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Technology & digitalization opportunities in SME apparel sector: an Indian perspective

Abstract

The apparel industry plays a significant role in India's manufacturing, employment generation, and export-oriented economic development, with small and medium-sized enterprises (SMEs) constituting an important part of the sector. However, the adoption of digital technologies among SMEs remains constrained by financial, technological, infrastructural, and skill-related challenges. Against this background, this study examines the awareness of digitalization among Indian apparel SMEs, identifies the major challenges associated with technology adoption, and explores the role of government support in facilitating digital transformation. The study adopts a qualitative and descriptive approach based on interviews with 28 apparel manufacturing primarily SMEs a few large firms and buying houses located in Delhi NCR, Bengaluru, Tirupur, Ludhiana, and Jaipur. The findings indicate that most participating firms are aware of digitalization and recognize its potential benefits; however, their depth of knowledge and level of adoption vary considerably. Technologies such as CLO 3D, CAD/CAM, automated cutting, IoT-based supply chain tracking, and digital printing are being adopted selectively. High investment costs, limited return on investment for smaller production volumes, shortage of skilled personnel, inadequate training, infrastructure limitations, and the absence of mandatory buyer requirements for certain technologies remain major barriers. Rather than investing directly in expensive digital infrastructure, several SMEs rely on third-party service providers for specialized digital activities such as CLO 3D design, CAD/CAM and supply chain tracking. The findings suggest that a phased and need-based digitalization strategy, combined with accessible technology services, industry-oriented training, and appropriate financial and institutional support, can enable apparel SMEs to improve competitiveness, operational efficiency, and sustainability. The study contributes to the understanding of practical digitalization opportunities and constraints within India's apparel SME sector and provides directions for future research on the measurable business outcomes of digital technology adoption.

Keywords: digitalization, technology adoption, apparel SMEs, digital transformation, CLO 3D, industry 4.0, supply chain, sustainability

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Santosh Kumar Tarai,[1] Vikrant Bharti,[2] Priyadharshini K,[1] Pratyaksha Sharma[3]
[1]Associate Professor, National Institute of Fashion Technology, India
[2]Merchandising Manager, Asmara Apparel Pvt Ltd, India
[3]Ex-Master Student of Fashion Management Studies, National Institute of Fashion Technology, India

Correspondence: Dr. Santosh Kumar Tarai, Associate Professor, National Institute of Fashion Technology, Bhubaneswar, India

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Introduction

Several authors have noted that the apparel industry is a crucial sector for generating export revenue and plays a significant role in the economic advancement of numerous developing nations. Moreover, it is widely regarded as one of the foremost and most globally integrated sectors, as it serves as a crucial catalyst for economic expansion, progress, foreign exchange, and job opportunities. It is also called a starter industry for the economy, as it provides for manufacturing development and export-oriented industrialization in any country in the world. This sector requires a lower level of technology, lower fixed costs, and less investment compared to other manufacturing industries.[1,2] Therefore, the apparel business in the global market holds a significant share, which is equal to eight times the textile contribution to the export trade (Knappe 2005). This sector is dominated by SME firms among the apparel-producing countries due to its contribution to the economy as well as socio-economic development at large.

Given the sector's importance, industries in India cannot adequately sustain the country's large population in terms of employment and social upliftment without specifically engaging and prioritizing the SME sector, particularly apparel manufacturing units operating in various clusters and non-cluster areas. The Indian apparel industry, particularly the SME sector, contributes significantly to the Indian economy in terms of GDP, exports, employment, and other economic activities in the domestic market. The sector in India contributes 80 percent of the total apparel export share to the world market.[3]

The world has witnessed several industrial revolutions, and with each revolution, industries have adopted different approaches to sustain and fulfil market demands. We are now in the middle of the Fourth Industrial Revolution, which is being driven by digitalization and accelerated communication through the web. This unprecedented wave of digitalization is anticipated to significantly transform business activities in the near future. Due to various disruptive events occurring globally, such as geopolitical conflicts, the COVID-19 pandemic, ongoing wars in Ukraine and West Asia, and numerous natural disasters, customers are increasingly challenging manufacturers, brands, retailers, and buyers to prioritize digital infrastructure, which is supported by the abundance of digital information available that facilitates quick and easy decision-making for customers.

Several global studies conducted by companies like Boston Consulting, IBM, and Cap Gemini have demonstrated that business model innovation delivers a higher potential for success than product and process innovations. In the present context, this connection is even becoming increasingly important in the textile industry, influenced by the ongoing digitalization and push for sustainability. India's manufacturing output share is around 3% as compared to China's 28% in the world (UN Statistical Division data, 2019). Further, the government of India attempts to achieve a 5 trillion economy by 2028-29; therefore, the development of the SME sector has been a major focus, as it plays a vital role in increasing manufacturing activity in the economy. Technological innovation and the development of digital

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platforms in manufacturing and other economic sectors could benefit SMEs by reducing the number of physical activities, lowering costs, enhancing sustainability, and helping to achieve the SDG criteria. The study aims to understand SMEs' awareness of the digitalization process and any new software they have used.

Literature review

Industrial revolution and its importance

The journey of the textile and apparel industries has witnessed many phases of the Industrial Revolution for the last two centuries, and necessary measures have been adopted over this period to fulfil the socio-economic requirements. For instance, almost 200 years ago, the first industrial revolution began with the steam engine and the mechanical loom. Priority was given to wool and cotton as the economic drivers during that period for mass-scale production to meet the requirement. Similarly, advancements in technology, machines, and ICT, along with the era of liberalization and globalization, have impacted the industry, particularly SME firms, which have been compelled to take various actions in their operations, such as updating technology strategies and compliance measures.

Since the First Industrial Revolution, machines, electronics, and digital computers have made apparel production ever more efficient. We are now in the middle of the "Fourth Industrial Revolution".[4] According to him, 4IR is powered by emerging technologies, such as 3D printing, big data, or artificial intelligence (AI). It differs from the first three industrial revolutions, in which mechanization, electricity, and information and communication technology (ICT), in order, are the main drivers of industrial changes[4,5] cited in Lee, Keun, et al.[6] The fourth Industrial Revolution, also known as the digital economy has ushered in an unprecedented wave of digitalization and is expected to be the game changer in business activities.

Effect of COVID-19 and the importance of digitalisation

Since the Covid-19 pandemic, digitalization has become even more urgent. Owing to travel restrictions and lockdowns, European consumption shifted away from physical retail to e-commerce. Trade fairs went online because buyers were unable to visit factories. This situation increased the need to digitalize approval processes, from lab dips to fit samples. Moreover, the growing demand for smaller orders and flexible services accelerated the already ongoing automation and digitalization of apparel production.

Platform systems and hybrid networks in the textile industry are creating new supply chains that were previously difficult to envisage. Parts of established supply chains are being skipped to put customers and producers into direct contact quickly and easily. Both business-to-business (B2B) and business-to-consumer (B2C) options are now available. A few companies, such as Meesho in India and Shein in China and USA, are successful in their models and have created benchmarks for others. These two examples are united in the fact that they come into direct contact with end users via the Web and thus use transparency in the supply chain to ensure their economic success as well as sustainability.

A business model, to put it simply, is the way someone engages in business. The streams of data and transparency in supply chains have created new business models in the textile industry. These can provide customers with the information they need to make a "sustainable" purchase decision. Such business models also manage to bypass intermediaries in the global textile trade through direct communication, allowing companies to control margins and costs. The paper suggests that initially, switching to online methods leads to job losses because of decreased labour input. But over time, as the use of online methods increases, new jobs will emerge. However, as online methods become more prevalent, new jobs emerge. It stresses that MSMEs prefer tax payment deferrals, tax rate reduction, and loan repayment deferral and other possible forms of support offered by the government.[7]

Effect of digitalisation on innovation and productivity

Additionally, it can be observed that the utilization of digital communication technology is positively associated with labour productivity, depending on the presence of innovation.[8] A similar earlier study by ITC[9] emphasized the role of information and communication technology (ICT) and e-commerce; digitalization presents significant opportunities for small and medium-sized enterprises (SMEs) and micro-enterprises. From the perspective of small and medium-sized enterprise (SME) manufacturers, the digitalization of the value chain has a few advantages, like partnering with platforms that have the potential to expand their customer base and increased sales, ultimately resulting in improved labour productivity. Large corporations can effectively reduce client acquisition costs and enhance labour productivity by engaging with platforms. Labour productivity is determined by the efficiency of income generation.[6] Therefore, technology can help both big and small businesses innovate in several ways. Small and medium-sized businesses (SMEs) don't have a lot of money or people, so making it challenging for them to adopt digital technologies and experiment with new products and processes. A lack of a digitalization plan, an organizational culture resistant to change, and ineffective business models are among the key factors hindering digitalization. But internal research and development (R&D) could reduce the positive effect of digital technologies on creativity.[10] Even though digitalization as a whole is a good thing, many SMEs still have employees with limited digital skills. Many SMEs remain far from embracing digital change, necessitating further efforts in this direction. Managers of small and medium-sized enterprises (SMEs) are encouraged to leverage the benefits of digital transformation to generate new ideas and make their businesses more resilient.[11] Mim et al.[12] identified investment, infrastructure, IT capabilities, and skilled workers as important for Industry 4.0 adoption, which can enable apparel firms to improve production efficiency, technological integration, and competitiveness.

The environmental and sustainability case for digital fashion

Integrating the right tools efficiently is vital in enhancing brand performance.[13] It highlights the relationship between digitalization and CSR and mentions how the companies can use a portfolio of digital technologies like artificial intelligence, big data analytics, intelligent transport systems, and IoT to achieve responsible digitalization.[14] The fashion industry is making slow strides toward sustainability because of the overproduction of physical goods. Transforming into meta-fashion with cross-platform compatibility is the way forward.[15] Government policies must equip students and workers with the necessary digital and professional skills.[16] Singh et al.[17] identified infrastructure, investment, skilled workforce, and organizational readiness as key barriers to Industry 4.0 adoption, and addressing these issues can improve operational efficiency, productivity, and **competitiveness** in the Indian textile industry.

Identification of research gap

Many studies have addressed and highlighted issues, namely expensive software, lack of skilled workforce, infrastructure, sufficient capital, lack of government incentives, etc. It is observed that SMEs are willing to digitalize their work processes; however, not

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all buyers are looking for manufacturers or suppliers that use digital technologies. There are insufficient prior studies on digitalization platform measures and their impact on business in India. However, a research gap exists in the awareness and adoption of digitalization processes among SME firms in India. By addressing this research gap, the study will enrich the literature on the importance of digitalization and its benefits in the SME sector with regard to efficient manufacturing and cost reduction, thus leading to better business operations and a sustainable environment in light of the global carbon footprint.

Aim and objectives of the study:

a) To understand SMEs' awareness of digitalization and its impact on business.

b) To identify any obstacles and challenges for SME firms during the digitalization process.

c) To identify government schemes that are available to support the digitalization process and enhance digital infrastructure.

Methodology

The study involved interviews with 28 apparel manufacturing SMEs located in Delhi NCR, Bengaluru, Tirupur, Ludhiana, and Jaipur. Ahead of these interviews, we conducted a deep dive into the ongoing digital advancements already in practice among established buying houses, large manufacturing firms, and tech-enabled B2B sourcing and manufacturing marketplaces. Following this thorough review, a questionnaire was designed to ascertain whether these digital tools have a footprint in SMEs, as well as the reasons for their non-adoption. It aims to understand how firms adopt digitalization processes and procure new design software advancements in a rapidly changing technological and digital environment, focusing on improving operational efficiency and meeting the expectations of buyers and the market while ensuring sustainability. In this context, we contacted firms from our professional network that were reasonably known to us. We gathered opinions from managerial-level personnel over the phone, based on specific key questions that are discussed below. These firms have between 15 and more than 15 years of experience. We selected the firms based on their annual turnover, number of pieces shipped in a month, the number of machines and outsourcing capabilities (based on whether processing activities are performed in-house or outsourced) namely, printing and washing units. Besides, we have also followed the criteria of SME firms 'selection based on their investment in plant and machineries/equipment as per the MSMED Act, 2006 in India. In recent times, although the definition under the MSME Act has been changed in August, 2026, however, our study is restricted to the earlier definition. The numbers of small and medium-sized firms are combined according to the criteria and the descriptive statistics of sample profiles are presented in Table 1. We have also included opinions from freelancers and the Clo 3D vendor who are providing support to the firms and educational institutes. The information collected from them has been used to get comprehensive knowledge and formulate a policy-making framework. Additionally, the study includes a case study of a reputable buying house in India, which provides a detailed discussion on digital components for clarity.

Table 1 Manufacturers' profiles

Firm	Firm size	Product	No. of firms	Location	Digitalization adoption	Use of CLO 3D software: Own/ third-party support
Manufacturer-Exporter	S	Apparel	8	Delhi NCR, Ludhiana, Jaipur	Yes	Third Party
Manufacturer-Exporter	M	Apparel	15	Delhi NCR, Bangalore, Tirupur	yes	Third party
Manufacturer-Exporter	L	Apparel	3	Delhi NCR, Bangalore	yes	Own
Buying House	(Well-known reputed)	Apparel business	2	Delhi NCR	yes	Own

Authors' own compilation based on telephonic inputs. S-Small, M-Medium and L-Large firms

Interviews with SME export firms

1) What is the level of awareness regarding the digitalization process and its impact on export business among SME export firms? All SMEs are well aware of digitalization and have adopted it to varying degrees through training programs provided by the Government of India and subcontracting services from third parties. However, some firms indicated that they may consider digitalization in the future if expertise, skilled personnel, government support, and sufficient business volume become available.

2) What are the obstacles and challenges faced by SME export firms during the digitalization process? Most firms have faced financial constraints, as the software is costly and requires both expertise and manpower to operate and maintain. While 3D Clo, real-time tracking, and automated CAM/CAD cutting are not immediate mandatory requirements for buyer validation, these technologies are being utilized as needed and are often subcontracted to third parties.

3) What factors drive SME firms to implement Clo3D software, and what challenges do they face during its adoption?

Most large retailers use Clo 3D to assess the overall appearance of a garment on a body and match parameters; however, its use is restricted to plaids, stripes, and prints, not solids. Currently, the requirement for Clo 3D is limited to overall look approval, which is less significant in production and slightly more important in product development; however, the core implementation of Clo 3D—digitally signing fits without a physical sample to expedite the process is still lacking. We also found that none of the known buyer's/retailer's sign-off fits/proto/pre-production samples digitally, which actually is the core purpose of CLO 3D technology and hence restricted to limited use in the trade. We also found that automatic cutting is not a mandatory requirement from any retailer; it only helps suppliers control wastage and fabric efficiency. However, this setup requires a significant investment, and the return on investment (ROI) for SMEs is not favourable given their overall volume and capacity. Therefore, it is more suitable for a large export house that has a significant volume, allowing it to cover the return on investment (ROI). Moreover, supply chain tracking/IoT is not a mandatory requirement from any retailer. SMEs use this technology on a case-by-case basis by collaborating with third-party companies that provide these services for a nominal fee rather than investing in it directly. From the software vendor's perspective, using

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Clo 3D software can significantly improve efficiency and reduce garment development and production costs, depending on the volume.

Findings

Firms classified as SMEs across the sample reported that they are aware of the digitalization process and its benefits. However, they do not have in-depth knowledge about the process. Firms with more than 15 years of experience possess better knowledge and capacity, while the use of digital technologies in pattern making and printing is primarily associated with medium-sized firms. It was found that mostly well-established buying houses, namely Triburg, Li & Fung, and Asmara Apparels, and manufacturing large firms like Shahi Exports, Texport Industries, and Sahu Exports have been using CLO 3D software for prototype development.

But, in the context of SME firms, they have started adopting digital ways of working with available financial support schemes from the government (Ministry of Textile web portal), likely ATUFS,[18] SAMARTH,[19] Digital MSME schemes, and the Lean Manufacturing Competitiveness Scheme (LMCS).

We found that due to limited use of Clo 3D, small and medium-sized firms have refrained from investing in this platform. When asked how they compete with their rivals and meet the needs of buyers and designers, they indicated that they typically outsource these activities from third-party companies that offer sustainable costs. On further investigation, buying agencies like Li& Fung provide CLO 3D design support to their vendors free of charge, supported by an in-house team of trained professionals and facilities as per market requirements. Similarly, other digital services like CAD/CAM cutting and supply chain real-time tracking modules are also available with Tech-enabled B2B Sourcing and Manufacturing Marketplaces companies like Gennie Mode, Groyyo, and Fashinza.

Possibility of digital strategy for SME manufacturing firms

CLO: CLO is a powerful 3D fashion design software used for digital pattern making and grading, allowing users to see patterns sewn together and draped on a 3D avatar, test fits, silhouettes, and style lines digitally to reduce the need for costly physical clothing samples. It's actively used for generating high-resolution images and professional presentations for marketing or design reviews. Below is the detailed analysis of this technology, based on inputs received from the buying agency, which is already using this software, along with inputs from personnel associated with tech-enabled B2B sourcing and manufacturing marketplaces.

What CLO 3D software does:

1) Pattern Creation: The process starts with creating a digital pattern for the garment. Designers can either bring in 2D patterns from CAD software or use CLO 3D's pattern creation tools to make new ones.

2) Garment Design: Once the pattern is ready, designers can use CLO's easy-to-use 3D design tools to turn the flat patterns into 3D garments. They can change the patterns in different ways to make different styles, shapes, and design elements.

3) Fabric Choice: Designers can choose from a large library of virtual fabrics in the software or add their own fabric textures. The chosen fabric is then applied to the 3D garment, and the physical properties of the fabric are simulated.

4) One of CLO 3D's key features is its advanced fabric simulation system. As a garment is designed, the software accurately predicts how the selected fabric would behave in real life by taking into account properties such as weight, stretch, drape, and stiffness. This allows the virtual fabric to move, fold, and behave realistically, giving designers a more accurate representation of how the finished garment would look and behave in real life.

5) Virtual fitting and adjustments: Designers can try on the virtual garment on a 3D model, adjusting seam allowances, lengths, and other factors to achieve the right fit. The simulation of the cloth lets them see how the garment falls and fits the body.

6) Visualization and rendering: Once the garment has been created and fitted, designers can see it on a 3D model in different poses and angles. CLO has choices for realistic rendering that let you see how the garment will look in different lighting.

7) Sample prototyping: Clo 3D can be used to make virtual designs that look like real sample clothes. This makes it less important to make a physical sample, which saves time and money during the planning and development process.

8) Animation and presentation: In addition to still pictures, Clo 3D enables users make animations and videos that show how the garment moves and flows on a virtual model. This software is helpful for graphic communication, marketing, and presentations.

In a nutshell, CLO 3D accelerates the design process, reduces costs, and makes it easier for creators to experiment with different ideas and make changes efficiently. Traditionally, producing a physical sample garment and shipping it overseas involved significant time and cost. Before the adoption of CLO 3D, developing a drape sample could take approximately four to five days, after which the sample would be sent overseas for review. However, if the sample was rejected, the process had to be repeated, resulting in additional costs as well as wasted time and effort. By incorporating CLO 3D at the design stage, the company can visualize and evaluate garments virtually before producing physical samples, making the overall development process more efficient and cost-effective in Figure 1 and Figure 2.

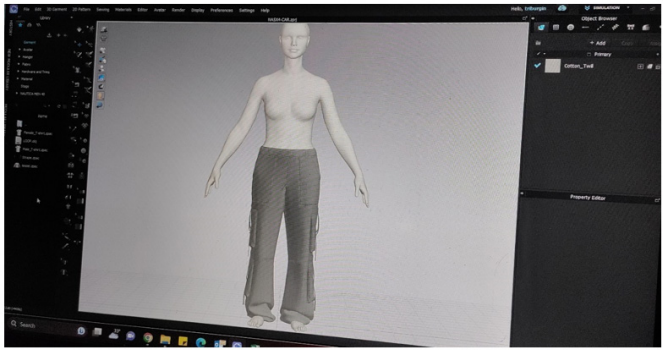

Figure 1 On Screen CLO3D model.

Figure 2 CLO 3D Software at work in an Indian buying house.

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CAD/CAM cutting systems: Implementing Computer Numerical Control (CNC) cutting systems and CAD software to optimize fabric usage. Specifically, the Morgan Tecnica Next2 automated cloth cutter is an Italian-based company and now has its distribution across the globe as well as in India in Figure 3. Its onboard AI algorithms, digital brushless motors, and vacuum stabilization that enable high-speed, heavy-duty automated multi-ply fabric cutting precisely for knits, wovens, and technical textiles. Furthermore, it operates at high speed and can cut up to 80 m/min across multi-ply compressed fabric lays (up to 9 cm thick) with zero buffer compared to a 2 mm to 5 mm buffer between pieces in manual cutting. This technology significantly reduces fabric wastage. Due to high capital expenditure, adoption of this technology is currently concentrated among large-scale enterprises.

Supply chain tracking: Using IoT sensors and cloud platforms for real-time tracking of productivity and inventory management. Several specialized technology companies focus entirely on creating IoT hardware sensors, RFID infrastructure, and cloud-based platforms specifically designed for the garment and textile manufacturing industries. These solutions help factories monitor worker productivity, live shop-floor bottlenecks, and material inventory. The information was collected from personnel associated and managing the entire system for well-known large-scale export houses based in Delhi NCR and Bangalore.

A few well-known dedicated garment shop-floor tracking & productivity platforms such as Yatrix IoT, Intellier (Nidle Platform), and Apna ERP have specialized platforms that focus primarily on Real-Time Production Tracking (RTPT) and Work-in-Progress (WIP) tracking using smart terminal or RFID. While the hardware and software cost is manageable, the maintenance cost of peripherals such as cellular fees, GPS, and cloud analytics, the adoption of this technology is currently concentrated among large-scale enterprises and tech-enabled B2B sourcing and manufacturing marketplaces (Table 2).

Figure 3 Morgan Tecnica Next2 at Sri Lanka garment unit.

Table 2 Benefits of digital strategies for SME firms

Strategy	Focus
Quick turnaround time with 3D sampling/Fitting	· Manual labour is time-consuming and slows the process. Digital embroidery or printing makes the entire process fast. The machine is programmed once and stops only when the target is met. ·An important development in manufacturing is 3D design and prototyping. Designing garments in 3D software helps designers understand fit better, reduces quality issues, and reduces the need to send samples back and forth for approval, saving time and money. · Digitalization in fashion design involves shifting from traditional 2D sketches to using 3D tools in CAD systems. In this 3D environment, garment design integrates draping, styling, and 3D/2D synchronization (including drawing, flat pattern design, fabric control, and logo placement) on a virtual platform. · Leading clothing retailers such as Adidas, Nike, Under Armour, Victoria's Secret, and Next have successfully applied such design technology with the development of the latest software that facilitates 3D designs within the virtual platform. For example, Browzwear offers software like Lotta for 3D fashion design, and Clo3D offers 3D garment visualization. ·As digital customization options do not require any additional equipment to fulfil the order requirement, they can save considerable costs compared with older, traditional methods.
Cost-effective	·This is due to a reduction in the need for on-site resources, a reduction in the number of warehouses needed, and a reduction in the need to print paper-based documents. The reduction in the need for on-site resources means that companies do not need to employ additional staff to manage various processes. Instead, they can use digitization to centralize these processes and manage them remotely.
Versatility	· Digital printers and embroidery machines can customize an extensive range of materials and fabrics with high efficiency. ·The newest tracking solutions, such as barcodes, RFID chips, and online platforms, enable manufacturers to track incoming and outgoing shipments in real time and to track material flow through the factory. Brands and retailers use AI to predict sales of specific products in certain locations, adjusting their inventory accordingly in nearby warehouses.

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Table 2 Continued...

	· This is achieved by allowing companies to utilize only the necessary assets at the right time. These assets can be centralized and managed from a single location, which helps to streamline processes by reducing the need for on-site resources and manual data entry.
Streamlining processes	· Digitization is also helping to streamline processes by reducing the need for manual work, such as measuring and folding fabrics.
	· Many technology support companies like Groyyo, Gennie Mode, and Fashinza provide live, on-site visibility of supply-chain movement to their clients. This helps track orders in real time.
Sustainability	· The supply chain and IT operations management became considerably more sustainable once textile plants were digitalized, they significantly enhanced the sustainability of the supply chain and IT operations management. The garment-making machinery is programmed to create clothing of comparable quality. The use of cloud technology frees managers from the effort of manually administering software, allowing them to complete their tasks more quickly and effectively. The textile business is changing to incorporate greener practices, like lowering CO□ emissions, raising energy efficiency, and promoting sensible use. Larger organizations benefit from these solutions, but smaller, resource-constrained businesses stand to gain more.
Staying competitive	· The process of digitization should be viewed as a tool to help firms become more competitive, as routine manual tasks can also be digitally changed to provide an advantage at every level of competition.
	· For changing business models and improving employee satisfaction, customer expectations, and customer behaviour, using digital transformation solutions to improve administrative processes might be advantageous.
	· Opening the e-commerce portal and establishing direct contact with customers helps increase revenue. Today there are many startups with design inputs on their websites that enable customers to customize their garments online with colours and designs.
Enable global reach and faster marketing	· Digitization is helping companies achieve global reach and faster marketing in the textile and apparel sector by allowing companies to make their products available to a wider audience.
	· It also allows faster marketing, as companies can publish content more quickly and at a lower cost, which helps to promote their products to a wider audience.
Scope of digital products and social media platforms	· Digital products and social media platforms provide wider connectivity and access to consumer preferences, as well as potential customers for SME firms.
	· These platforms provide wider connectivity and helps SME firms understand consumer preferences and reach potential customers. It also helps to understand competitive strategies.

Challenges and limitations of digitization in the SMEs:

a) Despite the clear benefits of automated cutting systems, IoT tracking, and 3D sampling, small and medium-sized enterprises (SMEs) in India's textile and apparel hubs (such as Tirupur, Ludhiana, Jaipur, and Delhi NCR) face major hurdles when adopting these technologies.

b) High Capital Expenditure (CapEx) and Long ROI: For an SME operating on razor-thin margins (typically 3% to 5%), the upfront investment required for advanced digitalization is a massive financial barrier. Prohibitive hardware costs: high-end AI-driven machinery like the Morgan Tecnica Next2, automated multi-ply spreaders, or specialized CNC fabric cutters can cost tens of lakhs to crores of rupees.

c) Subscription Fatigue: While cloud-based ERPs and IoT tracking platforms lower upfront costs, monthly software-as-a-service (SaaS) subscription fees create permanent overhead costs that small exporters struggle to sustain during seasonal market slowdowns.

Massive digital skill gaps and observed labour resistance:

a) The Indian garment manufacturing sector relies heavily on low-skilled, migratory, and contract labour; and there is an additional cost of training for new technology. For example, transitioning from physical paper chalking or manual cutting to managing a touchscreen CNC interface or digital pattern-grading software (like TUKACAD) requires technical literacy that many workers lack. Pattern masters and manual cutter operators often resist digital tracking tools like IoT floor terminals or RFID badges, fearing that real-time surveillance will disrupt their piece-rate wages or lead to job replacement.

b) An IoT or ERP system is effective only if data flows seamlessly. When an SME sends half-finished garment bundles to a third-party embroidery job worker that uses manual logs, the digital supply chain tracking can break down completely. There has been a severe lack of scalable cloud infrastructure, as digital tools depend heavily on stable utilities, which are not always guaranteed in many semi-urban Indian industrial clusters. Further, real-time IoT floor dashboards require uninterrupted Wi-Fi and cloud access. Frequent network drops in rural or tier-2 industrial pockets lead to data gaps, rendering live productivity metrics inaccurate.

c) Sudden power fluctuations can crash smart sewing terminals or damage the sensitive electronic microcontrollers found inside AI-powered cutting machinery, necessitating expensive stabilizer infrastructure.

d) Another limitation of digitization in the textile and apparel industries is that businesses with limited resources may require assistance in adapting to the new technology. Companies with limited resources will most likely continue to use traditional methods of data collection and analysis, whereas those with the capital to invest in new technologies will benefit the most from digitization.

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e) The cost of 3D sampling and fitting is also high. There is a scarcity of qualified individuals to hire and support the process.[20–22]

Conclusion

This qualitative study examined the opportunities and challenges associated with digitalization in the Indian apparel sector through interviews with managerial-level personnel from 28 organizations, comprising small, medium and large apparel manufacturers and buying houses located across selected apparel clusters. The findings indicate that digitalization is increasingly relevant to apparel businesses as firms respond to changing market expectations, including the demand for quality products, value-added services and faster delivery. However, the interviews suggest that awareness of digitalization does not necessarily result in extensive adoption. The extent of adoption varies according to firm size, organizational experience, production volume, investment capacity, availability of skilled personnel and specific buyer requirements.

The participating firms reported selective use or access to technologies such as CLO 3D, CAD/CAM, automated cutting and supply-chain tracking. CLO 3D was mainly associated with product development and visualization, while automated cutting was viewed as useful for improving fabric utilization and controlling wastage. However, respondents indicated that these technologies were not universally required by buyers. Consequently, firms with lower production volumes may find it difficult to justify the investment required for advanced digital systems.

A significant finding of the study is the role of third-party service providers in enabling SMEs to access digital capabilities. The participating firms indicated that specialized activities such as CLO 3D, CAD/CAM and supply-chain tracking could be outsourced when establishing and maintaining an in-house system was not economically feasible. This provides an alternative pathway for SMEs to benefit from digital technologies without bearing the complete cost of software, equipment and specialized manpower.

The study also highlights the importance of skills, training and institutional support in facilitating digitalization. Government initiatives such as ATUFS, SAMARTH and the Lean Manufacturing Competitiveness Scheme provide relevant mechanisms for technology upgrading, skill development and process improvement. However, the present study does not empirically evaluate the implementation or actual benefits received by the participating firms from these schemes.

Overall, the findings suggest that digitalization among Indian apparel SMEs should be approached through a **phased, need-based and economically viable strategy** rather than through indiscriminate investment in advanced technologies. Firms can prioritize technologies that address specific operational requirements and use third-party services where direct ownership is not justified. Although digitalization has the potential to improve operational efficiency, resource utilization, product development and sustainability, the present study does not quantitatively measure these outcomes. Future research should therefore examine firm-level data to assess the impact of digital adoption on productivity, costs, material utilization, sustainability and competitiveness.

Limitations and future studies

This study primarily focuses on qualitative research from Indian SME firms rather than conducting a quantitative analysis. Additionally, the study has a very small sample size, focusing only on four apparel clusters, and it could not capture more samples due to paucity of time.

Case examples such as CLO 3D and Morgan Tecnica Next2 illustrate adoption possibilities but do not comprehensively capture digitalization experiences across India's SME apparel industry. The study does not quantitatively measure the actual improvement in productivity, cost savings, and export competitiveness resulting from digitalization. Regional infrastructure constraints (power, internet connectivity) are discussed generally, but their varying severity across different states and industrial clusters is not empirically studied. The effectiveness of government schemes like ATUFS, SAMARTH, and the Digital MSME Scheme is discussed based on policy design rather than post-implementation outcomes.

Future research could adopt a mixed-methods approach, combining structured surveys and financial data from a larger, cross-sectoral sample of SMEs to statistically validate the characteristics discussed in this study.

Research scholars may use longitudinal studies tracking SMEs before and after digital adoption, which would help establish causal relationships between digitalization and measurable business performance indicators.

Future studies could explore comparative digitalization patterns across other developing economies or examine the role of emerging technologies like AI and blockchain in addressing the scalability and trust issues identified in SME supply chains. To help SMEs prioritize investment based on affordability and expected returns, future research could compare cost-benefit frameworks for basic ERP, advanced IoT, and AI-driven automation.

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Conflicts of interest

The authors declare no potential conflicts of interest.

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