IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received June 23, 2019, accepted July 3, 2019, date of publication July 15, 2019, date of current version August 1, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2928979

A Detailed Review of Artificial Intelligence Applied in the Fashion and Apparel Industry

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This work was supported by the European Commission through the Framework of Erasmus Mundus Joint Doctorate Program-SMDTex.

ABSTRACT The enormous impact of artificial intelligence has been realized in transforming the fashion and apparel industry in the past decades. However, the research in this domain is scattered and mainly focuses on one of the stages of the supply chain. Due to this, it is difficult to comprehend the work conducted in the distinct domain of the fashion and apparel industry. Therefore, this paper aims to study the impact and the significance of artificial intelligence in the fashion and apparel industry in the last decades throughout the supply chain. Following this objective, we performed a systematic literature review of research articles (journal and conference) associated with artificial intelligence in the fashion and apparel industry. Articles were retrieved from two popular databases ''Scopus'' and ''Web of Science'' and the article screening was completed in five phases resulting in 149 articles. This was followed by article categorization which was grounded on the proposed taxonomy and was completed in two steps. First, the research articles were categorized according to the artificial intelligence methods applied such as machine learning, expert systems, decision support system, optimization, and image recognition and computer vision. Second, the articles were categorized based on supply chain stages targeted such as design, fabric production, apparel production, and distribution. In addition, the supply chain stages were further classified based on business-to-business (B2B) and business-to-consumer (B2C) to give a broader outlook of the industry. As a result of the categorizations, research gaps were identified in the applications of AI techniques, at the supply chain stages and from a business (B2B/B2C) perspective. Based on these gaps, the future prospects of the AI in this domain are discussed. These can benefit the researchers in academics and industrial practitioners working in the domain of the fashion and apparel industry.

INDEX TERMS Artificial intelligence, big data analytics, machine learning, expert systems, fashion and apparel industry.

I. INTRODUCTION

Fashion and apparel (F&A) industry is one of the largest economies contributing 38% to the Asia Pacific, 26% to Europe and 22% to North America [1]. According to Business of Fashion, (2019), F&A sales are projected to grow by 7.5% and 5.5% in the Asia Pacific and Europe respectively. F&A is also one of the largest waste producers globally [3] because of problems like overproduction and product returns. The principal reason behind this is the consumer's dissatisfaction with the products offered by the industry in terms of size, color, and style. Hence, it is essential for the industry to become customer-centric for successfully regulating environment-friendly manufacturing practices. Consequently, it is important that the industry adopt sustainable production practices to alleviate waste production and management. One of the ways of achieving this can be by taking advantage of emerging Artificial Intelligence (AI) techniques for creating a sustainable digital supply chain [4].

The associate editor coordinating the review of this manuscript and approving it for publication was Zijian Zhang.

In the past decades, AI has transformed many industries like health, transportation, and manufacturing due to its capability to solve problems using conventional mathematical models [5]–[7]. The application of AI has been recognized in the F&A industry at various stages such as apparel design, pattern making, forecasting sales production, supply chain management [8], [9].

With the emergence of globalization and digitalization, AI has gained attention to connect businesses globally. In the last decade, the F&A industry has utilized AI to a certain extent for improving supply chain processes like apparel production [10], fabric inspection [11], distribution [12]. This was important as the F&A industry is volatile and it is always challenging to quickly respond to change in trends and continuously evolving consumer's demands.

An additional impact of digitalization is noticed in consumer behavior in the F&A industry. The increase in awareness and advent of new offline and online mediums has changed the contemporary consumer's decision-making pattern, influenced by the various online and offline mediums [13]. It is, therefore, important to create digital platforms for efficient requirements elicitation and collection. This can be attained by utilizing the benefits accompanied by Information technology (IT), Artificial intelligence (AI) techniques, big data analytical tools and other current technologies [14].

Evidently, the F&A industry is one of the most dynamic industries with new data being generated every time a new garment is designed, produced and sold [15]. However, the industry still lacks the extensive adoption of AI methods. The industry is still using computational tools based on classical algorithms and modern AI techniques are confined to academic research. Hence, it is a requisite for the industry to adopt new AI techniques to have a competitive advantage and improve business profitability. To do this, it is indispensable to have a consolidated description of different AI techniques used in research to target various business problems in the F&A supply chain.

After scrutinizing the extant literature in this domain, we encountered a few review articles, where the focus was on either AI or supply chain in F&A. For instance, the review conducted in [8] shows categorization of research articles on the basis of four operation processes in the apparel industry: apparel design, manufacturing, retailing, and supply chain management. This study presented the limitations of academic research that hinders the application of AI methods at an industrial level and also found that the F&A industry received less recognition from AI research groups. The work represented in [16] was restricted to AI algorithms, ''Decision support systems'' and ''Intelligent systems'' in the textile and apparel supply chain. In addition, this study only considered journal articles for the review. In contrast to these two reviews, the review carried out in [17] focuses on ''Data mining and Machine learning models'' implemented in the textile industry. According to this study, classification techniques were applied more frequently as compared to clustering techniques.

Despite valuable contributions to the previous literature reviews, when observed, none of the reviews studied the overall impact of AI in the F&A industry. In addition, there is a need to have a broader outlook of AI techniques employed for improving business operations at different supply chain stages. Furthermore, no study emphasized on defining the F&A supply chain stages according to the business perspective. Every business is composed of Business-to-Business (B2B) and Business-to-Consumer (B2C) transactions. In a traditional business setting, every personnel involved in business operations has knowledge confined to a specific domain. However, with the proliferation of AI technology, the complexity of business operations has risen, making it important for individuals (industrial researchers, academic researchers, managers) to have interdisciplinary knowledge.

By segregating the supply chain operations into B2B and B2C, the purpose is to provide a roadmap for individuals who are willing to expand the horizon of their expertise to help the F&A industry in improving their business models and profitability.

The objectives of this study are threefold. First, to do an in-depth analysis of the ongoing trend of AI in the F&A industry over the last decades. For this, no time constraint was introduced while retrieving the articles from scientific databases. Second, to understand the exploitation of AI techniques employed at various F&A chain stages. This is to examine the industrial transformation from a technical perspective. Third, to comprehend the utilization of AI techniques with a business perspective in F&A supply chain. Hence, this paper addresses the following research questions:

RQ1. What is the impact of Artificial Intelligence on F&A Industry over the past decades?

RQ2. Where have the AI methods been applied in F&A supply chain?

RQ3. To what extent has research addressed the supply chain problems from a B2B and/or B2C perspective?

In this direction, this research aims to conduct a systematic and comprehensive literature review of AI methods applied in the F&A industry in the past decades. This study is viable for an independent researcher to understand AI trend in F&A irrespective of their domain. Another important attribute of this work is the consideration of all journal and conference publications, which is rarely found in other review studies.

The remaining article is organized as follows: Section II outlines the research framework for conducting the systematic literature review. Section III describes the steps involved in the article screening process. Section IV represents the taxonomy proposed for the classification of AI methods and F&A supply chain. This is followed by section V that discusses the analysis and findings of the review process. Section VI and VII present the research gaps identified, future implications, conclusion, and limitations.

II. RESEARCH FRAMEWORK

In an attempt to answer the research questions, this study presents a systematic literature review (SLR) focusing on

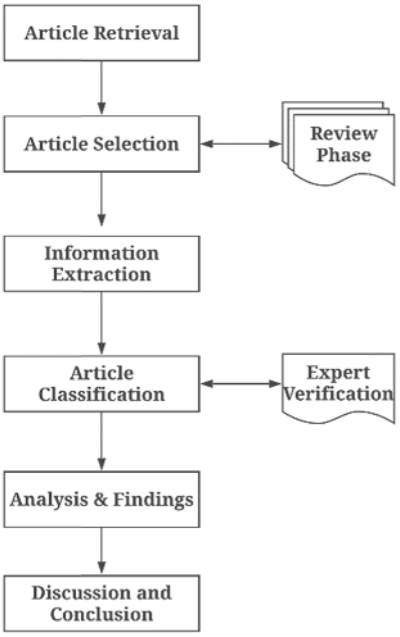

FIGURE 1. Systematic literature review: Research framework.

TABLE 1. Competencies of researchers.

Researcher	Competencies	
	Major	Minor
First Researcher	Artificial Intelligence, Data Science, Expert Systems, Machine Learning	Fashion, Textile, Supply Chain, Management
Second Researcher	Fashion and Apparel Supply Chain, Fashion Technology, Information Technology, Data analysis	Machine Learning, Artificial Intelligence
Expert Researcher	Significant Knowledge of Both Domains (AI and F&A)	NA

artificial intelligence methods applied in the F&A industry. An SLR methodology was chosen to make the research more rational, transparent and reproducible [18].

Based on the research focus, the methodology adopted is shown in Figure 1. The review process commenced with collecting and preparing data from scientific databases. Subsequently, articles were selected in five phases (depicted in Figure 2), strictly adhering to the inclusion and exclusion criteria defined in table 4 and 5. Finally, the selected articles were considered for classification (described in section IV) and further analysis complying with the research questions. There were two researchers involved in the entire review process and one expert researcher for the validation of the classification process. The competencies of each researcher can be seen in the following Table 1.

III. ARTICLE SCREENING PROCESS

The article screening process is presented in Figure 2. It is comprised of three steps, namely article retrieval, article selection, and information extraction.

TABLE 2. Synonyms of the targeted search keywords.

Artificial Intelligence (AI)	Fashion and Apparel (F&A)
Machine Learning	Fashion Industry
Deep Learning	Garment Industry
Data Mining	Apparel Industry
Artificial Intelligence	Clothing Industry
Data Analytics	Textile Industry
Expert Systems	
Knowledge Systems	
Intelligent Systems	
Decision Support Systems	
Data Management	

A. ARTICLE RETRIEVAL

This section discusses the steps involved in article retrieval, which is the initial part of the article selection process. The first step was to choose the databases to conduct the SLR. Two popular scientific databases, Scopus and Web of Science, were selected because of their popularity in academia. In addition, these databases index most of the journals and conference proceedings. Especially, most of the work in this research's domain is also indexed in these two databases [19], [20].

This was followed by formulating the search string, which included all the synonyms related to artificial intelligence and the F&A industry (shown in Table 2). The final search string defined for both the databases are as follows:

1) SEARCH STRING FOR SCOPUS

TITLE-ABS-KEY ((“Machine learning” OR“deep learning” OR “data mining” OR “artificial intelligence” OR “data analytics” OR “expert system”OR “knowledge system” OR “intelligent system” OR”decision support system”) AND ((fashion OR garment∗ OR apparel∗ OR cloth∗ OR textile∗) industry∗)) AND (LIMIT-TO (LANGUAGE, “ENGLISH”)))

2) SEARCH STRING FOR WEB OF SCIENCE

TS = (((“Machine learning″ OR “deep learning” OR “data mining” OR ”artificial intelligence” OR “data analytics” OR “expert system” OR “knowledge system” OR “intelligent system” OR “decision support system”) AND ((fashion OR garment∗ OR apparel∗ OR cloth∗ OR textile∗) industr∗)))

Refined By: **LANGUAGES:** (ENGLISH)

where,
TITLE-ABS-KEY/ TS = Title, Abstract, and Keywords
AND/ OR = Boolean operators to connect different keywords

∗ = used for loose/approximate phrase
“ = used for exact phrase

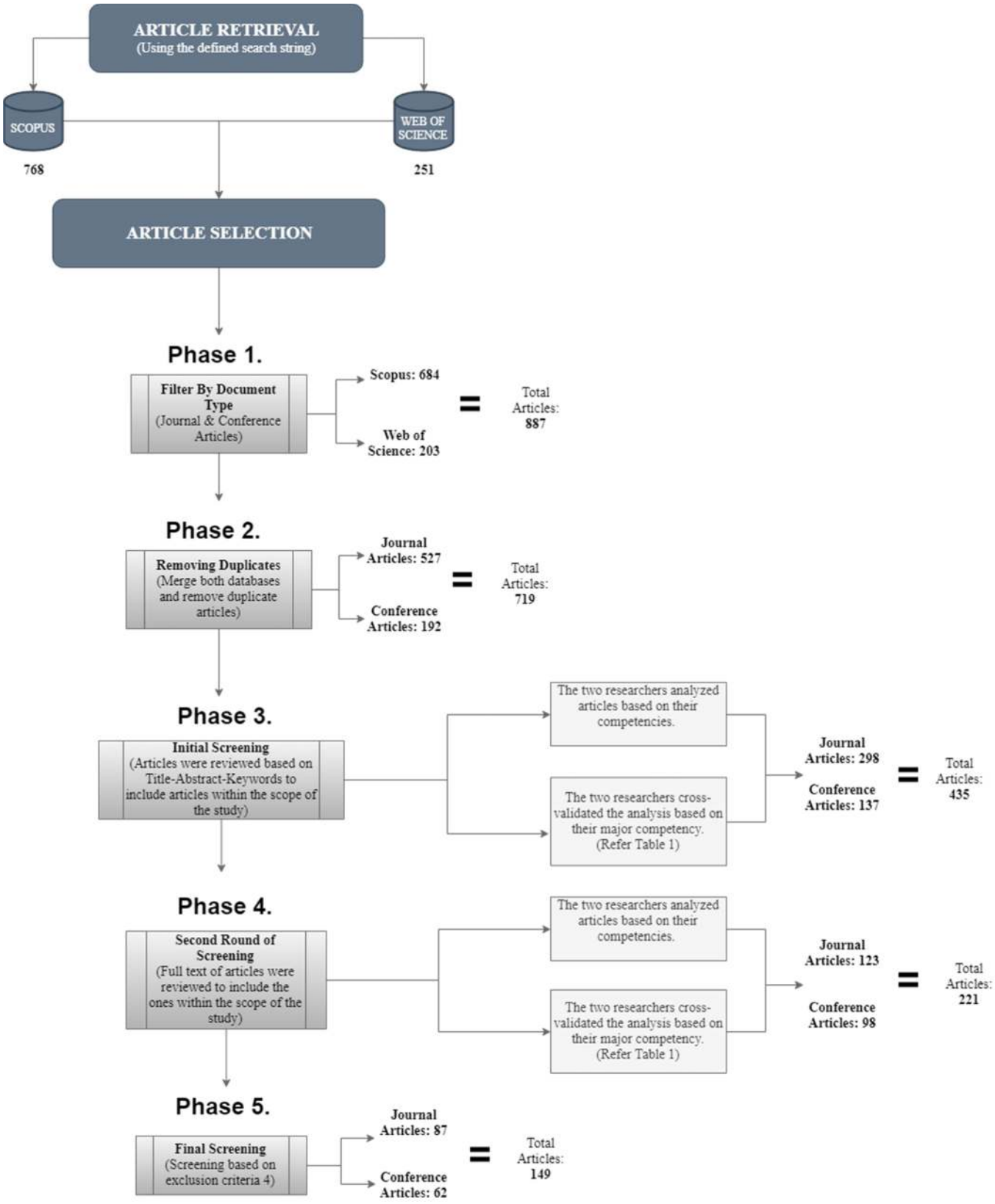

FIGURE 2. Article screening process.

TABLE 3. Extracted documents.

Scopus		Web of Science	
Document Type	Number of Articles	Document Type	Number of Articles
Conference Paper	319	Articles	138
Article	352	Conference Paper	65
Conference Review	44	Book and Book Chapter	48
Book and Book Chapter	32		
Review	13		
Article in Press	6		
Editorial	1		
Note	1		
Total	**768**		**251**

TABLE 4. Inclusion criteria.

Number	Criteria	Reason for Inclusion
1	No time Constraint	To understand the overall trend of AI in the F&A domain to answer RQ1
2	All Journal Articles and Conference Proceedings indexed in Scopus and Web of Science Databases	These databases index most of the journals and conference proceedings in the research field; To make sure that all articles relevant for addressing our three RQs are fetched
3	All countries and markets	To prevent biases while investigating the literature
4	All researches that applied AI techniques in F&A domain	To recognize all the stages in F&A supply chain where the implementation and execution of AI has been realized (to answer RQ2)
5	All researches conducted with a perspective of B2B, B2C or Both in F&A domain	To examine the extent with which business problems have been acknowledged using AI (to answer RQ3)

TABLE 5. Exclusion criteria.

Number	Criteria	Reason for Exclusion
1	Grey literature	To maintain the scientific reliability of the literature review
2	Non-English articles	To eliminate the misapprehension while scrutinizing the articles and avoid language barrier
3	Indutries that are not F&A industry	As the study concentrated on Fashion and Apparel industry
4	Research discussing theoretical and/or conceptual frameworks	To ensure the empirical validation of the AI models that can be applied in F&A industry

The execution of these search strings on Scopus and Web of Science yielded 768 and 251 articles (total articles 1019) respectively. The different document types are shown in Table 3. In Scopus, the research articles were found from a time-period of 33 years (1989-2018). Whereas on Web of Science, the time period was of 18 years (1991-2017). It should be noted that no time constraint was applied while searching for articles as the aim was to study all the work done in the research domain, fulfilling the goal of RQ1. The article selection process was carried out using certain inclusion and exclusion criteria enumerated in Table 4 and 5.

B. ARTICLE SELECTION

This section describes the rigorous screening process employed by the two researchers involved in order to select the articles relevant to address the research questions. The screening included five phases as shown in Figure 2. In the 'Phase 1', the articles were filtered by document type in accordance with inclusion criteria 2 and exclusion criteria 1, resulting into 684 articles in Scopus and 203 articles in Web of Science (total articles 887). In the 'Phase 2', the articles from both data sets were merged into one and redundant articles were eliminated, reducing the articles to 527 from journals and 192 from conference proceedings (total articles 719). In the 'Phase 3', initial screening was carried out by analyzing the "Title-Abstract-Keywords", conforming to inclusion criteria 3 & 4 and exclusion criteria 3. The initial screening was conducted in two sub-phases. First, the two researchers analyzed articles according to their competencies. Second, the two researchers cross-validated the analysis based on their major competencies (refer to Table 1). At this stage, the number of articles decreased to 298 from journals and 137 from conference proceedings (total articles 435).

Similarly, considering the same inclusion and exclusion criteria in the 'Phase 4', the two researchers first studied and analyzed the "Full text" of the articles, and then cross-validated the analysis based on their major competencies (refer Table 1). While accessing the full texts, a few conference articles were encountered having published only abstracts. Such abstracts were excluded from the study. At this point, the number of remaining articles were 123 from journals and 98 from conference proceedings (total articles 221).

Lastly, in the 'Phase 5', the articles were scanned based on the exclusion criteria 4. The rationale was to include studies where the conceptual AI model was implemented and empirically validated. The final count of the articles was 87 from journals and 62 from conference proceedings (total articles 149). In all the phases, the articles were excluded based on the consensus between the two researchers.

The final 149 articles were considered for the classification based on supply chain stages, applied artificial intelligence techniques, and business perspective: B2B and B2C. To accomplish this, different stages in F&A supply chain and classes in AI (explained in detail in section IV) were defined. Further, the F&A supply chain stages were categorized into Business-to-Business (B2B) and Business-to-Customer (B2C). This classification was important to get a clear outlook of the different AI classes applied at the F&A supply chain stages to address the research questions as this would help to identify opportunities with AI to accomplish business-related problems in F&A industry.

C. INFORMATION EXTRACTION

This section discusses the process followed for extracting information and classifying the selected articles based on supply chain stages, artificial intelligence classes, B2B and B2C to address our research questions RQ1, RQ2, and RQ3. The 149 articles were thoroughly examined to extract the following information:

1) *Applied AI class and algorithm*
2) *Supply chain stage under study*
3) *Business perspective: B2B and B2C*
4) *Research gaps Identified*

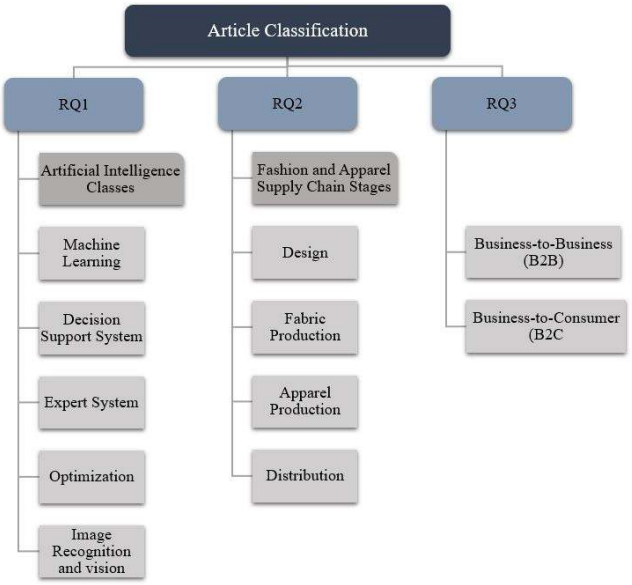

FIGURE 3. Article classification based on research questions.

The article classification conforming to the research questions is represented in Figure 3. As it can be seen, RQ1 is focused on understanding the overall trend of AI in the F&A industry. Hence, the focus of the screening process was limited to those articles discussing the implementation and execution of AI techniques in the F&A industry. To acknowledge RQ1, AI techniques were divided into five categories: Machine Learning, Decision Support System, Expert System, Optimization, and Image Recognition & Vision. The algorithms considered under each class are discussed in section IV.B. While extracting information, these classes were assigned to the articles.

RQ2 is aimed at identifying the various stages in the supply chain at which the AI method was employed. Hence, during the information extraction stage, the supply chain stage under study was recorded. To acknowledge RQ2, the supply chain stages were classified as Design, Fabric Production, Apparel Production, and Distribution. The processes considered under these stages are shown in Figure 4. While extracting information, the articles were assigned these supply chain stages.

RQ3 aims to understand the extent of business problems being a focus of research studies. To do this, the supply chain stages identified were further categorized from a business perspective into B2B and B2C (discussed in detail in section IV.A and Table 6). These classes were allocated to the research articles during information extraction.

This classification of research articles was verified with the help of an expert researcher actively involved in research related to artificial intelligence and F&A industry from the past two decades. The competency of the expert researcher is also mentioned in Table 1.

TABLE 6. B2B and B2C activities in the F&A industry.

B2B	B2C
Fashion Design	Fashion Design
Textile Design	Textile Design
Spinning	Dyeing & Printing
Weaving or Knitting	Cutting
Dyeing, Printing, Finishing & Inspection	Sewing & Assembly
Cutting	Finished Garment
Sewing & Assembly	Retailing
Finished Textile	E-commerce
Wholesaling	
Retailing	

IV. ADOPTED STRUCTURE FOR CLASSIFICATION OF ARTICLES

This section elucidates the structure of the fashion and apparel supply chain and attempts to cluster different supply chain stages into B2B and B2C. This is discussed in sub-section IV.A, which proposes a taxonomy to address RQ 2 and RQ 3 respectively. Similarly, AI techniques were assembled into five classes as explained in the sub-section IV.B to propose a taxonomy to address RQ 1.

A. PROPOSED TAXONOMY OF FASHION & APPAREL SUPPLY CHAIN STAGES

The fashion and apparel supply chain is a complex network of various actors designated worldwide. It deals with a diversity of raw materials: fiber, yarn, fabric, dyestuff, and other chemicals, and the related processes are broadly classified into four stages: design, fabric production, apparel production, and distribution as shown in figure 4. Traditionally, the supply chain follows a push system [21], where the brand owners or retailers (buyer) provide the manufacturers with information like the design or technical specification of the fabric and garment to be produced, the volume of the products, sizes in which the garment is to be produced. The fabric and garment producers follow the instructions to create samples, which upon approval by the buyer are converted into finished fabric and garment respectively. Usually, the finished fabrics are the raw material for the apparel production process. Finally, the finished garments are transported to a wholesaler or retailer. In the case of the wholesaler, there is another actor, which acts as a distributor between the consumer and the wholesaler. On the other hand, in the case of the retailer, the garments are sold through one or more channels, for instance, brick & mortar stores, web-shops (e-commerce), departmental stores, multi-brand retailers.

The designers employed by retailers are responsible for creating collections based on the current market and trend analysis. In most scenarios, retailers do not own any production house and play an important role to bring the products into the market. Hence, in the conventional supply chain, all the actors from design up to retailers/brand owners are

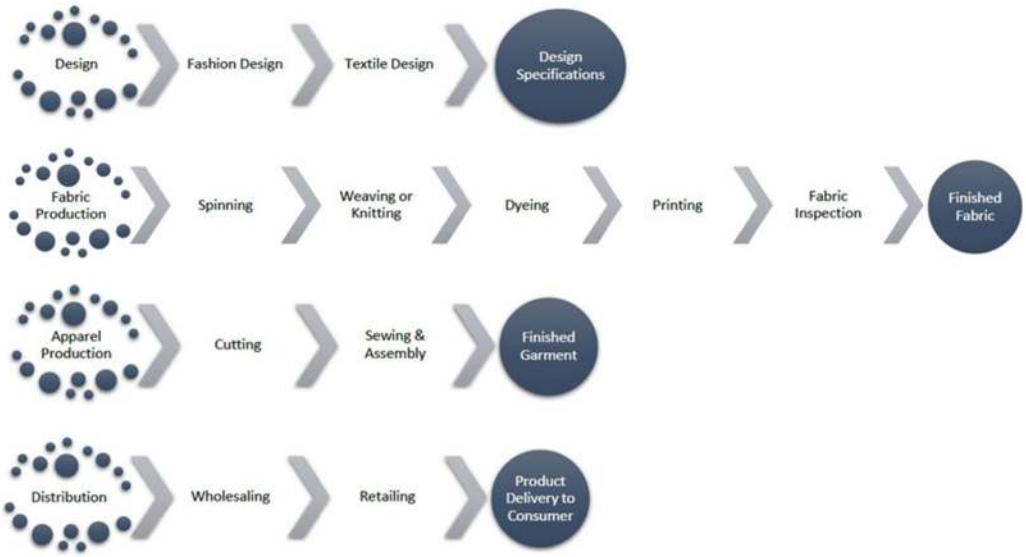

FIGURE 4. Stages in F&A supply chain.

considered as Business to business (B2B) as their primary customers are other businesses, while retailers are considered as business to consumer (B2C) as their primary customers are the end-users or consumers. However, in the past decade, with the advent of e-commerce, the definition of B2B and B2C has evolved [22]. Therefore, it has become important for the industry to adapt to this change and create new business strategies. It has also become vital to give a comprehensive demarcation between B2B and B2C, and how AI can help in combating problems at these segments.

1) B2B (BUSINESS-TO-BUSINESS)

The F&A industry has a convoluted supply chain due to diverse product categories and their short lifecycle. The contemporary consumer has increased awareness and information related to the latest styles and designs [23]. Therefore, consumer buying behavior and engagement has changed. This is highly influenced by the proliferation of social media and internet [24], which is a widespread medium for dissemination of information related to the latest fashion trends, upcoming fashion weeks and popular celebrities. Due to this, the F&A supply chain has to rapidly change the collections to fulfill the growing consumer demand [25]. Hence, it is driven by a combination of business-to-business (B2B) and business-to-consumer (B2C) transactions. In any business, the number of B2B transactions is higher in comparison to that of B2C transactions [26], [27]. The main reason for this is that for every product there can be as many B2B transactions as there are sub-components or raw materials involved, while there will be only one B2C transaction.

Business to business (B2B) in the F&A industry is referred to as the commerce between two or more businesses. A B2B transaction, thus, will occur when a business demands raw material for the production process to manufacture the product (e.g. garment manufacturer buying yarn), needs services for operational reasons (e.g. employing a third-party logistics service provider), re-sells goods and services produced by other businesses (e.g. a retailer buying products from manufacturer). The goal of a B2B transaction is to help their business stay profitable, competitive and successful. Table 2 shows the classification of the supply chain into B2B.

2) B2C (BUSINESS-TO-CONSUMER)

B2C refers to the transactions conducted directly between a business and consumers who are the end-users of its product and/or services [28]. Behind a B2C transaction is a well-researched consumer regarding their options in order to find the best price and quality tradeoff. Traditionally, B2C referred to outlet shopping, however, with the rise of internet, smartphones and other mobile technology, a set of completely new B2C business channels have developed in the form of e-commerce, m-commerce, social media commerce or selling products and services over the internet [29]. It has become important for B2C companies to be omnipresent because of uncertainty in consumer behavior over different retail channels [30]. The success of a B2C model depends on the capacity of a business to evolve based on new technologies that are widely used by the consumers. Businesses that rely on B2C sales must maintain good relations with consumers to ensure their retention and loyalty.

In addition to this, another set of B2C transactions have evolved with the adoption of mass customization (MC) to fulfill growing consumer needs. In this, consumer interactions with the business increases and can even occur at the product development stage. Hence, fashion or textile design, dyeing, printing, cutting, sewing & assembly can all have customer involvement. Table 2 shows the classification of the supply chain into B2B and B2C.

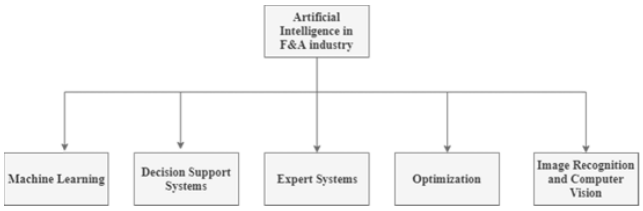

FIGURE 5. Classification of AI in the F&A industry.

B. PROPOSED TAXONOMY OF APPLIED AI METHODS IN F&A SUPPLY CHAIN

Artificial intelligence has already proved its capability to solve the real world problems due to its heuristic characteristics of generalizing data. In the last three decades, the F&A industry has undergone a number of changes and AI has played a key role in this transformation. Currently, the F&A industry is equipped with advanced machines required at the various stages of apparel production, which has improved the overall efficiency of the industrial processes [9]. Application of AI is well explained and categorized by operating processes at a managerial level in the F&A [8]. However, these researches lack the categorization of the applied AI in the F&A supply chain. The study in [8] explains the research issues in the operating process of the apparel industry. This study found that AI research has 45% contribution to apparel manufacturing issues, approximately 9% to apparel forecasting and 4.2% to fashion recommendation.

Research in [17] is a comprehensive review of classification and clustering techniques utilized in the F&A industry and shows that classification algorithms have been used more than clustering. On the contrary, this research work does not talk about linear and non-linear predictive models. Moreover, this research does not convey about the current applications of computer vision and deep learning [31], customer analytics [32], optimization techniques [33], and big data analytics for digital manufacturing and customization [15], [34]. Taking into account the recent research conducted in the area of AI in F&A, this study categorizes the AI into five broad classes as shown in Figure 5.

1) MACHINE LEARNING

Machine Learning is a technical process by which the computers are trained to perform the assigned task without human intervention and learns from the patterns of the data itself. Mathematical models are built on historical data to predict and find hidden patterns to make a future decision [35]. Machine Learning can be classified as Supervised or Unsupervised learning.

Supervised Learning- is a parametric model and it has input (independent variables) and target variable (dependent variable) [36]. Supervised model performance can be improved by optimizing the model parameters through iterative processes [37]. Based on the research problem, it could be a classification or regression task and this relies on dependent variable whether it is categorical or numerical.

Unsupervised Learning- models have only input attributes or independent variables with the main task of grouping similar data points. This grouping the similar pattern data points is called clustering and this process creates their own labels [35].

Machine learning has been implemented in the F&A industry for sales prediction [38], trend analysis, color prediction [39], demand forecasting [40], fabric defect detection [41], predicting fabric behavior using mechanical properties [42].

2) DECISION SUPPORT SYSTEMS

The decision support system (DSS) is used in an organization at the commercial level for taking mid-level or high-level managerial decisions. It can be automatized or regulated by a human or blend of both. Few authors considered the decision support systems as a software tool whereas others considered it as a system that can be integrated with the business to make intelligent decisions [43]. Research in [44] states that DSS combines the mathematical model with conventional data retrieval methods; it is flexible and adapts to the organizational environment as per defined strategy. In the F&A industry, it is widely used to industrialize innumerable tasks by optimizing decision making process in the supply chain [45] Decision support systems help the various actors in apparel manufacturing and production to choose appropriate process and resources to decrease the overall cost and enhance the performance of the apparel supply chain [46].

3) EXPERT SYSTEMS

In artificial intelligence, 'Expert system' is a system that makes a decision without human intervention [47]. It uses a reasoning approach to solve the complex problem, characterized by "if-then" rules. The first system was found around the 1970s and then gained popularity by 1980s [48]. They were considered the first popular software in the field of AI [36]. Expert systems are classified as Inference engine and knowledge base. 'Knowledge base' works on the principle of facts and rules, while 'inference engine' uses the rules to learn the facts and derive new facts [49]. In the F&A industry, it is applied in apparel manufacturing and production to select appropriate processes and equipment in order to generate minimal environmental pollution [50]. Furthermore, it has been applied for creating a recommendation engine in fashion retailing to improve the overall satisfaction of customers [51].

4) OPTIMIZATION

Artificial intelligence has the ability to solve complex problems and find numerous solutions by intelligent searching [36], [52]. Classical search algorithm starts with some random guess and this is improved using the iterative process. 'Hill climbing', 'Beam search' and 'Random optimization' are some of these methods [53]. Machine learning algorithms use 'search algorithms', which are based on optimization techniques. Simple exhaustive searches [52], [54]

are too slow and therefore 'Heuristics' approach is adapted to serve as a technique to find a solution. The limitation of the heuristics search approach is that it fails to work with smaller datasets [55]. An evolutionary algorithm is another form of optimization search, which starts with the initial guesses of the population permitting them to mutate, recombine and select the best one while discarding others. Popular Evolutionary algorithms are genetic algorithms (GA), gene expression programming and genetic programming [56], [57]. Distributed search method could be done using 'swarm intelligent' algorithms. GA is extensively used in the F&A industry to overcome the problems of scheduling and design layout of the apparel production [58], [59]. GA has the ability to respond to quick changes in the fashion industry. This algorithm has been used to improve the fitting services as well [60].

5) IMAGE RECOGNITION AND VISION

In Artificial intelligence, Computer vision is a scientific area, which trains a machine to achieve high-level interpretation of the images or videos. These images or videos can come from many sources such as the medical field, global sensing position, cameras [61], [62]. The principal tasks of computer vision algorithms are extraction, pre-processing, exploring the high dimensional data and creating supervised or unsupervised models [63]. Models use the concept of geometry, statistics, physics, and machine learning theory to get insights into the image understanding [64]. Object recognition, video tracking, motion estimation are some of the sub-areas in the field of computer vision [65]. Machine vision is applied in F&A to automate many industrial applications like inspection and process control [66]. Image recognition and vision is also popular for content-based image retrieval systems, virtual try-on and augmented reality in the F&A industry [67]–[69].

V. ANALYSIS AND FINDINGS

According to our research framework, we selected 149 articles, which includes articles from both journals and conference proceedings. The articles were classified based on the taxonomy discussed in the previous section (refer section IV). This section discusses the result of our review addressing the three research questions in the form of distribution of articles. Section V.A and V.B correspond to RQ 1 by presenting the overall trend of AI in the F&A industry. Section V.C supports RQ 2 by showing articles that applied AI methods at various F&A supply chain stages. Section V.D correlates to RQ 3 by exhibiting articles by B2B and B2C. All the extracted information from the articles a) AI class, b) Methods, c) Supply chain stages and processes, d) B2B/B2C and the corresponding count of articles are consolidated in the form of Table 8 and 9 for journals and conferences respectively.

A. THE OVERALL DISTRIBUTION OF ARTICLES OVER TIME

The overall trend of the articles published in three decades (1989 to 2018) is shown in figure 6. As can be observed, maximum research in the field of AI in F&A has been carried out in the last decade (2009-2018), which accounts for approximately 56% of the total articles reviewed. While in the first two decades, it was 11% and 33% respectively. Hence, even though AI methods were introduced long back in the 1950s [36] but their capability was realized much later in the last decade.

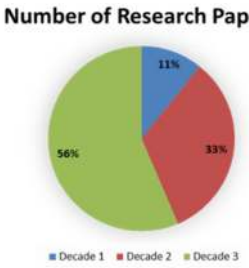

FIGURE 6. Decade-wise article representation of AI in F&A.

The detailed trend per year of articles published in journals and conference proceedings is depicted in Figure 7. As can be seen, the overall importance of this research domain has been equal in both journals and conferences. The only downward slope is visible for conference publications between the year 2013 and 2016 as highlighted in Figure 7. Apart from this, figure 8 shows the top 10 authors and institutions contributing to the literature of AI in the F&A industry.

B. DISTRIBUTION OF ARTICLES BY APPLIED AI OVER TIME

In this section, a comprehensive result of the review in terms of the number of articles classified based on the AI classes defined in section IV.B is shown in figure 9. The maximum number of articles are published in the field of machine learning with a total contribution of 42%, followed by expert systems with 28%, and the least contribution of the other three AI classes.

The distribution of articles in journals and conferences since 1989 has been shown in figure 10. The AI class 'Machine learning' has been applied multiple times in journal articles since 1991. There are two peaks visible for journal articles in the year 2007 and 2017 with 4 and 7 articles published respectively. Whereas for conference articles, it has been applied since the year 2000 with three major peaks in the year 2010, 2012 and 2016 with 4, 3, and 7 articles respectively. On the other hand, the AI class 'Expert system' was widely used since 1994 in journal articles while in conference articles there has been no research after 2014. For AI class 'decision support system', there has been very little work in conference articles, while a gradual increase in presence is realized in journal articles since 2010. For 'image recognition', its presence is visible since 2009 in both journal and conference articles, being the least applied AI class (also shown in figure 10). In addition, it can be noticed that since the year 2017, its application has increased in journal articles. In contrast to other classes, for optimization, there were more articles in the conference as compared to journals.

FIGURE 7. Overall trend of AI in F&A since 1989.

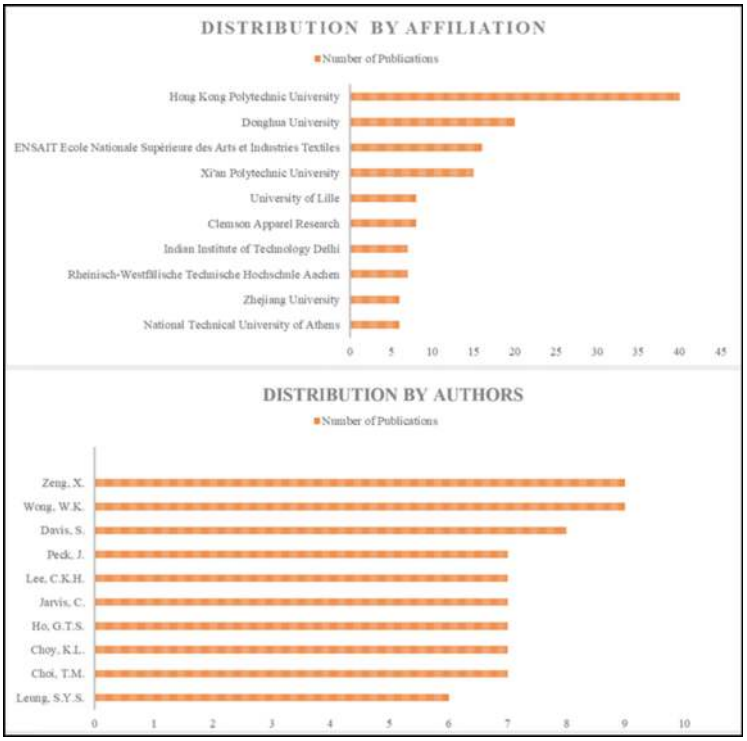

FIGURE 8. Top 10 affiliations and authors.

C. DISTRIBUTION OF ARTICLES BY APPLICATION OF AI IN F&A SUPPLY CHAIN

As shown in table 7, machine learning and expert systems have been applied widely at the four F&A supply chain stages, with least research in design. This is followed by optimization that has been applied with the least focus at the distribution stage.

The classification of articles by applied AI methods in F&A supply chain is shown in figure 11. In apparel production, all AI classes are applied in journal articles, while in conference articles image recognition and decision support system has been not used. In design, research has focused on three AI classes: optimization, machine learning, and expert systems for journal articles, whereas the expert system is not applied in conference articles. In distribution, majorly used AI classes are machine learning, decision support systems, and expert systems in journal articles, while the focus has been on machine learning and image recognition in conference articles. In fabric production, all AI classes have been widely used with a major focus on machine learning and Expert systems. Additionally, there has been growing use of image recognition in fabric inspection, which is a process under fabric production (described in section IV.A).

D. DISTRIBUTION OF ARTICLES BY B2B AND B2C OVER TIME

As discussed in the previous sections the importance of B2B and B2C in F&A, we classified the articles based on their business focus. As can be seen in figure 12, research is focused on solving the issues related to B2B and there is

Decision Support Systems	Expert System	Machine Learning	Optimization	Image recognition
13	41	63	20	12

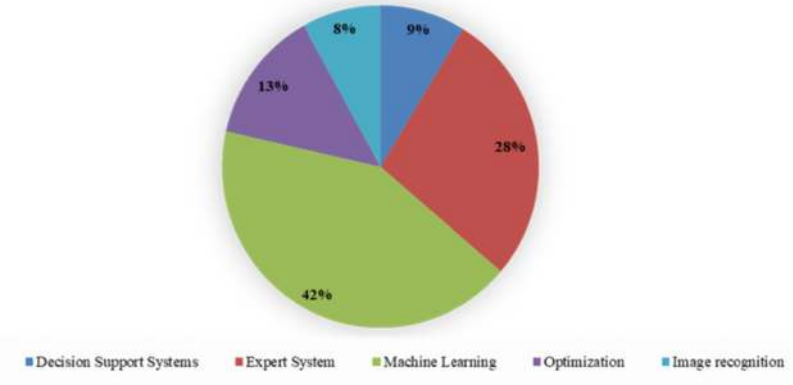

FIGURE 9. Total distribution of articles by AI methods applied.

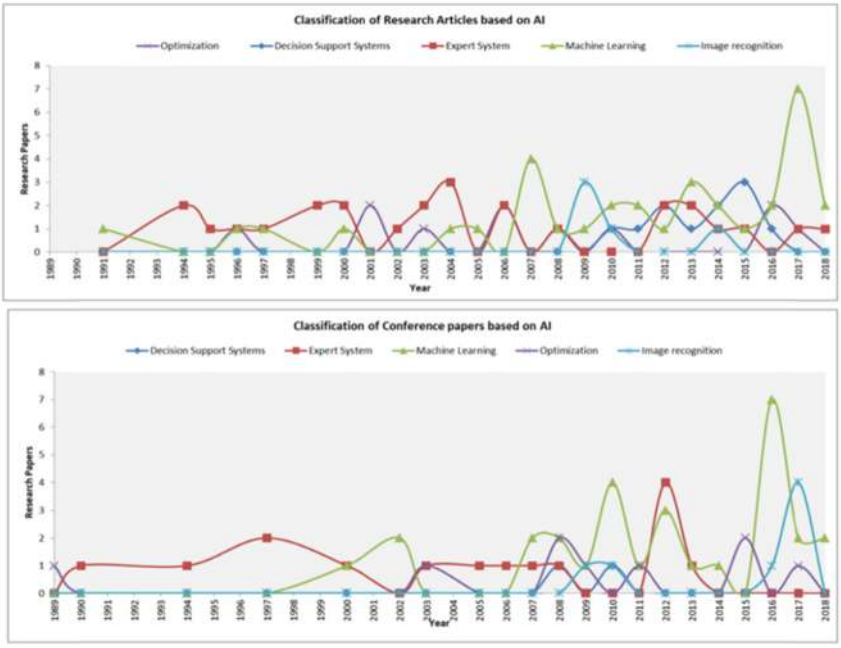

FIGURE 10. Distribution of articles by applied AI over time.

TABLE 7. Count of applied artificial articles in F&A supply chain.

	Decision support systems	Expert System	Machine Learning	Optimization	Image recognition	
Apparel Production	4	11	19	8	2	44
Design	0	4	2	3	0	9
Distribution	7	10	20	2	3	42
Fabric Production	2	16	22	7	7	54
	13	41	63	20	12	Total =149

little attention on B2C both in journal and conference articles. To get a clear picture, figure 13 shows the distribution of articles in three decades separately for B2B, B2C and both.

There were total 149 articles reviewed, out of which 122, 13 and 14 belonged to B2B, B2C and both (B2B/B2C) respectively. If we consider B2B, as shown in figure 13, substantial research has been carried out in all three decades as compared to B2C. In the case of B2C, the total number of articles published in itself is low i.e. 13. Out of this, only two were published in the second decade and rest were

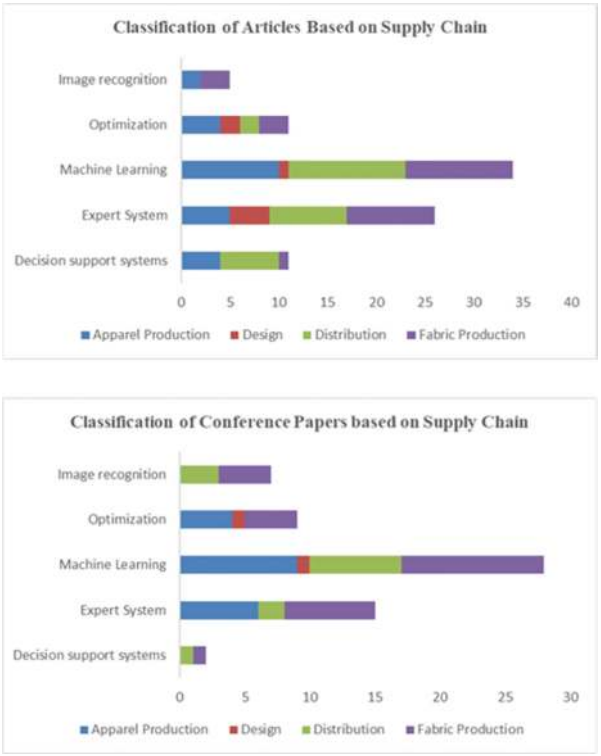

FIGURE 11. Distribution by supply chain processes.

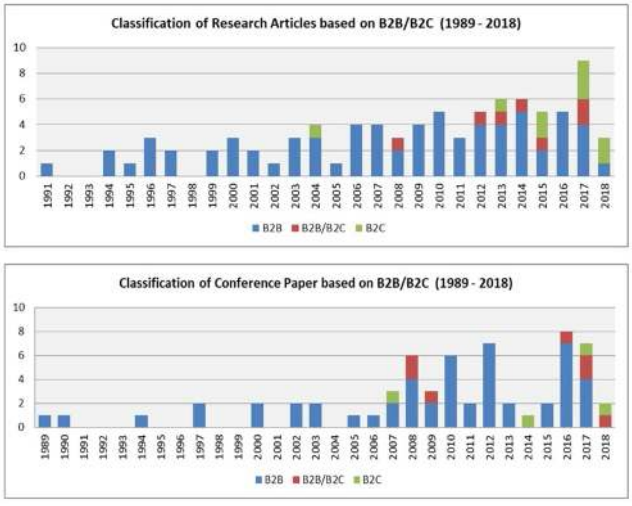

FIGURE 12. Distribution of articles by B2B and B2C.

published in decade 3. There were no articles published in decade 1. By both, it is meant that the focus of the study is both B2B and B2C. The total number of articles, in this case, is 14, out of which ten were published in the third decade and four in the second decade. There were no articles published in decade 1 for this as well. As a conclusion, we can say that little work has been done with the perspective of B2C and there is a need to attend to this gap.

VI. DISCUSSION AND IMPLICATIONS

Based on the review conducted following the proposed research framework and addressing the three research questions, this study recognized a number of gaps with respect to applied AI in the F&A industry. These gaps in research provide the foundation to recommend future research direction in the F&A and AI domain.

A. GAPS AND IMPLICATIONS

As discussed in section IV.A, most of the research related to AI in F&A industry has been carried out in the last decade (2009 to 2018), accounting to 56% of the total number of publications in the year 1989-2018. This shows that even though the AI methods existed since 1989, they have recently gained popularity in research related to F&A industrial problems. Although AI has left its footprint in research, it is still far from being implemented at the industrial level. One of the reasons for this is that researchers working in AI may lack expertise in F&A and at the same time, the professionals working in the industry may lack expertise in AI. In addition, industries are skeptical about the benefits of AI and big data analytics. Therefore, it is important that they look at the cost and benefit tradeoff to be able to exploit the full potential of AI.

In section V.B, we classified the articles based on their focus on B2B and B2C. The result demonstrates that most of the research work has been carried to target B2B business problems, accounting to 81% of the total number of publications. Whereas, little research has been conducted with a B2C perspective, accounting to approximately 8% of the total publications. This clearly illustrates that research needs to focus on B2C business problems. According to the State of Fashion (2019), two of the major industrial challenges faced will be rapidly changing consumer preferences and competition from online and omnichannel. Therefore, research related to the F&A industry needs to shift their focus to B2C, taking into account the importance of AI. AI can help to analyze consumer footprint omnichannel, which can help in creating personalized consumer database or profiles helping to improve business profitability and providing a competitive advantage.

In section V.C and V.D, we classified the articles based on applied AI method in the F&A supply chain. Most of the research articles fall under machine learning and expert systems class, which has been extensively applied at the supply chain stages: apparel production, fabric production, and distribution. Decision support systems, optimization and image recognition class have a more or less similar number of research articles published in this domain. Their application was seen to some extent at all three stages. However, least representation of these algorithms was observed at the design stage. It gives an impression that little focus has been given to design-related problems and hence, there is a huge scope of AI applications at this stage. For instance, AI methods can be used to create systems that can help fashion and product designers to capture consumer needs and preferences more

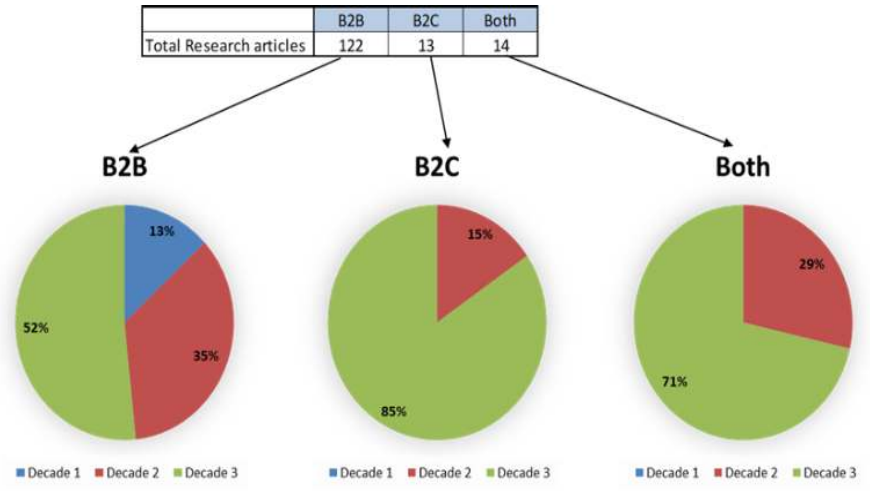

FIGURE 13. Decade-wise article representation of B2B, B2C and both.

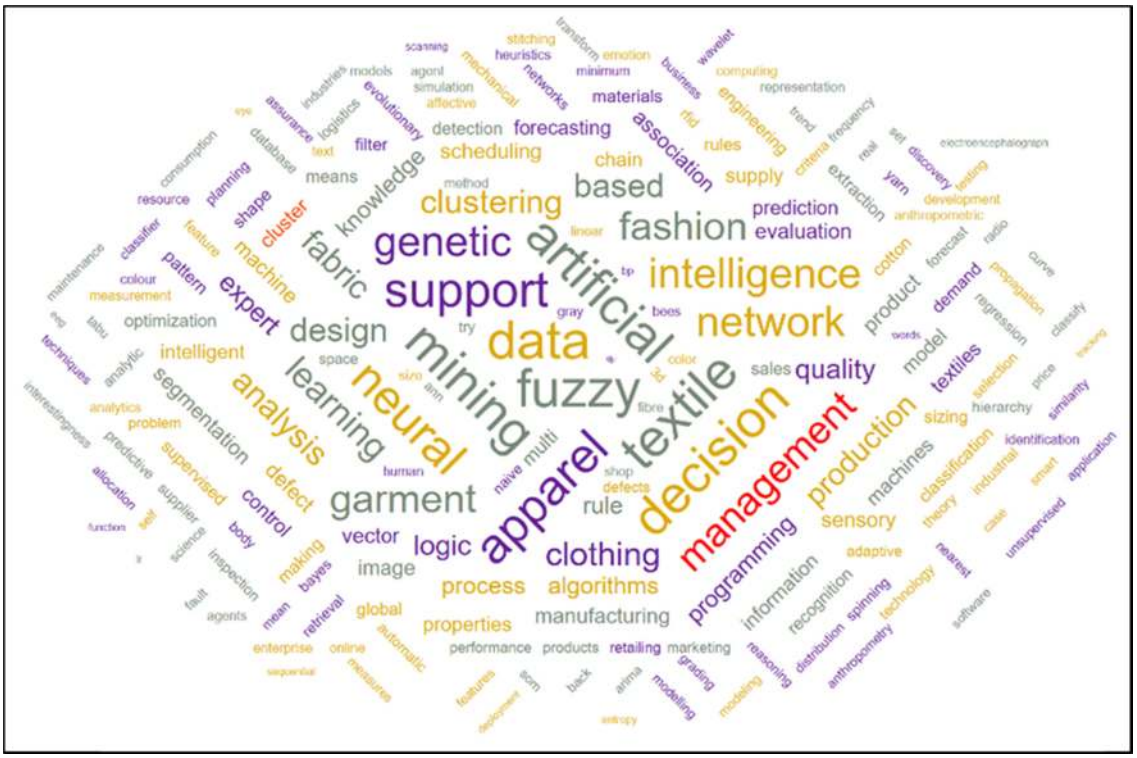

FIGURE 14. Word cloud using text mining on abstracts.

accurately and conveniently. Hence, the products offered can be more targeted to the market segments. In addition, predictive tools that use consumer's historical (past transactions) and social media (real-time demand) data can facilitate the product development/designing process. The AI methods applied in 149 articles can be seen in Table 8 and 9.

To get an outlook of the most popular AI methods used and their applications in F&A, we applied text mining on the abstracts of the selected 149 articles. Accordingly, a word cloud was created shown in figure 14. As a result, it was observed that genetic algorithm, artificial neural network, and fuzzy logic are the most popular methods applied for prediction (yarn, fabric properties, color), evaluation (quality inspection, defect detection), forecasting (trend analysis, supplier selection, demand forecasting).

B. FUTURE RESEARCH AREAS

Based on the analysis and gaps identified, we suggest some future directions of AI methods in the F&A supply chain. Machine learning techniques could be beneficial for fashion

TABLE 8. AI methods used at various supply chain stages and processes in journal articles.

AI Class	Method/ Technique used	Department Targeted	Process Targeted	B2B/B2C	Journal Articles Count	Reference
Machine Learning	BP-ANN 9 back propagation artificial neural network; k-means clustering; sequential clustering; fuzzy logic; A two-level clustering method (SOM network+ K-means); Naïve Bayes; Support vector machine; Gene expression programming (GEP); FCM (fuzzy clustering using MSE); Non parametric regression forecasting; supervised clustering; K-Medoids ;CN2-SD; ANN regression; RFM modeling; Association rule; ELM (extreme learning machine); GA; fuzzy constraint logic system, fuzzy rules, fuzzy sets; feed-forward neural network, back-propagation algorithm; decision tree, classification, and regression tree, factor analysis; Regression; Treelearner; root mean square; Fuzzy Efficiency based Classifier System; Logistic regression; Bucket Brigade Algorithm; neural networks using the error back propagation mode, e-neuro fuzzy engine; DIDT technique (Top-Down Induction of Decision Trees ID3; data mining; text mining; semantic data analysis;	Apparel Manufacturing 10, Design 1, Distribution 14, Fabric Production 11	Cutting 2; Dyeing/ Printing/ Finishing/ Inspection 1; Finished Garments 2; Retailing 12; Sewing 4; Spinning 9;	B2B/B2C 4, B2B 25, B2C 5	34	[70] [38] [71] [72] [73] [74] [75] [76] [39] [77] [78] [79] [80] [81] [82] [83] [84] [85] [86] [41] [87] [87] [88] [89] [90] [91] [92] [93] [42] [94] [95] [96]
Decision support system	Fuzzy logic; fuzzy association rule mining (FARM); classification, regression, clustering and association analysis; Linear optimization with constraints; Fuzzy inference; Fuzzy aggregation; adaptive-network-based fuzzy inference system (ANFIS); analytic hierarchy process (AHP); TOPSIS;	Apparel Manufacturing 4, Distribution 6, Fabric Production 1,	Finished Garments 4; Retailing 6; Spinning 1;	B2B 9, B2C 2	11	[97] [98] [99] [100] [101] [12] [102] [103] [104] [105] [106]
Expert System	Association rules; ES named ES-EXITUS has been implemented using the SSM and the DMM; Fuzzy association rule mining; Fuzzy logic; clustering and probabilistic neural network (PNN); hybrid OLAP-association rule mining; Ontology, semantic web, multiple agents; Genetic Algorithm; gradient descent optimization, fuzzy sets; Chi-square test, Correspondence analysis; parametric cubic spline and bi-cubic surface patch, object-oriented technology for building the knowledge base; Linear programming, computer-based heuristic; Semantic network, heuristic rules; Bézier curve models evolutionary model; Sensitivity analysis, Cognitive mapping technique, cluster analysis; Normalization model; Programming language used Microsoft Visual C++ version 4.0, Rule-based expert system; Object-oriented representation technique; t-test, sensory evaluation;	Apparel Manufacturing 5, Design 4, Distribution 8, Fabric Production 9,	Cutting 1; Dyeing, Printing, Finishing, Inspection 5; Fashion Design 2; Finished Garments 1; Retailing 5; Sewing 2; Textile Design 2; Weaving or knitting 1; Wholesaling 1;	B2B/B2C 3, B2B 21, B2C 2	26	[107] [108] [109] [110] [111] [112] [113] [114] [115] [116] [117] [50] [118] [119] [120] [121] [122] [123] [124] [125] [126] [127] [128]
Optimization	Constraint and non-constraint optimization; simulation-based model; fuzzy rule optimization; Tabu-Bees algorithm; linear approximation; Evolutionary algorithms; Genetic algorithm; Morse function, topological analysis; Content-based filtering, wavelet decomposition using Haar transform collaborative filtering, vector correlation using the Pearson correlation coefficient; symbolic regression module; Multiple regression analysis, extrapolative forecasting and an adaptive Holt-Winters forecasting;	Apparel Manufacturing 4, Design 2, Distribution 2, Fabric Production 3,	Cutting 2; Fashion Design 1; Finished Garments; Retailing 2; Sewing 1; Spinning 1; Weaving or knitting 1; Wholesaling 1;	B2B 11	11	[129] [130] [131] [132] [46] [133] [134] [94] [135] [136]
Vision	ANN and image processing; K-means clustering, Naïve Bayesian, and a multi-layered perceptron (MLP); NN and GA; Back propagation neural network (NN);	Apparel Manufacturing 2, Fabric Production 3,	Finished Garments 2; Sewing 1; Spinning 1; Textile Design; Weaving or knitting 1;	B2B 5	5	[11] [137] [138] [139] [140]

TABLE 9. AI methods used at various supply chain stages and processes in conference articles.

AI Class	Methods/ Techniques used	Department Targeted	Process Targeted	B2B/B2C	Conference paper count	Reference
Machine Learning	SOA-based data mining framework, classification, ARIMA and KNN models, text mining, naive Bayes classifier, SOM neural network, EM cluster and ELM (extreme learning machine) same prediction, SVM and AdaBoost, artificial neural network, case-based reasoning, supervised learning, self-organizing maps, principal component analysis, type-2 fuzzy sets, clustering, correlation analysis, optimal bandwidth selection in kernel density, ontology, RDF, Multilayer Perceptron, J48 decision tree, k-nearest neighbor, classifier ripper, C4.5 and PART, neuro-fuzzy with subtractive clustering and genetic algorithm (ANFIS-GA) technique, Java, C/C++, Viswanathan-Bagchi algorithm, correlation, wavelet transform, neural network.	Fabric Production 11, Distribution 7, Apparel Manufacturing 9, Design 1,	Weaving or knitting 3, Retailing 8, Spinning 5, Dyeing, printing and finishing 2, Finished Garments 3, Sewing 3, Cutting 2, Textile Design 1, Fashion Design 1	B2B/B2C 2, B2B 23, B2C 3	**28**	[141] [142] [143] [144] [145] [146] [147] [148] [149] [150] [151] [152] [153] [154] [155] [156] [157] [158] [159] [160] [161] [162] [163] [164] [165] [166] [167] [168]
Decision support system	Self-adaptive genetic algorithm, genetic algorithm, top-down and bottom-up analysis, dynamic optimization algorithms, Maximum Principle of Pontryaguin.	Distribution 1, Fabric Production 1	Finished Garments 1, Retailing 1	B2B 1, B2B/B2C 1	**2**	[169] [170]
Expert System	Rule-based, rough set theory, fuzzy, case-based reasoning, fuzzy logic, fuzzy logic sensory evaluation, Fuzzy neural network, Unsupervised learning, fuzzy clustering, genetic algorithm, approximate reasoning module, Rule-based System Shell , Metric-based Fuzzy Logic and artificial neural network, If-Then Rules for knowledge base, least-square regression analysis, linear regression, event series	Distribution 2, Fabric Production 7, Apparel manufacturing 6	Retailing 2, Spinning 3, Dyeing, Printing, Finishing and Inspection 2, Finished garment 1, Yarn to Fabric 1, Cutting 1	B2B 14, B2B/B2C 1	**15**	[171] [172] [173] [174] [10] [175] [176] [177] [178] [179] [180] [181] [182] [183] [184]
Optimization	Stochastic descent, list algorithm, Evolutionary computing and genetic algorithm, Fuzzy set, geometric analysis method, Mirabit algorithm, apriori algorithm, Heuristic methods,	Fabric Production 4, Apparel manufacturing 4, Design 1	Spinning 3, Finished garments 1, Dyeing, printing and finishing 1, Cutting 3	B2B 8, B2B/B2C 1	**9**	[185] [59] [186] [187] [188] [189] [190] [191] [192]
Vision	Conditional Random Fields (CRF), Bayesian classification, CNN based classifier, computer vision, classification, consensus style centralizing auto-encoder (CSCAE), Gabor filter, Gaussian kernel, image processing using IMAQ, median filter, stereovision method	Fabric Production 4, Distribution 3	Weaving or knitting 1, Spinning 3, Retailing 3	B2B 5, B2C 1, B2B/B2C 1	**7**	[193] [194] [195] [196] [197] [198] [199]

and product designers. They can take its advantage in predictive analysis of future trends based on historical and real-time data. This can also prove promising in improving the existing recommendation engines, which currently rely on collaborative or content-based filtering. These engines can be improved by integrating with consumer data from social media and real-time trends from fashion blogs, magazines and other social networks like Pinterest, Instagram. Additionally, the performance of existing predictive models can be enhanced with the help of advanced techniques like ensemble learning and transfer learning. An instance is the use of random forest instead of decision trees, the use of which has outperformed the classical model in terms of computational time [201], [202].

Another application area in F&A is mass customization, where machine learning can be used to reduce the lead times by creating a classifier that could be trained on the existing style database, enabling the product designers to

prepare the raw material inventory in advance. Pre-trained deep learning models using a library like Keras [203], inception model [204] along with big data analytics can be used to create co-design platforms with style recommendations helping consumers in co-designing garments.

One of the important application of image recognition and computer vision is to target the key consumer pain point of not having an appropriate size of the garment. This problem has been addressed with the help of virtual fitting tools. However, these tools are still at a nascent stage and can be highly improved with the help of these techniques.

As we have noticed that fuzzy techniques and genetic algorithms are exhaustively used for expert systems, decision support systems and optimization. These techniques can be combined with advanced AI techniques to enhance the computational ability of a machine learning algorithm. Similarly, if the classical forecasting model is combined with AI it can lead to better forecasting in terms of seasonality and trends.

It is evident from the review that the F&A industry still lacks an integrated platform for data sharing and communication amongst its stakeholders and consumers. An integrated platform has become a necessity to quickly respond to customer's growing needs and preferences and improving consumer satisfaction and loyalty. AI has a lot of potentials to create and maintain such a platform. This platform can help the industry to provide interactive communication, improved supply chain organization, hence, leading to a digitally connected supply chain. Another possibility is by merging AI techniques with blockchain technology, which can ensure security and transparency between consumers and various supply chain actors. The industry can be benefitted by integrating their business with cloud-based technologies like Microsoft Azure, Amazon web services, IBM Watson, etc., and parallel computing tools for big data analytics like Hadoop and Hive. If the fashion industry can successfully adopt the aforementioned AI techniques, it will be easier to integrate B2B and B2C leading to a sustainable business orientation of B2B2C. This will be fully achievable only when the F&A industry equip 'FAIR' data principle [205] in strategizing their business.

VII. CONCLUSION

The aim of the study was to conduct a systematic literature review to address the three defined research questions (RQ1, RQ2, and RQ3). In line with the research framework, we retrieved 1019 articles published between 1989 and 2018, from two popular academic databases: Scopus and Web of Science. The article screening process was carried out in five phases (shown in figure 2), which resulted in 149 articles. To extract information from these articles and address our research questions, a taxonomy was proposed considering AI methods and F&A supply chain stages acknowledging RQ1 and RQ2 respectively. To acknowledge RQ3, F&A supply chain was further classified into B2B and B2C.

The research analysis says that most of the work in the field of F&A was carried out in the last decade (2009-2018) with the most applied AI categories being ''Machine Learning'' and ''Expert Systems''. It was observed that the techniques most used in Machine Learning were predictive algorithms like regression and SVM, and whereas in the case of Expert Systems were ''Artificial Neural Network'', ''Genetic Algorithm'' and ''Fuzzy Logic'' for modeling F&A supply chain problems. Certainly, no application of algorithms like ''deep learning'' and ''transfer learning'' was realized. Further, very few research articles talked about ''Big Data'' in the field of F&A, which clearly states that the industry has not fully realized the potential of data analytics and AI.

This research found that F&A supply chain stages: ''Apparel Production'', ''Fabric Production'' and ''Distribution'' received maximum attention when applying AI techniques, whereas ''Design'' was the least focused. Additionally, a significant contribution was noted towards B2B problems compared to B2C. Hence, research needs to adopt a B2C perspective to be able to offer consumer-oriented solutions to the industry.

A comprehensive review reveals the research gap and implication presented in section VI stating that F&A needs a transformation in their supply chain by using AI techniques at the industrial level. With this, the industry can move towards a digital and sustainable supply chain. The implications and future directions proposed in this study can be beneficial for academic and industrial researchers, and industrial practitioners, who are willing to provide a substantial contribution to the subject area.

Regardless of this valuable work, there are some limitations to this study. First, the articles were searched in two databases, while there could be other databases that are relevant. Second, the publications apart from English were excluded. There could be valuable research available in other languages. Third, even though the review process was completed rigorously, it could still be prone to human error. Fourth, this study was restricted to researches with an empirical validation of the proposed AI models. There could be beneficial theoretical and conceptual frameworks in research, which were missed because of the exclusion criterion. Fifth, even though the synonyms considered for article retrieval were carefully decided, the study could have missed some articles due to different terminology being used. Seventh, grey literature was excluded from the review process, which also includes industrial reports. These reports can provide helpful insights and contribution in this domain.

ACKNOWLEDGMENT

The authors would like to thank and appreciate the support of the expert researcher for helping us with validating the proposed taxonomy.

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