Reviving Kashmiri Handloom: Leveraging Emerging Technologies for Preservation and Premiumization

Vishad Vivek Singh, Sanchita Joshi, Vikrant Khazanchi and Sanish Shirish Kulkarni

Abstract

The existence of the centuries-old traditional Kashmiri handloom industry, particularly Pashmina shawls and carpets, faces a serious threat due to the inundation of markets with cheap, machine-made products. This, coupled with the existence of exploitative middlemen, technology non-upgradation, and other legacy challenges, has led to extremely low wages and penury among the Kashmiri artisans. The seriousness of the situation is reflected in the fact that the younger generation are abandoning centuries-old traditions for more secure alternative livelihoods. With this backdrop, the objective of this article is to elucidate potential emerging technology use cases, which can help revive the production and post-production supply chains of Kashmiri handloom products, specifically Pashmina shawls and Kashmiri carpets. The study is based on qualitative data gathered via focus group discussions, unstructured interviews, and a two-day field immersion workshop conducted with Kashmiri artisans, government officials, and Indian technology startups between December 2022 and June 2023. Findings from the study suggest that the pain points primarily afflicting Kashmiri handloom products pertain to authentication and (re)premiumization and preservation of skills and knowledge of master artisans to ensure perpetuation of the handmade. In this regard, the study suggests that there is scope and a need to systematically integrate a range of emerging technology solutions, such as PUF-based QR codes, IoT sensors, AI and ML technologies, and AR, based on a technology stack approach in Kashmiri Pashmina and carpet supply chains. From a policy perspective, the article emphasizes the need to overcome the 3A challenges—awareness, availability/affordability, and access—to ensure successful technology adoption and trickle-down benefits to Kashmiri artisan communities. The research findings provide guidelines to policymakers, stressing the importance of

building a multi-stakeholder approach, engaging the artisans, government, innovators, and civil society to collaborate for successful integration of technology in handloom production and post-production value chains. Such initiatives shall empower the handloom sector and provide a competitive edge in the global market.

Keywords: Kashmiri handloom, emerging technology, technology adoption, Pashmina, Kashmiri carpets, preservation, premiumization

Introduction

Handloom products are an integral part of India's socio-cultural milieu and economy. The handloom industry in India has evolved tremendously over time, embodying the cultural richness and diversity of its geographic regions as well as the many waves of history that have swept the subcontinent. However, evolution has not been without its challenges. Almost 200 years of British imperialism wrecked the handloom and handicrafts sector, which otherwise was the backbone of India's economy (Kumar et. al., 2021). Even after gaining independence, artisans have continued to struggle with low wages, outdated techniques, and an inundation of markets with cheap machine-made products, which has significant human development implications for over one crore artisans across 2,000 specialized craft clusters in India—including 1,463 handloom clusters and 744 handicraft clusters under the Ambedkar Hastshilp Vikas Yojana (Development Commissioner Handlooms, n.d.; Ministry of Textiles, n.d.). According to the latest estimates, for 66 percent of weaver households, average monthly income from all sources is less than Rs 5,000 (Ministry of Textiles, 2020). Moreover, about 26 percent of the weaver households are Antyodaya (poorest of the poor) card holders, reflecting the abject situation of the artisans associated with the handloom sector (ibid.). However, when juxtaposed with the fact that handloom exports alone were valued at INR 1,446 crore in 2022-23, according to the Development Commissioner Handlooms, n.d.), the artisans' income situation reflects an aberration, necessitating urgent policy interventions.

Within India, the Union Territory of Jammu and Kashmir is especially world-renowned for its ultra-luxury, niche, and high-quality products like Pashmina shawls, particularly Kani, and Kashmiri carpets. The Jammu and Kashmir handloom sector, together with handicrafts, employs around 3.5 lakh artisans, with significant implications for livelihood security and human development. However, despite being the mainstay of the region's economy, the total handicrafts and handloom exports from Jammu and Kashmir have declined sharply from INR 1,643 crore in 2011-12 to INR 635 crore in 2020-21 (AGNIi

Mission, 2023). This downward trend can be attributed to a variety of challenges afflicting the sector. These include the prevalence of exploitative middlemen, credit access, the threat to intergenerational continuation due to lack of interest among the younger generation, lack of brand image, product design and development not in tandem with market demand, competition with machine/power loom-made products, international competition, and inadequacy of appropriate marketing platforms (Government of Jammu and Kashmir, 2020; Majeed and Swalehin, 2020; Ishrat et. al., 2020).

However, the state policymakers (especially the Directorate of Handicrafts and Handloom, Kashmir) are actively instating measures to resolve these pain points and direct efforts towards (re)premiumization and preservation of Kashmiri handloom products. In this regard, a key pillar of their strategy is emerging technology integration in the handloom product supply chain. For example, Jammu and Kashmir is the first Indian union territory to deploy QR-based codes for all its crafts to track product provenance (Sinha, 2023). Such forward-looking initiatives leveraging India's technological capabilities not only help revive and make Kashmiri handloom products relevant in the market but also provide a case for larger integration of technology within India's traditional handloom industries.

At present, Industry 4.0 pervades every aspect of life in the 21st century. It subsumes within it a gamut of emerging technologies such as artificial intelligence (AI), machine learning (ML), the internet of things (IoT), and cyber-physical systems (CPS). It is characterized by technology fusion—the merger of the physical and the digital, with significant implications for both industrial and human development. These technologies, constantly evolving themselves, are finding new and varied use cases and revolutionizing industries (Malik, Muhammad and Waheed, 2024), even for those sectors where technology integration has been a bare minimum. For instance, cottage industries, specifically the centuries-old traditions of handloom weaving, are exemplified by the government of Jammu and Kashmir.

The integration of advanced technology systems such as AI, IoT, and ML can redefine traditional craftsmanship. They can play an instrumental role at almost every node of handloom product supply chains and help enhance productivity, distinguish handmade products from machine-made ones, provide enhanced consumer experience with more effective and interactive articulation of the product narrative and immersive experience, expand reach to global markets, and allow for global knowledge exchange (Aounzou, Kalloubi and Boulaalam, 2022; Zabulis et al., 2022; Halim, Ibrahim and Tawab, 2024). Each of these, in turn, can help hyperlocal artisans reap benefits in terms of livelihood

security and fair and higher wages while simultaneously ensuring the intergenerational continuity of their craft.

With this backdrop, the objective of the research is to elaborate on the role that emerging technology solutions can play in the preservation and premiumization of the Kashmiri handloom industry, particularly the Pashmina and carpet supply chains, which also represent a larger adoption use case across India's handloom sector.

Literature Review

The Kashmiri handloom industry, particularly the production and post-production supply chains of high-value Pashmina shawls and carpets, is afflicted with numerous challenges, which threaten its growth and very existence. Majeed and Swalehin (2020) explore deeper the socio-economic conditions and challenges faced by carpet weavers in the Pulwama district of Jammu and Kashmir. The findings suggest that carpet weavers belong to the poorest of the poor households, with conditions further aggravated due to exploitation by middlemen and intermediaries, resulting in lower wages. This highlights that the Kashmiri carpet industry is in the throes of decline, which can be primarily attributed to unsustainable competition from machine-made products and rapidly changing consumer preferences. These challenges have resulted in a reluctance from younger generations to continue to associate themselves with the craft. Meanwhile, Ishrat et al. (2020) analyze various issues afflicting the Kashmir handloom industry, with special reference to the supply chain of cashmere (pashmina). The key issues identified include a high level of supply chain fragmentation with repercussions for efficiency and quality; a decline in traditional skills among the younger generation due to the increasing non-lucrativeness of the industry; and the middlemen trap, an impediment for artisans to directly access markets and consumers, which also erodes profit share. Moreover, limited technology and innovation adoption is highlighted as an important concern, as it makes the handloom sector lose out in the competition against machine-made products. Similarly, Kumar et al. (2021) elaborate on the evolution of the overall Indian handloom industry and point out that it requires technological advancements and innovation-driven reforms to ensure competitiveness in the global economy.

Hence, it becomes important to assess the role emerging technology can and is playing in the handloom industry. In this context, literature highlights the role of artificial intelligence (AI) in revolutionizing the handloom sector. AI can be utilized in handloom product supply chains to optimize designs, improve quality control, and streamline

production. According to Jennifer et al. (2024), AI-driven systems can help automate defect detection in fabrics, where machine learning (ML) algorithms identify woven fabric imperfections, reducing the scope of human error and ensuring consistency. Similarly, computer-based vision systems have been implemented to ensure textile quality control, offering automated solutions to detect problems pertaining to broken yarns and color variations. According to Sabeenian, Paramasivam and Dinesh, (2012), such systems can provide high accuracy and help ensure that handwoven products meet high-quality standards. In simulations conducted by the authors, the system achieved a 96.6 percent accuracy in detecting defects in silk fabrics. Halim, Ibrahim and Tawab (2024) further substantiate that AI can play an instrumental role in small heritage industries by way of improved design quality, reduced production times, and creation of new applications for traditional crafts, such as furnishings and accessories. They further highlight that AI adoption can help revitalize textile arts and crafts and boost their socio-economic contributions, providing a sustainable way forward in present-day's rapidly evolving markets.

In addition to AI, the Internet of Things (IoT) can play a significant role in modernizing traditional handloom operations. IoT-enabled devices, such as sensors and RFID tags, can be used to track loom performance, monitor worker efficiency, and manage energy consumption. In this context, Ingavale et al. (2024) describe an IoT-based system for automating power looms, which minimizes power wastage and records worker performance. IoT integration helps bridge the chasm between traditional craftsmanship and modern operational efficiency, allowing real-time monitoring and control without compromising the nuances of the manual weaving process. Moreover, deep learning approaches have been developed to authenticate traditional handloom textiles from counterfeit powerloom imitations. Das et al. (2024) introduced a Deep Metric Learning (DML) model that achieved 97.8 percent accuracy in distinguishing genuine handloom fabrics from their powerloom counterparts. Further, as noted by Jennifer et al. (2024), AI integration with handloom product supply chains can help predict demand fluctuations, optimize inventory management and logistics, and facilitate the efficient management of production cycles, which are aligned with real-time market needs.

Meanwhile, Jamaludin et al. (2023) highlight the role of mobile applications in enhancing real-time interaction and digital marketing for artisans, allowing them to expand market reach. Notably, augmented reality (AR) applications can enable users to digitally visualize traditional motifs, thereby promoting both cultural preservation and consumer engagement.

While there exists a gamut of technologies, which can help reimagine and redefine how handloom products are actually made and perceived by consumers, significant adoption challenges exist. As noted by Jennifer et al. (2024), training and upskilling of artisans to use emerging technologies is often overlooked. As such, artisans are unable to leverage the benefits of AI and IoT innovations. This calls attention to the need to prioritize capacity building and accessibility. Meanwhile, Bortamuly and Goswami (2015) suggest that education, income levels, and access to government support play a critical role in the adoption of technology. For instance, industry owners with higher levels of education and income are more likely to adopt modern technologies, while smaller owners often lack the resources or knowledge to seamlessly make a transition.

Thus, the main takeaway from the literature review is that while emerging technologies can complement the 'hand' and help transform the handloom product supply chains, there is a need for policymakers to take cognizance of the adoption challenges and put in place requisite interventions, lending a 'helping hand' to overcome the same.

Methodology

The research is based on primary data (supplemented with secondary data) conducted by the authors as part of the Government of India's AGNIi Mission program setup under the aegis of the Office of the Principal Scientific Adviser and Invest India. The research was undertaken in close collaboration with the Directorate of Handicrafts and Handloom, Kashmir, in the handicrafts and handloom clusters of Srinagar, Jammu and Kashmir. The field visits were conducted during December 2022 and June 2023. The authors conducted a series of Focus Group Discussions (FGDs) and unstructured interviews with Kashmiri artisans engaged with making carpets and Pashmina shawls in the clusters of Narwara, Kathi Darwaza, Zadibal, and Bagh Ali Mardan Khan, in Srinagar; along with senior officials from the Directorate of Handicrafts and Handloom, Kashmir, and its allied agencies, namely the School of Design, Craft Development Institute, Indian Institute of Carpet Technology, UNDP's (Handloom Project) facility, and the Pashmina Testing Facility; and select Indian emerging technology startups.

The methodology was executed in three broad parts (Table 1):

First, in December 2022, the authors undertook a field visit and conducted FGDs and unstructured interviews with Pashmina shawl and carpet artisans and government officials to surface pain points. With regard to the FGDs, the organizing principle was the handloom product supply chain with which the artisans engaged, and the objective was to identify pain points in the production and post-production supply chains, especially

with respect to tools, designs, and market access. As such, three FGDs (with 8 participants in each) were conducted: one with weavers associated with carpets, another with Pashmina shawl weavers, and a third with artisans engaged with embroidery (Sozni) on Pashmina shawls. It is to be noted that Sozni embroidery is an important post-loom process and constitutes an important value addition to the final product. It consists of back-breaking manual work, which is in direct competition with machine-made embroidery. With regard to the participants' demographics, for the two FGDs with carpet and Pashmina weavers, participants were largely male in the age group of 30-50 years; however, the embroiderers' group comprised young women in the age group of 20-25 years. This hints at the gendered work distribution in the Kashmiri handloom product supply chains wherein women are largely engaged in non-loom but highly value-added activities. Additionally, unstructured interviews were used for interactions with master artisans (five) and government officials (thirty). The objective was to better understand the legacy practices, the evolution of Kashmiri Pashmina shawls and carpets over time, and the existing policies and programmatic interventions in place.

Second, based on the pain points identified during the field visit in December 2022, the authors subsequently (between January and April 2023) identified nine Indian emerging technology startups and government research institutions (Table 1). The objective was to better understand the scope and possibility of emerging technology integration in the supply chain of Pashmina shawls and carpets.

Third, in June 2023, a two-day Field Immersion Workshop was conducted in Srinagar to bring together the artisans and representatives from startups and government research institutions. The objective was to better understand the integration of emerging technologies in the supply chain of Pashmina shawls and Kashmiri carpets in terms of operational scenarios and technical functional requirements. These interactions were free-flowing discussions between the artisans and representatives from startups and government research institutions mediated by the authors. The Immersion Workshop included 10 artisans (five Pashmina weavers and five carpet weavers), two representatives each from six Indian technology startups, and government research institutions (Table 1). The workshop was structured as a problem-solution matching exercise, wherein the artisans demonstrated the pain points, and representatives from startups and research institutions deliberated on existing or probable emerging technology interventions.

Thus, a well-grounded methodology was adopted to both understand pain points and identify the scope of emerging technology interventions.

Table 1: Overview of objectives, methods, and participants

S.No.	Objectives	Methodology	Participant Details
1.	Pain-point identification	FGDs *(Each was conducted at the location of work)*	Three FGDs: 1. Pashmina shawl weavers (8 participants, 30–50 years, males) 2. Carpet weavers (8 participants, 30–50-years, males) 3. Sozni embroiderers (8 participants, 20–25-years, females)
		Unstructured interviews	1. 5 Master artisans 2. 30 Government officials • 10 Officials: Directorate of Handicrafts and Handloom, Kashmir • 8 Experts: Craft Museum (School of Designs), Srinagar • 7 Domain Experts: Indian Institute of Carpet Technology, Srinagar • 5 Officials: UNDP's (Handloom Project) facility
2.	Scope of integrating emerging technology solutions	Free-flowing discussions	9 Indian emerging technology startups related to mixed reality, AI, IoT, and provenance tracking Government research institutions: Bombay Textile Research Institute, Wool Research Association, and RuTAG Centres of IIT Madras and Roorkee
3.	Understanding emerging technology integration with regards to field operational scenarios and actual technology functional requirements	Two-day field immersion workshop in Srinagar (included visits to Craft Museum (School of Designs), Indian Institute of Carpet	10 artisans (5 Pashmina shawl weavers and 5 carpet weavers) 2 representatives each from six Indian emerging technology startups related to mixed reality, AI, IoT, and provenance tracking

S.No.	Objectives	Methodology	Participant Details
		Technology, Craft Development Institute, Wool Processing Unit, dyeing clusters, Pashmina testing facility, Pashmina weaving centres, carpet weaving clusters, and export houses) Free-flowing discussions	2 representatives each from government research institutions (Bombay Textile Research Institute, Wool Research Association, and RuTAG Centres of IIT Madras and Roorkee)

Source: Authors' compilation

Integration of Emerging Technologies with Kashmiri Handloom Products

It emerged during the FGDs and interviews that the easy availability of cheap counterfeit machine-made products has had the most adverse impact on the Kashmiri handloom industry, with various second-order challenges that have severe implications for artisans' livelihoods and the continuity of the handmade itself.

The emerging technology innovations provide significant opportunities to revive the traditional Kashmiri handloom industry with significant benefits for artisans and help to preserve Kashmir's centuries-old rich handloom heritage, which otherwise runs the peril of languishment (Ishrat et al., 2020). A systematic approach is required to integrate technology with Kashmir's handloom industry with a focus on addressing two broad problem statements that encompass different supply chain nodes: (a) authentication and (re)premiumization of Kashmiri handloom products and (b) preservation of skills and knowledge of Kashmiri master artisans for intergenerational transfer to ensure the perpetuation of the handmade. These problem statements were identified on the basis of interactions with artisans and officials during the FGDs, interviews, and the field immersion workshop. Table 2 describes a select overview of qualitative insights that emerged from the discussions and their alignment with the problem statements.

Table 2: Select qualitative insights

S.No.	Problem Statement	Qualitative Insights
1.	Authentication and (re)premiumization of Kashmiri handloom products	**Lack of traceability and control on product labelling:** "After we sell the shawl, we don't know where it goes or how is it labelled." (FGD – Pashmina weavers) **Loss of value due to competition from machine-made products:** "Machine-made products are similar. Customers don't know the difference and bargain even when buying original Kani or Sozni embroidery products. This has also significantly brought down wages." (FGD – Embroidery artisans) **Lack of technology awareness**: "We have never heard of IoT or AI." (FGD – Carpet weavers) **Desire for technology adoption:** "If I can scan a code that shows this is my shawl, how I made it, then the buyer will trust and be ready to pay the price. This is something we need, something that can prove our work." (Pashmina weaver, Field Immersion Workshop) **Multiplicity of government interventions and lack of awareness:** "Government has launched QR codes and hologram tags, but their multiplicity has confused artisans and some in remote regions are not even aware." (Government official, interview) **Emerging technology solution for authentication:** "Our IoT device can be placed on the loom without requiring any alterations. It tracks weaving real-time and provides each shawl with a digital footprint." (IoT startup, Field Immersion Workshop)
2.	Preservation of skills and knowledge of Kashmiri master artisans for intergenerational transfer to ensure the perpetuation of the handmade	**Physical vulnerability of traditional Taleem designs:** "All my Taleems are handwritten and old. If they tear or get wet, the design is lost forever." (Master carpet weaver, interview) **Intergenerational skill transmission:** "My son doesn't know how to read the Taleem. He says it is difficult. He wishes if he could use a phone or computer to learn faster." (FGD – Carpet weaver)

S.No.	Problem Statement	Qualitative Insights
		Lack of systematic preservation: "Taleems are largely lying in the homes of artisans. One more flood like 2014 and they will be gone forever." (FGD – Carpet weaver)
		Emerging technology solution for preservation: "Our OCR can read Taleem scripts. We can build tools to digitise the designs so that they are never lost." (AI startup, Field Immersion Workshop)
		Desire for technology adoption: "If this AI tool can read Taleems and turn them digital, even my grandchildren will be able to read and our craft will be saved." (FGD – Carpet weaver)
		Saving the handmade: "We need digital repositories where artisans can archive designs, document processes, and connect with national and international artisans and design houses to include global market trends." (Craft Museum, School of Designs official, interview)

Source: Authors' compilation from primary data collected between December 2022 – June 2023

In this context, the following sub-sections elaborate on emerging technology use cases for (re)premiumization, preservation, and propagation within the Kashmiri handloom industry based on pain points identified via qualitative unstructured interviews and focus group discussions with both local Kashmiri artisans and senior officials at the Directorate of Handicrafts and Handloom, Kashmir.

Authentication and (re)premiumization of Kashmiri handloom through emerging technology integration

With regard to premiumization, the pivotal issue faced by Kashmiri artisans pertains to the inability of consumers to authenticate handmade Kashmiri products in the market. Markets are flooded with mass-produced machine-made/power loom imitations, especially from surrounding industrial regions of Amritsar and Ludhiana, which are often passed off as genuine Kashmiri handloom. Moreover, the introduction of multiple labels—plastic, hologram, and fabric-based tags for Geographic Indication (GI) and non-GI products—has created further confusion for consumers about product authenticity. The repercussions of this situation have primarily been two-fold: a devaluation of true

craftsmanship and a significant decline in artisan wages, with some artisans today earning as little as Rs. 200 per day.

Further, while Kashmiri handloom products like Pashmina and carpets are meant and designed for niche luxury markets, there is little awareness among consumers about their distinguishing features, with implications on market demand. For example, authentic Kashmiri Pashmina with fibers measuring 12-13 microns (Shakyawar et al., 2013) is more premium than cashmere, measuring 12-20 microns (as corroborated during FGDs and interviews); however, due to lack of consumer awareness, the former is unable to capture and leverage the gains in global luxury handloom markets, with a major consequence for Kashmiri artisans.

Last but not least, Kashmiri handloom markets are characterized by the pervasiveness of middlemen, which further erodes the artisan earnings. As surfaced during FGDs, artisans mostly rely on middlemen (most times large exporters) for market access and branding, who typically control the marketing narrative and mostly marginalize artisans with just a meager share of the products' final price.

Considering the above-identified issues, a range of emerging technology interventions can be utilized in a 'stack approach' to help resolve the pain points. In the Information Technology (IT) sector, the technology stack approach refers to the systematic selection and integration of various technologies, for instance, programming languages, database management systems, operating systems, and frameworks, to develop effective solutions for complex problems (Nikulchev, Ilin and Gusev, 2021). A similar approach can be extended to real-world challenges by leveraging a combination of technologies. This would entail breaking down a larger problem statement into smaller components, and each technology in the stack can address a specific aspect of the problem, ultimately leading to a comprehensive and efficient solution.

In this regard, a key identified solution pertains to the usage of Physically Unclonable Function (PUF) QR codes, which provide a digital fingerprint for each unique product, allowing to check for and establish authenticity. PUF-based QR codes make use of unique, unclonable physical properties that arise from random variations during the manufacturing process, making them highly secure and resistant to counterfeiting. The authors' conversation with an Indian startup that offers PUF-based QR codes as products brought to light that unlike traditional QR codes, which can be easily replicated, PUF-based QR codes embed these random physical variations, providing a unique identifier that cannot be cloned or tampered with. Their usage helps certify that a handloom product is genuinely handmade and simultaneously allows consumers to trace its entire

production journey—from raw material sourcing to the final finished product. For instance, consumers can instantly scan PUF QR codes on, say, a Kani Pashmina shawl or a Kashmiri carpet to learn about the artisan involved in making the piece, the knot count, weaving techniques, etc., establishing authenticity, premium quality, and a direct connection between the buyer and the weaver, significantly increasing the chances of purchase.

In addition to PUF QR codes, IoT sensors can be deployed on handlooms to capture real-time motion data during the weaving process. These sensors have the capabilities to track the subtle hand movements of the artisans involved in handloom weaving, making it possible to differentiate between handmade and machine-made products. The data captured via these IoT sensors can be stored and analyzed to provide verifiable proof that a Kashmiri handloom item was woven by hand, rather than on a power loom. Additionally, machine learning-based optical scanners can be introduced to further enhance product verification by detecting the number of knots per inch in carpets and shawls. These scanners, combined with QR code technology, help consumers get a comprehensive understanding of a product's specifications, further establishing product authenticity and uniqueness.

It is important to note that the above-mentioned technological interventions do not simply authenticate and establish the distinctness of Kashmiri handloom products; they can also be used to further enhance consumer experience by allowing artisans and producers to present the consumers with the productive narrative. In this regard, technologies of narrative, such as augmented reality (AR) and interactive displays, can be integrated with the marketing process, offering consumers a visually rich experience, which explains the cultural and historical significance of products.

Digital preservation of Kashmiri handloom heritage

Another major problem identified during the FGDs and qualitative interviews, as also elaborated upon by Ishrat et al. (2020), concerns the lack of preservation of skills and knowledge of Kashmiri master artisans. Most Kashmiri master artisans are aging and nearing the end of their careers, and there is almost no one to take their place. Hence, it becomes imperative to document and preserve their expertise and techniques before they are lost to time. This is especially a pressing concern in the case of Taleems. According to Majeed and Swalehin (2020), Taleems, a unique feature of Kashmir, are coded design instructions used by carpet weavers in the region. These are centuries-old 'handwritten algorithms,' written on fragile sheets of paper, which aid the hand on the

loom. Taleems convey important information like thread colors, knots per square inch, and weft lines, and they help artisans create unique Kashmiri carpet designs.

However, handwritten paper repositories of Taleems run the risk of degeneration over time. This can be attributed to both the fragility of the medium and natural calamities like the 2014 floods, which led to the loss of countless unique designs (Khan, 2023), as also stated during the FGDs and interviews, necessitating interventions for preservation. While concerned authorities in Kashmir have undertaken measures to initiate Taleem digitization, the conventional process is slow and entails manual transcription of Taleem symbols into software, which slows down production and jeopardizes the preservation of traditional weaving techniques.

In this regard, an innovative emerging technology solution, which utilizes AI and ML, can be significantly useful. An AI-based solution, enabled by Optical Character Recognition (OCR) technology, powered by Convolutional Neural Networks and Long Short-Term Memory architectures, can help expedite and automate the digitization of Taleems more accurately. These advanced computer vision systems scan the physical Taleems and convert them into digital formats, aiding preservation and creation of a digital design repository. Additionally, customized machine learning algorithms can be developed to extract designs from images and generate new Taleems, offering to both preserve and innovate upon traditional patterns.

Various benefits can be reaped from the adoption of these technological interventions. The use of AI-driven OCR technology enhances the efficiency of the weaving process, as it significantly reduces the time required for digitization. This allows artisans to focus more on the craft while ensuring the integrity of traditional designs. Furthermore, accurate digitization of Taleems helps safeguard centuries-old designs and techniques, preserving them for future generations and ensuring the continuity of the region's cultural legacy. Creation of digital design repositories via the use of emerging technologies can help empower artisans, as they acquire access to innumerable traditional and contemporary design patterns, which can be modified and adapted as per the demands of modern consumers and markets.

With regard to digitization, another area of intervention should focus on building a digital global knowledge exchange platform, which allows artisans to access best practices and designs from around the world. The platform can function as a digital design bank, where artisans can browse, contribute to, and learn from a wide array of designs that reflect both traditional craftsmanship and modern market trends. By fostering a global dialogue around design and craft, such a platform will not only enrich

artisan knowledge but also present fresh opportunities for collaboration and market expansion.

Last but not least, an emerging technology intervention, which can help place traditional Kashmiri handloom products in global markets, is the introduction of digital infotainment technologies. These include interactive museum displays, augmented reality exhibits, and virtual reality tours, which can help create an engaging and educational experience for national and international tourists visiting Jammu and Kashmir. It is important to note that tourist footfall in Jammu and Kashmir has been significant in recent years, and officially it stood at approximately 2.1 crore during 2023 that further rose to 2.3 crore in 2024 (India Brand Equity Foundation, 2025). These digital interventions will enable museums to serve as a cultural landmark as well as a learning platform, where students, artisans, and tourists can explore the rich history of Kashmiri handlooms and handicrafts, with implications for translating into purchases.

Conclusion

Industry 4.0 solutions can have far-reaching positive implications on every node of the supply chain for Kashmiri handloom products. Be it design, production, marketing, or distribution, they can redefine the contours of craftsmanship and help Kashmiri cultural heritage adapt to the needs of the 21st century's fashion market demands. In this context, the present paper elaborates on various avenues for integrating emerging technology solutions within Kashmiri handloom product supply chains. Emerging technologies such as PUF-based QR codes, IoT sensors, AI and ML technologies, and AR can help build a niche narrative for Kashmiri handloom products and completely transform their perception among national and international consumers with both micro- and macroeconomic implications.

From a policy perspective, the identified emerging technology use cases for Kashmiri handloom products discussed in this article can be emulated and scaled across India's 1,463 handloom clusters (Development Commissioner Handlooms, n.d.), with the caveat that technology complements the 'hand' and does not substitute it. Policymakers need to intelligently and effectively leverage emerging technology solutions to serve as a conduit between the hyperlocal artisans and global markets. These initiatives can help drive a wider technology-enabled transformation with multiplier effects for approximately 32 lakh handloom workers (Ministry of Textiles, 2020) in terms of livelihood security and varied parameters of human development, with downstream benefits for the Indian economy at large.

However, successful technology integration to leverage tangible benefits would be contingent on overcoming the 3A challenges—awareness, availability/affordability, and access—which impede technology adoption, a not-so-straightforward process. The 3A challenges, which require immediate policy attention, include the following:

- Awareness: Technology adoption is a function of the perceived attributes of innovation, namely, relative advantage, compatibility, complexity, trialability, and observability (Rogers, 1962), which might not always be apparent to adopters, especially rural adopter communities characterized by low levels of education and awareness. The genesis of the same is information asymmetries between adopters (handloom artisan communities in this case) and innovators about the various purposes the innovation can serve and its inherent advantages. Hence, the first step towards successful adoption is to educate artisan communities about the potential technology use cases in the handloom product supply chains. In this context, the government and civil society should create avenues like immersion workshops (as organized and conducted by the authors) to break silos and facilitate dialogue between innovators and artisans. Such an effort would facilitate a bilateral flow of innovation, enabling adoption. Additionally, it will help improve existing innovations and allow for new use-case discovery.

- Availability/Affordability: Even if the artisans are aware of the benefits technology integration can bring, resource constraint is a reality. As highlighted earlier, Indian artisan communities are characterized by low levels of income. However, emerging technology solutions usually entail high device costs as well as additional costs for any infrastructure requirements, significantly impeding adoption. Resolving such problems would require governments to become 'procurers of first resort.' Leveraging emerging technology solutions via government procurement mechanisms will help build an effective foundation to scale technology adoption among artisans of the region. The procured solutions can be provided to artisans at subsidized rates or made available for usage with a minor fee at government Common Facility Centers in handloom clusters.

- Access: The third facet of the problem is that handloom artisan communities are characterized by low levels of education. According to the Ministry of Textiles (2020), nearly 1 in 4 weavers have not received any form of formal education. Moreover, 14 percent have not completed primary-level education. This poses digital literacy barriers, wherein availability of technology does not guarantee usage and will have to be complemented with requisite skilling to

help unleash the potential of emerging technologies (Majumdar, Basu and Jain, 2021). Hence, policy mechanisms for the digital empowerment of artisans become imperative. With governments taking the first step, this would have to involve participation of civil society as well as big export houses, which can provide required access to artisan communities and help undertake organized skilling initiatives.

Thus, calibrated technology integration within handloom production and post-production value chains is a sine qua non to make our handloom sector globally competitive. However, this requires policymakers to adopt a multi-stakeholder approach, which brings together government, artisans, and innovators as well as civil society to overcome the 3A challenges, which deter successful technology adoption.

Acknowledgement

References

AGNIi Mission, 2023. *Innovation for Handicrafts and Handloom Cluster 1.*Office of the Principal Scientific Adviser to the Government of India, [online] Available at: <https://psa.gov.in/CMS/web/sites/default/files/publication/Innovation%20for%20Handicrafts%20%20and%20Handloom%20Cluster1.pdf> [Accessed 18 August 2025].

Aounzou, Y., Kalloubi, F., and Boulaalam, A., 2022. Toward an IoT-based system to ensure product identification of Moroccan handicrafts. In: S. Motahhir and B. Bossoufi, eds. *Digital technologies and applications. ICDTA 2022.* Lecture Notes in Networks and Systems, Cham: Springer. https://doi.org/10.1007/978-3-031-02447-4_29.

Bortamuly, A.B. and Goswami, K., 2015. Determinants of the adoption of modern technology in the handloom industry in Assam. *Technological Forecasting & Social Change* [e-journal] 96, pp.31-43. https://doi.org/10.1016/j.techfore.2014.04.018.

Das, A., Deka, A., Medhi, K. and Saikia, M.J., 2024. Deep learning to authenticate traditional handloom textiles. *Information,*[e-journal] 15(8), pp.465.https://doi.org/10.3390/info15080465.

Development Commissioner Handlooms, n.d. *Handloom Exports – 10 Years Data by HS Code*. [pdf] <https://handlooms.nic.in/assets/img/Statistics/HS%20code%2010%20yrs%20data.pdf>[Accessed 15 June 2025].

Development Commissioner Handlooms, n.d. *List of Handloom Clusters under AHVY*. [online] Available at: <https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fhandlooms.nic.in%2Fassets%2Fimg%2FHandloom%2520Clusters%2F2500.xlsx>[Accessed15 June 2025].

Government of Jammu and Kashmir, Industries and Commerce Department, n.d. *Jammu and Kashmir Wool Processing, Handloom, Handicrafts Policy - 2020*. [pdf] Available at:<https://jkindustriescommerce.nic.in/Orders%202020/54%20IND%20of%202020.pdf> [Accessed 28 September 2024].

Government of Jammu and Kashmir, 2020. *Order No. 54-IND of 2020: Recognition of Traditional Industries*. [pdf] Available at: <https://industriescommerce.jk.gov.in/Orders%202020/54%20IND%20of%202020.pdf> [Accessed 15 June 2025]

Halim, M.S.A., Ibrahim, G.E. and Tawab, F.M.A., 2024. Utilizing artificial intelligence techniques to develop some textile craft industries. *International Design Journal,* 14(5), pp.43-63. [online] Available at:<https://idj.journals.ekb.eg/article_372636.html> [Accessed 24 September 2024].

India Brand Equity Foundation, 2025. *About Jammu and Kashmir: Information on Tourism, Industries, Economy & Geography*. [online] Available at: <https://www.ibef.org/states/jammu-kashmir> [Accessed 19 August 2025].

Ingavale, S.U., Gujale, V.K., Karande, V.R., Katkar, A.S. and Patil, M.D., 2024. IoT-based automation of power loom in textile industries. [pdf] *International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET),* Available at:<https://www.ijmrset.com/upload/46_IoT.pdf> [Accessed 20 September 2024].

Ishrat, S.I., Grigg, N.P., Bezuidenhout, C.N. and Jayamaha, N.P., 2020. Sustainability issues in the traditional cashmere supply chain: Empirical evidence from Kashmir, India. *Sustainability,* [e-journal] 12(24), p.10359. https://doi.org/10.3390/su122410359.

Jamaludin, N.S.A., Othman, A.N., Albakry, N.S. and Yusoff, M.D.M., 2023. *The contribution and potential of digital transformation on Malaysian handicraft products.* [pdf] GSE e-journal of education. Available at: https://weedutech.com/journal/gse/toc/2023/2.pdf [Accessed 25 August 2025].

Jennifer, K.C., Indu, G.K., Hayavadana, J., Kulkarni, S.R., Srinivasulu, K., Kapoor, V., Priyadharshini, S.N. and Umamageshwari, S.,2024. *Application of artificial intelligence (AI) in the handloom industry*. [pdf] African Journal of Biological Sciences. Available at:<https://www.afjbs.com/uploads/paper/ef192e14ebcc64a6257c54678705d0e6.pdf> [Accessed 24 September 2024].

Khan, A.A., 2023. *Kashmir floods 2014: recovery to resilience.* National Institute of Disaster Management, Ministry of Home Affairs, New Delhi: India.

Kumar, V., Kumari, P., Yadav, P. and Kumar, M., 2021. Ancient to contemporary — The saga of Indian handloom sector. *Indian Journal of Fibre & Textile Research,* [e-journal] 46(4). https://doi.org/10.56042/ijftr.v46i4.59209.

Majeed, I. and Swalehin, M., 2020. Carpet weaving occupation in Kashmir: An analysis of socio-economic conditions of carpet weavers of Pulwama District. *Asian Journal of Economics, Business and Accounting,* [e-journal] 16(1), pp.41-49. https://doi.org/10.9734/AJEBA/2020/v16i130230.

Majumdar, B., Basu, S. and Jain, S., 2021. *Digital empowerment and Indian handlooms: Case-based policy recommendations.* [pdf] Economic and Political Weekly. Available at:<https://www.defindia.

org/wp-content/uploads/2021/04/Digital-Empowerment-and-Indian-Handlooms.pdf> [Accessed 19 September 2024].

Malik, S., Muhammad, K. and Waheed, Y., 2024. Artificial intelligence and industrial applications: A revolution in modern industries. *Ain Shams Engineering Journal,* [online] Available at:<https://www.researchgate.net/publication/381160287_Artificial_intelligence_and_industrial_applications-A_revolution_in_modern_industries> [Accessed 20 September 2024].

Ministry of Textiles, Fourth All India Handloom Census. *Office of the Development Commissioner for Handlooms, Ministry of Textiles, Government of India,* 2020. Available at: https://handlooms.nic.in/assets/img/Statistics/3736.pdf [Accessed 21 Sept. 2024].

Ministry of Textiles, n.d. *Directory of Handicraft Clusters under AHVY*. Available at: <http://www.craftclustersofindia.in/site/Cluster_Directory.aspx?mu_id=3> [Accessed15 June, 2025].

Nikulchev, E., Ilin, D. and Gusev, A., 2021. Technology stack selection model for software design of digital platforms. *Mathematics,* [e-journal] 9(4), p.308. https://doi.org/10.3390/math9040308.

Rogers, E.M., 1962. *Diffusion of Innovations,* 3rd ed. New York: The Free Press.

Sabeenian, R.S., Paramasivam, M.E. and Dinesh, P.M., 2012. Computer vision-based defect detection and identification in handloom silk fabrics. *International Journal of Computer Applications,* [online] Available at:<https://www.researchgate.net/publication/230750503_Computer_Vision_Based_Defect_Detection_and_Identification_in_Handloom_Silk_Fabrics> [Accessed 22 September 2024].

Shakyawar, D.B., Raja, A.S.M., Kumar, A., Pareek, P.K. and Wani, S.A., 2013. Pashmina fibre — Production, characteristics and utilization. *Indian Journal of Fibre & Textile Research,* [online] Available at:<https://www.researchgate.net/publication/265016291_Pashmina_fibre-Production_characteristics_utilisation> [Accessed 19 September 2024].

Sinha, M., 2023. LG launches QR code-based labels of 13 GI and non-GI registered crafts in J&K. *Economic Times*. [online] 29 January. Available at: <https://www.business-standard.com/article/current-affairs/lg-launches-qr-code-based-labels-of-13-gi-and-non-gi-registered-crafts-in-j-k-123012900681_1.html>[Accessed 15 June 2025].

Zabulis, X., Meghini, C., Dubois, A., Doulgeraki, P., Partarakis, N., Adami, I., Karuzaki, E., Carre, A-L., Patsiouras, N., Kaplanidi, D., Metilli, D., Bartalesi, V., Ringas, C., Tasiopoulou, E. and Stefanidi, Z., 2022. Digitisation of traditional craft processes. *Journal on Computing and Cultural Heritage (JOCCH),* [e-journal] 15(3), pp.1-24.https://doi.org/10.1145/3494675.

About the authors

Vishad Vivek Singh is Assistant Manager at Invest India, specializing in emerging technologies and innovation management. He holds a BTech from Delhi Technological University and is currently a part of the Technology & Innovation Division at Invest India. Previously, Vishad was involved with the AGNIi Mission, a part of the Prime Minister's Science, Technology, and Innovation Advisory Council, where he focused on mapping and developing technology stacks to address national-level challenges. His expertise includes identifying advanced solutions for tackling climate change, enhancing training and perimeter security for internal security forces, and emerging innovations for MSMEs, particularly in the handicrafts sector. Currently, Vishad is exploring India's capabilities across strategic technological sectors, with a specific emphasis on quantum technologies.

vishad.singh@investindia.org.in

Sanchita Joshi holds a PhD in Management from the Faculty of Management Studies, University of Delhi, and her research delves into gender disparities in time use, time poverty, and work participation in India. Previously, she was engaged as a consultant with the AGNIi Mission, Office of the Principal Scientific Adviser, Government of India, at Invest India, and has teaching experience at Delhi Technological University and the University of Delhi. Her research interests encompass gender, labor, technology, human development, climate change, and livelihoods.

sanchitajoshi03@gmail.com

Vikrant Khazanchi heads the Technology & Innovation focus at Invest India. In this role, he partners with collaborators from the Indian and the global innovation ecosystems to position India's R&D and technology capabilities in emerging and frontier sectors like quantum, AI, advanced materials, etc., for catalyzing investments in these domains. Previously, he was heading the AGNIi Mission under the Prime Minister's Science, Technology, and Innovation Advisory Council (PM-STIAC), where he formulated technology advice in national priority areas of national security, climate change, and human development for several government agencies. Prior to his work with the Government of India, Vikrant was based out of New York and has extensively worked in the fields of artificial intelligence, product development, and data science. He holds a bachelor's in technology from IIT Delhi.

vikrant.khazanchi@investindia.org.in

Sanish Shirish Kulkarni leads the Indo-Pacific Economic Framework (IPEF)'s Clean Economy engagements at Invest India. As a part of the Global Partnerships & Net Zero team at Invest India, Sanish focuses on leveraging multilateral organizations and plurilateral platforms for catalyzing investments in India's clean economy sectors. He focuses on building sustainable partnerships with diverse stakeholders, including governments, investors, project proponents, climate tech startups, etc. He has led the Human Development vertical at the AGNIi Mission, a program of the Office of the Principal Scientific Adviser to the Government of India. He has focused on the intersection of impact and technology, which could propel human-centered sectors like climate change as well as handicrafts and handlooms.

sanish.kulkarni@investindia.org.in