disruptive technologies enhance the efficiency, flexibility & competitiveness of the distribution value chain. Data driven innovation (DDI) in textiles, akin to other manufacturing sectors, is evolving in a dynamic & iterative manner, facilitating the concurrent operation of essential processes. Data can be extracted using sophisticated models, & the results are transformed into a comprehensible format (Hanson, 2017). The integration of information products featuring predictive algorithms can provide considerable benefits to the textile manufacturing industry, supporting the formulation of well-informed business strategies.

BDA assists organizations in depicting consumer behavior, understanding their preferences, developing effective marketing strategies, identifying sales transactions, & fostering long-term loyalty relationships. This results in complex decision-making scenarios where multiple factors impact the decision-making process of the company. Additionally, they are able to utilize BDA to forecast consumer loyalty, enabling the identification of loyal customers & the enhancement of profits, as a loyal customer can contribute an extra 25-100% in revenue. BDA was utilized in inventory management to guarantee that shelves remained adequately stocked & to respond to customer demands by linking the central warehouse with the retail locations, thereby facilitating access through cloud computing.

II. IoT

The Internet of Things (IoT) facilitates the retrieval of information through the scanning of QR codes, while cloud computing provides a means for data storage. This allows for smooth navigation between mobile applications & websites. IoT comprises a network of smart physical entities, including sensors, computers, machineries, assets, & products, which interact in conjunction with one another, the internet, & diverse applications. The Internet of Things (IoT) technology is currently being utilized in the retail sector, enabling sensors within physical spaces to interact with customers' mobile devices & monitor the lifecycle of products.

The Internet of Things (IoT) enables a range of functions including forecasting, replenishment, allocation, sourcing, logistics, order management & fulfilment, which are anticipated to be the future trends in the retail supply chain. As noted by Goldberg (2021), IoT is poised to revolutionize data acquisition systems. When IoT is incorporated into an Enterprise Resource Planning system, it allows for enhanced service delivery to end customers, including order automation & product delivery to partner organizations, in addition to data storage, retrieval, & analysis, all of which are integral components of traditional business intelligence. Additionally, the Internet of Things (IoT) supports tracking & monitoring capabilities, offering customers real-time location of data & order notifications. This approach is known as "Geo-location" based marketing.

III. Cloud Computing

Cloud computing is defined as the provision of computational power, data storage, software, & various IT resources on an on-demand basis over the internet through a platform. It involves the aggregation of computer resources, allowing multiple processes to utilize them simultaneously. This technology facilitates the sharing of an enterprise's resources. In addition, the system can be reached from any location, without the need for the

administrator to be physically present (Jayaram, 2017). The availability of real-time data via remote solutions connected through cloud computing & virtual infrastructure enables users to make well-informed decisions grounded in trustworthy information.

Cloud computing is widely recognized as a superior choice due to its cost-effectiveness & ease of use. Predictive manufacturing leverages big data analytics alongside cloud computing to facilitate the development of self-aware machines & systems. The integration of cloud computing with networks, databases, & marketing management systems has led to the creation of a cohesive cloud services platform in marketing management, effectively merging e-commerce with traditional business practices. This technology allows businesses to delegate certain aspects of the information technology value chain, leading to reductions in costs, enhanced flexibility, scalability, improved capacity utilization, greater efficiency, & increased mobility. Furthermore, cloud computing analytics offer fashion brands enhanced insights into their digital strategies through digital transformation services.

The cloud-based, service-oriented platform that offer digital fashion products & services, including B2B & B2C customizations & personalization, signify a significant innovation in business models. By utilizing a cloud-based fashion platform, the digital transformation of upstream processes will furnish real-time insights into evolving customer preferences, allowing downstream industries to implement digital solutions effectively. The growing awareness of environmental issues encourages stakeholders to embrace sustainable practices, particularly when the fashion value chain is transparent, enabling customers to trace the origins of their fashion items.

IV. Blockchain

Certain brands emphasize their distinctiveness by launching exclusive, digital items that incorporate cryptoart, an art generated through a singular algorithm or code capable of producing unique digital products & non-fungible tokens (NFTs) that utilize blockchain technology to verify the authenticity of the apparel. The practice of auctioning these items within a blockchain-supported marketplace further amplifies the uniqueness associated with owning such digital garments.

Revenue streams typically consist of online sales of digital apparel & income generated from consulting services aimed at facilitating the digital transformation within the fashion industry. The blockchain marketplace presents opportunities by utilizing cryptocurrency to engage creative artisans from diverse cultural & geographical backgrounds who lack access to conventional economic systems.

V. RFID

RFID technology that employs radio waves to convey data from an electronic chip, commonly referred to as a RFID tag or a label, attached to an object to a reader for the purpose of tracking and identifying that object. A key function of these identification systems is the collection & transmission of information pertaining to market or customer conditions. This system is termed radio-frequency identification (RFID) & consists of several components, including RFID tags, readers, and antennas.

RFID tags integrated into products have the capacity to retain extensive information concerning the products themselves, the manufacturing processes, & logistics operations. This data can be gathered by sensors located on machinery or at various points post-reading. Upon the sensor detecting the RFID tags embedded in materials, it transmits this information to the machines as a directive. Consequently, machines are able to perform their designated functions automatically.

VI. 3D printing

The reliability of 3D printing technologies is rapidly increasing, & they have already become well-established within the sportswear sector (Birtchnell and Urry, 2016; Korger et al., 2016). Notable examples in the market include knitted sneakers introduced by Nike and Adidas since 2012, which integrate electronic knitting with 3D printed soles. 3D printing technologies have extensive applications in the latter stages of the supply chain, especially in retail, where they facilitate virtual fitting options & decrease the rate of returns for online purchases (Robertson et al. 2020).

VII. Artificial Intelligence

Artificial Intelligence pertains to a machine's capacity to identify, retain information, acquire knowledge, & uncover new insights through the process of data mining. The implementation of on-demand production, supported by artificial intelligence & linked to the display of digital clothing to consumers, fosters a comprehensive approach to sustainability. Environmentally, this method minimizes or eradicates issues such as stockpiling, overproduction, pre-consumer waste, & excessive consumption of raw materials. Additionally, it influences garment pricing by potentially removing the expenses associated with unsold items, establishing a clearer pricing structure, & ensuring fair compensation for designers, manufacturers, & high-quality materials. This, in turn, promotes a balanced relationship between productivity & employment.

This organizational transformation bolsters & nurtures human capabilities, reduces the likelihood of human error, & enhances productivity while facilitating digital operations & innovations. By intelligently leveraging valuable data generated at multiple stages, AI-driven automation in the retail sector will reveal a multitude of opportunities to enhance operational efficiencies, improve quality, & elevate customer service levels.

Industry 4.0, underpinned by a variety of technological elements linked through information & communication technology (ICT), will provide real-time data concerning diverse processes and applications within an organizational structure. This capability will facilitate a better understanding of the current operational environment, uncover faults and failures, and draw attention to areas that could be improved, among various other factors. Furthermore, I4 applications have the potential to enhance self-awareness and productivity, offering more profound insights that can aid in decision-making processes. (Nunes et al., 2017; Ardito et al., 2019). In the context of smart manufacturing, the disruptive technologies associated with I4 facilitate enhancements in the new product development process (DeSilva et al., 2019). The adoption of I4 represents a significant strategic choice, necessitating that organizations evaluate their readiness for such a transition (Schumacher et al., 2019; Sony and Naik, 2019).

Advancements in 3D designing, virtual proto-typing, digital printing, RFID technology, smart manufacturing, & demand planning are poised to significantly influence the fashion industry's "see now, buy now" model, allowing for immediate purchase of collections both online & offline.Smart beacons, referred to as Bluetooth radio transmitters, have the capability to recognize when individuals pass by a retail establishment. Subsequently, they can transmit notifications to these individuals' mobile devices regarding exclusive offers, including discounts or promotional vouchers, aimed at encouraging them to make a purchase at that location. The emergence of "Screenwear" in contrast to "Streetwear" characterizes a selfie culture in which the visual representation & the outward appearance of a garment appear to hold significance.

Smart Factory for sustainability

The foundation of smart factories lies in cyber-physical systems. These systems are capable of addressing intricate challenges associated with supply chain operations & production. The implementation of smart factories is expected to bring about significant transformations in manufacturing & logistics processes. Smart factories have the potential to significantly decrease energy consumption during the manufacturing process. The costs associated with energy consumption have reached an unsustainable level in the textile & apparel sectors. Machines are capable of automatically activating during production activities & transitioning to standby mode once these activities are completed.

The duration that machines remain idle may exceed their operational time in various sectors, including the textile & apparel industries. Consequently, this can lead to significant reductions in both energy costs & consumption within textile manufacturing. When human labour is heavily utilized in production processes, workers can only engage in tasks within adequately illuminated environments, as they are unable to operate effectively in darkness. In contrast, machines can perform their functions without the necessity of lighting. Therefore, in a smart factory setting, workplace illumination is not a requirement. This approach can further decrease the energy demands of the textile industry.

Consumption patterns are increasingly aligning with ecological considerations, as consumers are prioritizing companies that demonstrate ethical practices & social responsibility, while also favoring environmentally

sustainable products & practices (Rinaldi 2019). Nevertheless, even those consumers who are deeply concerned about environmental & social issues often face conflicting motivations between their desire to remain fashionable & their intention to curtail consumption (Mandaric, Hunjet, and Vukovic 2022). Consequently, a cultural transformation in consumption habits, along with a shift in mindset within the industry & business sectors, is essential for achieving meaningful sustainable change (Niinimaki et al. 2020).

Digital Apparel for sustainability

Photorealistic representations of 3D digital apparel are increasingly prevalent. Digital agencies offer services that generate high-resolution scanned images along with metadata, enabling the creation of digital replicas of fabrics. McQuillan (2020) illustrates the potential of 3D software in promoting hybrid design & prototyping, which can contribute to the goal of zero-waste fashion design. Furthermore, visual experiences can be enriched by incorporating sonic & haptic technologies within virtual & augmented reality, thereby enhancing sensory perceptions in the digital environment.

Digital images are utilized to produce content for static, dynamic, & engaging audio-visual ads within marketing campaigns. Additionally, digital try-ons & customization allows for the virtual fitting of garments, offering a tailored fit, visual comfort assessment, & size suggestions that help minimize return rates. A three-dimensional retail environment enables customers to virtually try on & purchase apparel using immersive experiences that necessitate physical devices, like virtual reality headset & a touch controller. This platform facilitates product customization, empowering consumers to express their individuality while manipulating data parameters supported by a visualization that presents photographic representations of the customer's distinct design prior to production.

Digital plus physical retailing enables consumers to participate in real-time, dependable, & seamless phygital experiences when purchasing digital clothing. Through smartphone camera access for augmented reality, users can visualize themselves wearing these garments. This approach facilitates multiple & long-lasting applications by establishing an augmented reality digital personal wardrobe, allowing users to upload various digital content associated with a purchased physical item. Digital made-to-measure & an on-demand production is a prevalent strategy among small, digitally focused fashion companies that emphasize selective, unique, & personalized digital offerings.

A digital made-to-measure approach involves digital tailors who adjust virtual clothing to align perfectly with the client's body image, thereby facilitating the method of digital dressing. 3DVD provides bespoke tailoring services by utilizing precise digital measurements of a customer's body shape & offers a virtual preview of personalized garments on a tailored avatar.

Technological platforms facilitate the automatic transmission of technical digital files to manufacturing facilities, enabling tracking throughout the various stages of production. Virtual collections that enhance physical clothing, thereby broadening their product range. The provision of exclusively digital items is further supported by offering cyber-tailoring services, assisting consumers in fitting the digital garments they acquire onto their avatars. The sustainability advantages of digital clothing contribute significantly to their value proposition, particularly through the reduction of resource usage & the challenge to the prevailing culture of excessive consumption.

The virtualization of design & prototyping facilitates a more rapid workflow & decreases material consumption by minimizing or eliminating samples, while enhancing the collaborative planning among various segments of the value chain. The implementation of digital try-on options with customization capabilities ensures precision in production cycles, resulting in a reduction in returns. It has been observed that the digital creation of garments can lead to a 97% reduction in carbon dioxide (CO_2) emissions & conserve 3,300 litres of water.

Three-dimensional modelling has been identified as a tool that streamlines the zero-waste design methodology by facilitating sustainability-driven choices during the initial phases of the creative process, thereby reducing the volume of textile waste generated during the design stage (McQuillan 2020). Chile’s Atacama Desert has become a dumping ground of discarded clothes due to fast fashion (Bartlett & Merino, 2024).

The digital transformation of wholesale &marketing tools plays a significant role in minimizing or even eliminating the need for physical sampling & fabric waste during prototyping processes. This advancement not

only mitigates negative environmental impacts but also enhances cost efficiency, thereby accelerating time to market. A reduction in annual global travel & transportation related to Business-to-Business wholesale at the time of international fashion weeks across the four primary fashion seasons has been shown to decrease the carbon footprint by 241,000 tons of CO2, along with reducing financial expenditures (Carbon Trust and Ordre 2020).

The contemporary engagement with apparel through online shopping promotes environmental sustainability while also addressing sociocultural dimensions (Collins 2019). This approach accomplishes the social roles of fashion, which includes self-expression, identity representation, & communication through social media, while simultaneously decreasing the industry's carbon footprint & mitigating the cycle of single-use garments & waste in the physical world. It enhances the sustainability of digital experiences by establishing digital wardrobes that facilitate the archiving, resale, & repurposing of digital garments.

Digital apparel serves to offer personalized services via digital fitting & sizing tools that assess human measurements & allow for virtual try-ons. These technological innovations positively impact the reduction of returns, while digital customization, configuration, & styling services augments users' capacity for self-expression. Furthermore, creative sectors leverage these experiences to craft immersive virtual environments, thereby establishing a novel cultural landscape, the Metaverse, that connects brands & consumers, fostering new values & meanings. This, in turn, enriches customer experiences & may encourage sustainable behaviours. The utilization of digital garment models also contributes to minimizing stockholding & overproduction.

The strategy of preorder acquisitions and production-on-demand, which hinges on the tailored digital previews of fashion merchandise, instigates a considerable transformation in cultural and behavioural patterns from the consumer's standpoint. This approach enhances garment customization, thereby promoting diversity & individual self-expression. Additionally, the reshoring of garment production to a local level, utilizing controllable, durable, & environmentally sustainable materials while ensuring quality management of the workforce, yields beneficial effects on environmental sustainability by eliminating the need for long-distance materials & labour. Ultimately, this shift also positively influences social & cultural sustainability by ensuring fair & ethical treatment of workers & facilitating the cultural reclamation of indigenous manufacturing techniques.

Conclusion

The fashion industry is progressing towards the adoption of digital solutions, such as real-time visibility in supply chains, optimization of supply chains, on-demand cloud manufacturing, stock management, & alignment with demand forecasting. A prevalent form of digital platforms is the digital marketplace, & the highly personalised offering from e-commerce removes geographical barriers among participants in the value chain. Consequently, digital platforms have the potential to revolutionize the current value chain of the fashion industry into a revolutionary platform.

Organizations can gain a competitive advantage by utilizing emerging digital technologies, including cloud computing, analytics mobile applications, social media & the Internet of Things. Retail 4.0 transforms supply chains into customer-focused entities by facilitating the swift exchange of products & information across various channels, while also delivering highly personalized services to consumers. In the context of Retail 4.0, marketing intelligence is achieved through the gathering & analysis of user data, which provides significant insights into consumer behaviours & purchasing trends for marketing strategies.

The onset of a social distancing during the pandemic has heightened individuals' reliance on information & communication technology, social media, & mobile devices. This heightened reliance has transformed consumer purchasing behaviours. As big data continues to expand, conventional computing methods hinder the development of effective solutions for large-scale, complex challenges. The consumption of digital garments continues to contribute to carbon emissions due to the energy demands of 3DVD systems. While virtual reality & augmented reality technologies provide significant engagement in retail experiences, they also incur increased electricity consumption due to the ongoing connectivity required between mobile devices, cloud services, networks, & cellular towers.

The fashion industry is required to expedite the adoption of digital innovations by leveraging emerging technologies, including artificial intelligence, cloud computing, augmented reality, virtual reality, & blockchain.

The fashion value chain can be synchronized with real-time on-demand manufacturing processes, facilitating communication among stakeholders & customers within the system. Organizations are required to cultivate an environment that enables them to oversee information & processes throughout the extended supply chains in a cohesive, intelligent, & responsive way. Given the rising demand, technological progress, & heightened customer expectations, the apparel sector faces an urgent necessity to remain competitive by meeting customer demands & addressing their needs to thrive in the apparel sector.

The integration of advanced technologies within the apparel industry has recently demonstrated a remarkable transformation, steering the sector towards a more sustainable & genuinely customer-centric model. Apparel industry professionals must strategically plan, organize, & coordinate Industry 4.0 technologies to serve as facilitators that improve new product development performance & assist the industry in minimizing its carbon footprint.

The present managers & technicians within the textile sector predominantly belong to Generation Y & Generation Z. These two generations have received their education in a technologically advanced environment, characterized by their familiarity with the Internet & sophisticated processing & information technologies. Consequently, they exhibit a greater inclination to invest in environmentally sustainable biotechnologies.

The Indian textiles industry faces both opportunities & challenges due to digitalization, necessitating a strategic approach to address these issues. One notable opportunity is the potential increase in labour productivity within the textiles sector, driven by the integration of robotics, artificial intelligence, & the Internet of Things, which aim to improve efficiency & production capabilities.

The advancement of technologies such as 3-D printing, automation, robotics, the Internet of Things, artificial intelligence, & e-commerce is expected to lead to an increase in job opportunities, necessitating a greater number of specialists in these fields. However, in the employment sector, the integration of robots, AI, IoT, & automation may replace human labour in repetitive, labour-intensive manufacturing tasks.

The labour-intensive nature of the sector necessitates the replacement of human labour with digital technologies. Consequently, it is imperative to provide skill-intensive training, especially in digital skills, to current textile workers in order to avert potential job. Addressing the digital skills gap between those with digital competencies & those without is of utmost importance. The emphasis of training & educational institutions should transition from providing solely generic training skills to offering skills that are pertinent to the digital realm. This shift is essential to equip current & future employees to keep up with the swiftly changing digital environment, alleviating concerns about job security in the face of technological advancements. In addition to developing courses that are pertinent to industry needs, addressing the increase in precarious working conditions resulting from digitalization can be effectively achieved through the improved design & enforcement of labour laws. These laws should require employers within the industry to ensure that their employees receive adequate social & wage security.

The Indian textiles sector has the potential to benefit significantly from a heightened focus on enhancing its employment opportunities & export capabilities. Implementing such strategies would help mitigate the risk of substantial job losses, wage cuts, & unstable working conditions, including the absence of wage & social security. An adequate cyber security infrastructure is essential for textile units that are integrating digital technologies, ensuring the protection of employee security. It is imperative to adhere to the proper implementation of government initiatives, such as the National Cyber Security Mission.

Initially, textiles companies should be granted subsidized access to digital infrastructure, including affordable Wi-Fi & other critical ICT tools, to facilitate their entry into digital technologies. Furthermore, there is an immediate necessity to bridge the digital divide between urban & rural areas by lowering taxes on ICT goods & services in rural regions, promoting network expansion initiatives for ICT providers, & reducing import taxes for local content suppliers. It is essential to place significant focus on enhancing the skills of the workforce within the sector, as well as improving digital infrastructure & cybersecurity measures. Governments should prioritize national digital readiness to facilitate greater participation of companies in the digital economy as producers rather than merely consumers.

Organizations are required to cultivate an environment that enables them to oversee information & processes throughout the extended supply chains in a cohesive, intelligent, & responsive way. Given the rising demand, technological progress, & heightened customer expectations, the apparel sector faces an urgent necessity to remain competitive by meeting customer demands & addressing their needs to thrive in the apparel market.

Assessments of real environmental impacts do not account for the energy usage associated with data centers, networks, & blockchain transactions. The particular architecture employed, whether proof-of-work or non-proof-of-work, significantly influences the extent of environmental consequences. Given that the trajectory of energy efficiency in information & communication technologies (ICTs) suggests that the carbon footprint is unlikely to diminish, it is imperative for designers, policymakers, entrepreneurs, & everyday users to engage in proactive decision-making & adopt responsible practices to mitigate their environmental impact.

The integration of advanced technologies within the apparel industry has recently demonstrated a remarkable transformation, steering the sector towards a more sustainable & genuinely customer-centric model. The introduction of innovative services & processes, an enhanced focus on customer needs, increased customization, initiatives aimed at shortening lead times, novel marketing & distribution strategies, improved energy efficiency in production, proactive maintenance, automation of inbound logistics, intelligent data collection, & miniaturization represent pivotal trends that align with the principles of Industry 4.0.

The advancement of innovative smart materials & biomaterials has played a significant role in promoting sustainability within the clothing industry. As the second most polluting sector, the fashion industry faces an urgent demand for more sustainable fibers & a closed-loop system. In recent years, there has been a gradual increase in the development of biotechnology fabrics derived from cellulose sources, such as orange fiber & grape leather; however, challenges remain in scaling these materials for widespread use. To date, only a limited number of companies have successfully implemented large-scale production of recycled fabrics, utilizing advanced technologies like organic recycled cotton. The primary focus of fashion lies in the aesthetics of garments & the messages they convey, rather than their functional aspects. Consequently, the realm of 4.0 fashion garments remains the least advanced sector within the fashion industry.

Future Research

Future research can analyse the socio-technological factors that facilitate or hinder the digital transformation of the supply chain, from frontend and backend operations to consumer interactions, will yield valuable insights into the systemic conditions that must be established at the individual, corporate, inter-organizational, & policy levels to effectively integrate digital advancements with innovations & sustainability. Further investigation may concentrate on the inventive use of technologies to reshape the inspiration behind garment design, such as leveraging artificial intelligence & data science to guide sustainable decision-making & foster innovation.

Also, studies can be done on Industry 5.0, also known as Quantum Marketing, a term coined by Raja Rajamannar in 2021 which utilizes the quantum computing techniques & focusses on collaboration between human & machines for hyper personalization of marketing strategies.

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