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Research article

Prospects and current scenario of industry 4.0 in Bangladeshi textile and apparel industry

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A R T I C L E I N F O

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A B S T R A C T

This study aims to explore the scopes and challenges, rank the challenges, and provide strategic solutions for adopting Industry Revolution 4.0 (IR 4.0) in Bangladesh's textile and apparel industry. A random survey was administered to a total of 142 factories in Bangladesh. Both quantitative and qualitative methods of analysis were used in this study. The survey includes questions on important study variables, such as big data, smart factories, cyber-physical systems (CPS), the Internet of Things (IoT), interoperability, textile production, and industry performance. The Variable Destination Multiple Access (VDMA) Model has been adopted to design the questionnaire, focusing on qualitative and quantitative questions. The survey dataset was investigated through SmartPLS 4.0 by normality and confirmatory tests. Likert scale data have been analyzed through IBM SPSS software version 26.0 by the exploratory factor analysis method to rank the IR 4.0 adoption variables. Analysis of the survey data indicates the level of adoption of Industry 4.0 in terms of organizational strategy, investment, infrastructure, IT (Information Technology), Ready Made Garments (RMG) skilled workers, smart operations, and smart factories. The study shows that the variable "Review of the strategy using indicators" got the highest ranking in the external factor, 0.791. This clearly indicates that strategy formulation is the topmost priority among other IR 4.0 adoption variables. Consequently, "digital integration" got the lowest loading at 0.620, as IR 4.0 digital technology adoption is very low. The overall maturity level for IR 4.0 adoption in the Bangladesh textile and apparel industry is 1.91 on a 5-point scale, indicating a low adoption level. This study can help concerned policymakers and industrialists who want to implement Industry 4.0 in the textile and RMG sectors to stay competitive in the global market. Alongside this study, it also summarizes the IR 4.0 adoption level in 9 broad categories.

1. Introduction

Bangladesh's readymade garments (RMG) sector is now a USD 42.61 billion industry [1]. According to the Bangladesh Garment Manufacturers and Exporters Association (BGMEA), Bangladesh has the most LEED (Leadership in Energy and Environmental Design)-certified green factories. As of January 2023, the number is 183. Nine of Bangladesh's LEED-certified textile manufacturers were among the top 10 greenest factories in the world, and 500 more are currently pursuing LEED certification. Due to rapid technological advances, the textiles sector is poised to undergo a great transformation as industries enter the Fourth Industrial Revolution,

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commonly called IR 4.0. Industry 4.0, or IR 4.0, incorporates new technological advancements that aim to serve automation in manufacturing processes to enhance performance in production and delivery [2]. This poses a threat to Bangladesh's textile and apparel industry, which heavily relies on the labor force and has limited automation capability. The concerned parties and stakeholders must now act strategically to ensure the reforms needed to embrace the technological revolution. IR 4.0 is utilizing the latest innovations and technologies to restructure the industrial production system from the ground up, therefore making the production system inherently more intelligent, efficient, and adaptive. To embrace IR 4.0, developing nations that rely significantly on RMG exports, such as Bangladesh, must characterize the changing trends in managing operations, manufacturing, and chain production [3]. The Industry 4.0 revolution bridges the gap between the physical and digital worlds through advancements in robotics, artificial intelligence (AI), the Internet of Things (IoT), 3D printing, and many other remarkable features [4]. Traditional water and steam power production has been mechanized since the 1st and 2nd industrial revolutions, which led to the 3rd industrial revolution [5]. Lately, IR 4.0, with its extensive industrial automation, is interrupting almost every industry, starting from RMG and textiles to hospitality, from furniture to agro-processing, and even from leather and footwear to the tourism sector of Bangladesh. Approximately 4 million people work in the country's RMG and textile industries, accounting for 14 % of the GDP and 85 % of total export revenues [6]. Nowadays, the textile and apparel industry is also applying automation to stay on par with efficiency, growth, and global competition [6]. The use of IR 4.0 production systems in the textile and apparel industry can provide further comparative advantages such as instantaneous response to market fluctuations, detection and reduction of bottlenecks, elimination of waste, optimization of inventory, data-oriented decision-making, and many more. Implementation of IR 4.0 requires an ideal infrastructure that can enable collection and transformation, along with automation in the production system, enabling limitless opportunities and benefits [7].

1.1. Research objectives

There is a huge lack of studies conducted about the implementation of IR 4.0 in the textile and apparel industries in Bangladesh. This research study tries to address that gap by providing insight into the challenges in adopting IR 4.0 technology in the apparel industry of Bangladesh and whether the Bangladeshi industry will benefit from the introduction of IR 4.0. The main goal of this study was to assess the prospects, identify the difficulties, and offer practical solutions for implementing IR 4.0 in Bangladesh's textile and apparel industry. To achieve the goal, the following SMART objectives are formulated:

a) To assess the degree of IR 4.0 adoption in Bangladeshi Textile and Apparel factories.
b) To rank the current IR 4.0 challenge variables in broad focusing dimensions
c) To suggest potential solutions to those challenges.

1.2. Research questions

RQ1: How prepared are Bangladeshi RMG factories for IR 4.0 as per maturity level?
RQ2: How should Bangladesh's Textile and Apparel industry prepare to adopt and implement IR 4.0 to overcome the challenges?
RQ3: How can these challenges be reconciled and transformed into strategic solutions?

2. Literature review

2.1. The global textile and apparel market

The global textile market has become a trillion-dollar industry with the rise of the world's population and living standards. In 2015, the industry's net assessment was USD 1.7 trillion; by 2025, this figure is expected to increase to USD 2.6 trillion (source: Statista). The European Union, the USA, Canada, Japan, India, and China are the key competitors in this industry. Fig. 1 illustrates that the market size of the textile and apparel industry in the global market is expected to be 2.6T by 2025. The market size of the EU was 350 billion in

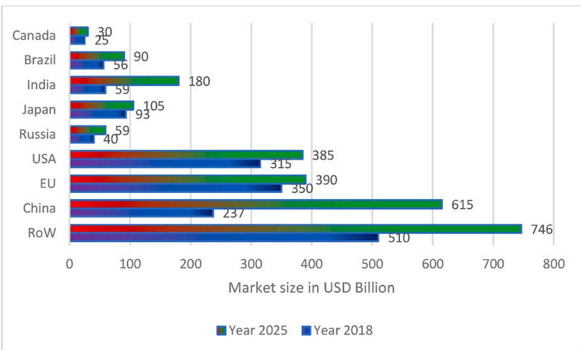

Fig. 1. The size of the textile and apparel industry in the global market from 2015 to 2025 [8].

2015 and is expected to reach 390 billion by 2025; the USA was 315 billion and is forecasted to reach 385 billion; China was 237 billion and is projected to reach 615 billion; Canada was 25 billion and is estimated to reach 30 billion; Japan was 93 billion and is forecasted to reach 105 billion; India was 59 billion and is forecasted to reach 180 billion by 2025; and the market size of the Rest of the World was 510 billion and it is forecasted to reach 746 billion by 2025 (Source: Statista).

Fig. 2 illustrates that in 2018, the size of apparel production pieces was 161B, which rose in the following year to 181 B. But in 2020, due to the COVID-19 pandemic situation, this volume of apparel production declined to 172B. From 2021, it started to rise again, and the volume of apparel production in the global market is expected to be 193.012 billion pieces by 2025 (source: Statista).

2.2. Industry 4.0: the idea and its robustness

Industry 4.0 concentrates on smart factories, where humans and machines are integrated using cyber-physical production systems (CPPS). Sustainability has gained the greatest importance these days, but IR 4.0 technologies have also reached an advanced destination [9]. IR 4.0 adopts disruptive technologies that supervise and control the industrial value chain to meet client needs. All three essential facets of the contemporary manufacturing process are covered by "Industry 4.0":

a) Increased vertical and horizontal value chain integration and digitization.
b) Use of intelligent networks to digitize product and service offerings.
c) Introduction of creative digital business models across the organization [10,11].

Even though IR 4.0's effects might not be immediate, they will still signal a paradigm change that will profoundly alter current modes of production, employment, and commerce in developing and developed countries. The capacity of CPS to carry out their tasks as independently as feasible also envisions environmentally sustainable building using green supply chain management, green supply chain processes, and green products [12–14]. To make informed decisions, address pressing issues, or prevent unpleasant situations, IR 4.0 enables the transparency of enormous volumes of data and information from all areas of the manufacturing process, human support systems, and visualizing information [15,16]. As a modern feature of technological advancement, IR 4.0 enables networking-based operations and smooth monitoring in industrial sectors [17].

2.3. Industry 4.0 in Bangladesh

Bangladesh, a nation in the Asia-Pacific area, has one of the fastest-rising economies with minor volatility. Bangladesh's export revenues are rising at a significant rate of around 10 %, and the country is expected to have the twenty-eighth largest economy in the world by 2030 [18,19]. The current industrialization state has thrown many challenges worldwide, including ecological calamities and disruptive environmental events. IR 4.0 technologies and technological advancements focus on these ecological hazards [20]. As a consequence of other industries, IR 4.0 technologies synergistically impact the textile and apparel supply chains upstream, downstream, and across many stages [21]. Recently, automation has disrupted almost every industry, including Bangladesh's RMG and textile industries. The RMG sector in Bangladesh is gradually implementing automation technology to keep up with productivity, development, and competition. However, the fourth industrial revolution lamentably poses a grave threat to the employment of unskilled, low-skilled, and semi-skilled workers [22].

2.4. Research gap

Various dimensions of the preparedness model may be most applicable for measuring the adoption of the textile and apparel sector in its pursuit of IR 4.0. Through a preparedness model, an organization can find out whether it can facilitate changes and can act upon the existing shortcomings [23,24] identified some core characteristics of IR 4.0: Interoperability, Virtualization, Real-Time Management, Internet of Services, and Modular Structure. IR 4.0 considers recent organizational innovations to achieve sustainability and

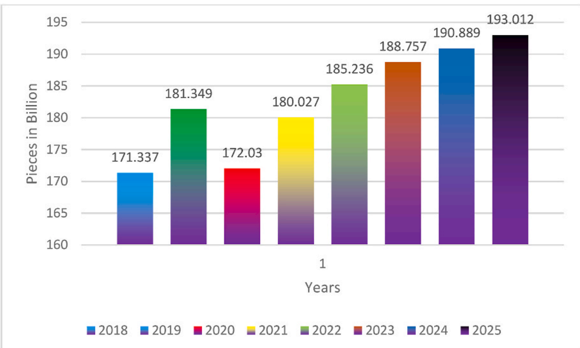

Fig. 2. The volume of apparel in the global market from 2018 to 2025 [8].

perform with comparative advantages.

Manufacturers must initially accept advanced technology and then install it in production, marketing, and design, enjoying the advantages of IR 4.0 [25]. Due to the lack of proper initiation of Industry 4.0 in textile and apparel processes, the industries are not well concerned about the unexpected challenges towards Industry 4.0 implementation after following up. In that case, a company has first to understand the challenges that it may have to face with associated Industry 4.0 technology. This study will investigate the industry 4.0 challenges and propose some solutions to mitigate them.

3. Methodology

Choosing an appropriate research method depends mainly on the nature and context of the study, such as descriptive or action research [26]. The expected results of this study require a hybrid approach containing qualitative and quantitative data analysis. The VDMA (Variable Destination Multiple Access) method has been employed to support the methodology for this study, as in this method, both qualitative and quantitative data can be collected from prospective respondents and analyzed simultaneously. The exploratory factor analysis (EFA) method has been employed to categorize IR 4.0 technology implementation challenges. A confirmatory factor analysis (CFA) method has been performed to test the validity of the data survey.

3.1. VDMA method

The concept of multiple access has been developed for satellite or wireless connections, in which the server point needs to be connected to multiple users at a time for a specific area [27]. In aspects of VDMA, this connection concept has been extended to variable destinations to cover major areas, incorporating multiple respondents to discover the full snapshot instantly. In the VDMA method, respondents from various destinations covering a large range of organizational types can be reached, with some major survey questionnaires focusing on the key aspects of the study. Among the questionnaires, respondents have to reply with some numerical point, like a rating scale for quantitative mode, or in the case of other descriptive questions, they can give their own opinion. After data collection from respondents, numerical data can be analyzed by setting priority assigned by the respondents in percentage form against various major questionnaire areas. Simultaneously, descriptive information can be directly explained regarding the study scope.

3.2. Sampling design

To conduct quantitative research, the following formula [25] has been used to determine the sample size n.

$$n = \frac{NX}{X + N - 1} \tag{1}$$

Where,

$$X = \frac{{Z_{\alpha/2}}^2 p(1-p)}{MOE^2} \tag{2}$$

and $Z_{\alpha/2}$ is the critical value of the Normal distribution at $\alpha/2$ (e.g., for a confidence level of 95 %, α is 0.05, and the critical value is 1.96); MOE (Mean of Error) is the margin of error; p is the sample proportion, and N is the population size.

3.3. Population size and sample size

The size of the population means the total number of distinct individuals, that is, the total number of textile and apparel industries in Bangladesh. The sample size does not change much for populations larger than 100,000. If the population size is small, a finite population correction is used for calculation. According to BGMEA (Bangladesh Garments Manufacturers and Exporters Association), the total number of garment factories in Bangladesh is 4500. As the population size is small, we use a finite population correction to account for sampling in this formula. In population size determination, the apparel industry has priority because, among the whole textile processing areas of spinning, knitting, weaving, dyeing, printing, washing, apparel, trims, and accessories, the apparel industry is still bound with numerous manual works. Some notable manually operated jobs encompass marker laying, fabric cutting, cut part sorting, budling, garment sewing, and most finishing and packing purposes. But for the present scenario of whole textile areas, we have

Table 1
List of various types of factories considered for the survey.

Factory Category	Frequency	Percentage (%)
Spinning	13	7.7
Weaving and knitting	17	10.1
Dyeing, printing, and washing	23	13.7
Apparel	46	27.4
Composite Mill	56	33.3
Trims &Accessories	13	7.7

also incorporated some of the notable factories from other textile factories.

Using the abovementioned equations (1) and (2), the sample size is 134. The sample proportion is taken from previous studies [25], where it was found that data gets saturated in the case of more than 120 Bangladesh factories.

$N = 4500, Z\alpha/2 = 1.96, p = 0.9, MOE = 0.05$

A plan is made to reach a total of 168 factories randomly through email and social media communication. As for the accuracy of the calculation, some incomplete and misleading responses have to be rejected. Table 1 represents the number and percentage of various factories that have been considered in this survey.

3.4. Questionnaire design and data collection

The 5-point Likert scale with five possible responses—from strongly disagree to agree strongly—was used to collect the data (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree). The complete questionnaire used in this study has been provided as supplementary materials. The psychometric scale is best for analyzing respondents' opinions and capturing their viewpoints in a quantitative way. It is also chosen since it increases the originality and depth of the data while lowering respondents' annoyance. The research items included in the questionnaire were chosen depending on the important study variables, namely big data, smart factories, CPS, IoT, textile production, and industry performance. It asked questions about attitudes and behaviors such as "lack of willingness to adopt IR 4.0," "lack of training procedures for skill development of employees to adopt IR 4.0," etc.

The questionnaire was distributed to the targeted population through email and social media using a Google form. Initially, managers' and employees' email addresses from both industries were gathered. Additionally, respondents were chosen at random. Respondents received proper instructions on completing the questionnaire and information about the study's goals through a Google Form description. The respondents who were not part of IR 4.0 were excluded. Table 2 shows the response percentage during data collection.

A total of 168 factories were reached randomly through email, LinkedIn, and social networks using the Google form. Upon this, 149 responses were received. However, 7 responses could not be used for analysis during the data cleaning process due to a lack of adequate responses. Ultimately, the analysis was done using the responses received from 142 factories.

After completing the data cleaning process, simple demographic data has been organized as frequency and percentage (%) along with three basic important information about their factories, represented in Table 3.

4. Results

4.1. Exploratory factor analysis (EFA)

Whether the factors are valid with survey data to recommend further comments, it is necessary to perform some consistency tests, like the Kaiser-Meyer-Olkin Test (KMO) and Bartlett's Test of Sphericity. As indicated in Table 4, the Kaiser-Meyer-Olkin Test (KMO) value is expressed as 0.927, and the KMO cutoff value is 0.50. This KMO value indicates that factors are good enough for factor analysis and denotes no severe multicollinearity data issues [28]. Bartlett's Test of Sphericity revealed a significant value of 0.000, showing $p < 0.05$. After performing the Kaiser-Meyer-Olkin Test (KMO) and Bartlett's Test of Sphericity, we performed principal component analysis (PCA) using IBM SPSS 26 and found the concerned rotating component matrix illustrated in Table 5. After successful factor reduction, it is to be mentioned that the factors have been subdivided into 5 major dimensions as per varimax rotation.

4.2. Confirmatory factor analysis

To test the confirmatory factors, Smart PLS has been utilized [29]. The external loads of the factors should be evaluated per individual indicators' reliability [30]. According to Ref. [28], 0.70 is the cut-off value for measuring a factor's components. Table 6 illustrates factors such as external loadings, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE). Table 6 illustrates CB-SEM (Smart PLS) output, it has been visualized that external loading for all components revealed more than 0.70. However, a value of Cronbach Alpha ranging from 0.91 to 1.00 reveals optimum consistency [31]. The composite reliability factor for all 5 dimensions is greater than the threshold value of 0.70; thus, the dataset has sufficient internal consistency and reliability [31]. The coefficient of variation (CV) analysis should be tested through average variance extracted (AVE), and the threshold value is 0.50. From

Table 2
Response rate during data collection through survey questionnaire.

Response	Frequency/Rate
Total number of questionnaires distributed	168
Total number of questionnaires returned	149
Total number of applicable questionnaires	142
Number of incomplete questionnaires	07
The overall response rate (149/168)	88.7 %
After data entry, overall response rate (142/168)	84.5 %

Table 3
Demography of the respondents and information about the factories.

Category	Frequency	Percentage (%)
Organizational Position		
Executive Officer	47	33.1
Senior Executive Officer	23	16.2
Senior Production Officer	24	16.9
Senior Merchandiser	26	18.3
Deputy General Manager	10	7
General Manager	12	8.4
Level of adaptation of IR 4.0		
Low	29	20.4
Medium	81	57
High	26	18.3
Very high	6	4.2
Lack for willingness of IR 4.0 adoption		
Strongly disagree	14	9.9
Strongly disagree	18	12.7
Neutral	46	32.4
Agree	37	26.1
Strongly agree	27	19.01
Investment for IR 4.0		
Already invested	38	26.8
Willing to invest	43	30.3
Not willing to invest	61	42.9

Table 4
KMO and Bartlett's test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.927
Bartlett's Test of Sphericity	Approx. Chi-Square	6553.278
	df.	153
	Sig.	0.000

Table 5
Rotating component matrix.

Dimensions	Criteria	Factor Loadings
Strategy and organization	Status of the Industry 4.0 strategy implementation	0.731
	Review of the strategy using indicators	0.791
	Investment for Industry 4.0	0.874
	Use of technology and innovation	0.755
Smart factory	Digital technologies integration	0.620
	Machines and infrastructure	0.633
	Data utilization	0.689
	IT infrastructure	0.749
Smart Operation	Use of cloud storage	0.689
	Sharing of information	0.749
	Automation system	0.663
Data-driven services	Availability of various services using data storage	0.671
	Data sharing among various departments	0.792
Employees	Related skills in IT	0.677
	Related skills in new technologies	0.689

Table 6, it has been exposed that the AVE value for all 5 dimensions indicates that the dataset has a sufficient coefficient of variation among the factors.

4.3. Normality test

The normality and validity of each variable can be measured by the skewness and kurtosis values. The optimum acceptable range for skewness is [−2, 2], and this parameter has a range of [−7, 7] for kurtosis. The skewness and kurtosis values, along with the standard deviation of our research variables, are given in Table 7. All the variables lie within the range and show the normality of the univariate distribution.

Table 6
Dataset validation.

Dimensions	Components	Loadings	Cronbach Alpha	CR	AVE
Strategy and organization	Status of the Industry 4.0 strategy implementation	0.842	0.920	0.922	0.659
	Review of the strategy using indicators	0.855			
	Investment for Industry 4.0	0.792			
	Use of technology and innovation	0.819			
Smart factory	Digital technologies integration	0.777	0.950	0.951	0.637
	Machines and infrastructure	0.784			
	Data utilization	0.705			
	IT Infrastructure	0.789			
Smart Operation	Use of cloud storage	0.737	0.933	0.981	0.589
	Sharing of information	0.788			
	Automation system	0.859			
Data-driven services	Availability of various services using data storage	0.771	0.954	0.922	0.651
	Data sharing among various departments	0.747			
Employees	Related skills in IT	0.868	0.948	0.936	0.688
	Related skills in new technologies	0.857			

Table 7
Normality values for challenges from survey data.

Variables	Mean	Median	Standard deviation	Excess kurtosis	Skewness	P Values
Status of the Industry 4.0 strategy implementation	4.256	4	0.734	1.254	−0.994	0.00
Review of the strategy using indicators	3.503	4	1.152	−0.646	−0.666	0.00
Investment for Industry 4.0	4.113	4	0.881	3.283	−1.536	0.00
Use of technology and innovation	3.918	4	0.812	3.488	−1.525	0.00
Digital technologies integration	3.836	4	0.733	1.686	−1.228	0.00
Machines and infrastructure	3.595	4	0.82	1.045	−0.984	0.00
Data utilization	3.313	3	0.871	−0.454	0.142	0.00
IT infrastructure	3.785	4	0.856	1.67	−1.051	0.00
Use of cloud storage	3.836	4	0.973	0.48	−0.943	0.00
Sharing of information	3.005	3	1.13	−1.002	−0.096	0.00
Automation system	3.785	4	0.781	2.606	−1.293	0.00
Availability of various services using data storage	3.415	4	0.97	0.202	−0.643	0.00
Data sharing among various departments	3.467	4	1.004	−0.175	−0.705	0.00
Related skills in IT	3.112	4	0.954	2.154	0.198	0.00
Related skills in new technologies	3.598	4	0.964	−0.159	−0.905	0.00

4.4. Maturity model determination

This study attempts to determine the maturity and adoption level of IR 4.0 for the Bangladeshi textile and apparel industries. For this purpose, this study employed the maturity model established, which measures maturity level in nine broad dimensions with 62 sub-dimensions based on a 5-point rating scale [32,33]. Respondents responded regarding maturity level in the same questionnaire for challenge variables using the VDMA approach. Responses were collected on a 5-point Likert scale, with 1 indicating a very low level of adoption, 3 meaning a medium level of adoption, and 5 denoting a very high level of adoption. Maturity levels for nine broad dimensions have been measured using equation (3) from Ref. [32]. Table 8 shows the maturity levels for nine dimensions, and Fig. 3 illustrates the maturity levels by radar chart.

Table 8
Maturity levels.

Maturity Dimensions	Maturity Level (5.0 Scale)
Technology	1.49
Operations	2.35
Strategy	1.89
People	1.88
Leadership	2.10
Governance	2.00
Products/Service	2.40
Customers	1.80
Culture	1.26
Overall Maturity Level	**1.91**

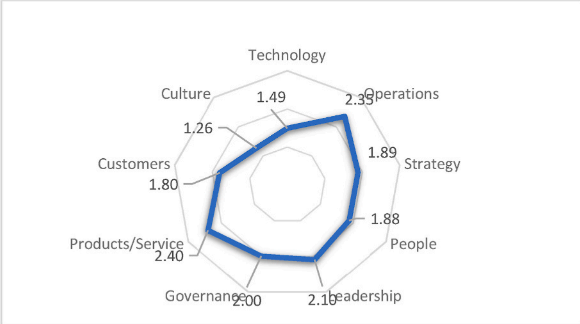

Fig. 3. Radar chart of maturity levels.

$$M_D = \frac{\sum_{i=1}^{n} M_{Dii} \ X \ g_{Dii}}{\sum_{i=1}^{n} g_{Dii}} \tag{3}$$

5. Discussion

From exploratory factor analysis, it has been visualized that the criteria “Review of the strategy using indicators” got the highest loading value in the external factor, 0.791. This clearly reveals that strategy formulation and tracking is the topmost priority among other IR 4.0 adoption variables. On the contrary, “digital integration” got the lowest loading at 0.620, as IR 4.0 digital technology adoption is very low. Stentoft and Rajkumar [34] conducted the exploratory factor analysis for Industry 4.0 drivers’ relevancy with other industries; while Marcon et al. [35] investigated the socio-economic factors associated with Industry 4.0 implementation. Drivers and barriers linked to the utilization of big data as a key indicator of Industry 4.0 have been examined byKonanahalli et al. [36]. Industry 4.0 technologies are still in the shadow mode to Bangladeshi Textile and Apparel industries as huge employment has been engaged in this industry with manual and semi-automatic processes. That is why, the overall maturity level was found to be only 1.91, indicating low adoption level as meanwhile, some modern manufacturing machinery has already been automated. Industry 4.0 maturity has been previously examined in the Tanzanian Apparel industry byNhelekwa et al. [33].

5.1. Assessment of the IR4.0 adoption level by VDMA model and EFA categories

5.1.1. Category 1: organizational strategy

According to the survey, only 14 % of the factories are deemed experienced in this category, and 53 % of factories are at the learning stage, whereas 33 % know very little about the revolution.

5.1.2. Category 2: smart factory

Digital integration, machine infrastructure, IT infrastructure, etc., are the indicators of assessing a smart factory operating under IR 4.0, according to the VDMA model. 14 % of the factories that implemented IR 4.0 have mentioned in the descriptive part of the survey the way of their implementation as smart factories and the benefits they are reaping right now:

a. The doffing processes in the spinning machinery have been automated.
b. The dyeing machinery can run the dyeing curve just by programming before operation.
c. Automatic conveyor reduces workers’ movement and keeps the pace of the sewing work without the work being piled up.
d. Less material waste, reduced costs, higher profit margins, quality assurance, fluid collaboration.

In contrast, according to the survey, more than 50 % of factories are laggards in infrastructure and smart machinery. Furthermore, no organization has yet become an infrastructure expert to adopt IR 4.0.

5.1.3. Category 3: smart operation

Most factories (69.4 %) have a long way to go to execute smart operations in IR 4.0, as they are all at an intermediate level right now. Only 14.8 % of the factories have experience in this category, and the other 22 % are at the beginner level. RFID is one of the major sensors linking items in smart operations, and factories like Zara, Adidas, Marks & Spencer, and H&M frequently use it for manufacturing, customer relationship management, supply chain management, and production management. RFID generates large data sets, encourages businesses to embrace IR 4.0, and offers self-optimizing choices. The study on RFID self-optimization in the textile and apparel industries revealed that 43 % of the factories agreed with the RFID self-optimizing decisions, 23 % strongly agreed with the matter, and 34 % remained neutral.

5.1.4. Category 4: data-driven services

Big data decreases the failure rate and increases overall equipment effectiveness (OEE). However, only 40 % of factories strongly agreed to utilize big data for the overall effectiveness of their factory performance, 32 % agreed with the utilization, and 28 % remained neutral.

5.1.5. Category 5: employees

Factories have a workforce with IT skills at an expert level to embrace IR 4.0, which is only 11 %. 24 % of factories have neutral-level employees to operate the complex systems of IR4.0. The primary reason for the shortage of IT-skilled people in Bangladesh's textile sector is that managers (65 % of factories) consider it an additional expense. By implementing automation, the company will reduce almost 50 % of its workers to make an economic balance in the industry, and most of the workers may lose their jobs. Adopting IR 4.0 is a big challenge due to the lack of IT-related training for workers and employees. According to the survey, a total of 74 % agree that there exists a severe scarcity in the willingness of the management to provide adequate training programs.

5.2. Managerial approach to IR 4.0 adoption

There might be a technological breakthrough in the near future. As a result, almost 73 % agreed that if Bangladesh's textile and apparel industries did not embrace IR 4.0 soon, they would be left behind. The survey shows management's commitment to implementing IR 4.0 is quite low. Due to a lack of desire, only 15 % of factories have expressed a high commitment to implementing IR 4.0, 36 % have expressed a medium commitment, and 49 % have remained neutral on this assertion. More than 50 % claim that one of the major challenges of IR 4.0 adoption is financing for implementing IT-based machinery and smart operations and financing for providing related training to the workforce. Therefore, Bangladesh's textile industry is still in the intermediate stage of adapting to the 4th revolution.

5.3. Major findings of the study

- More than half of the sampled manufacturers are at an intermediate stage regarding organizational strategy and the expertise necessary to implement IR 4.0.
- More than 50 % of factories are lagging in infrastructure.
- Most factories (70 %) have a long way to go before executing IR 4.0's intelligent operations.
- Only 16 % of the sampled manufacturers are at a professional level of preparation for data-driven services.
- Only 12 % of the workforce in factories is IT trained.
- Smart operation (43 %) and automation (32 %) would be wise choices for deploying IR 4.0.
- More than 50 % of the respondents said that the biggest obstacle to adopting IR 4.0 is funding the money to integrate IT-based machinery and smart operations.
- The overall survey on IR 4.0 adaptation potential and difficulties in the garment industry is at an intermediate level. The overall weighted result shows that Bangladesh is not yet sufficiently ready to embrace the highly complex and sophisticated phenomenon of the fourth industrial revolution.

5.4. Recommendations and solutions of the ranked challenges

Implementing IR 4.0 requires changes in knowledge, skills, and attitudes (KSAs) in hiring and training, both for employers and employees. People in the textile and apparel sectors must develop forward-thinking leadership skills while considering technology and innovation. Industries must abandon the conventional manufacturing method. Due to the growing usage of software, robotics, and data analytics, there will be a greater need for skilled personnel in the IT industry. Traditional workers and low-skilled workers will be at risk of losing their jobs. Before beginning a transition to IR 4.0, this danger must be considered. Therefore, industry owners should create training facilities for their existing workforce and invest in education programs to create a strong future workforce to adopt IR 4.0. To cope with this recent Industry 4.0 concept, textile and apparel processing factories need to plan for the early adoption of Industry 4.0 technologies.

6. Conclusion

The findings demonstrated that IR 4.0 has influenced socioeconomic changes in Bangladesh and contributed to a wave of disruptive technology deployment in manufacturing facilities. The study also showed that the Industry 4.0 revolution can be used to boost productivity, efficiency, global competitiveness, customer satisfaction, and the capacity to launch and grow new products and services. However, the new study also found that Bangladesh would have a hard time implementing the IR 4.0 revolution because it depends a lot on how long networks and technology last, how well they work together, how many people are available with the right skills, how much money they have, and how well they set up research and development (R&D) facilities. Additionally, the study found that introducing Bangladesh's Industry 4.0 revolution could pose concerns for managing and controlling cybersecurity, data privacy workers, SMEs, and industries, and the vulnerability to and volatility of global value chains by competitors. This study showed where the RMG factories in Bangladesh are now, and this finding alone is essential for policymakers, the business world, and academics. After a thorough evaluation, the study finds that most RMG factories are at an intermediate level in adapting to IR 4.0. The main limitation of the research was the lack of research or studies conducted on implementing IR 4.0 in Bangladesh's textile and apparel industries. It was challenging to find relevant information since there were so few articles about IR 4.0 and how it affected the use of cheap labor in the Bangladeshi textile sector. Nevertheless, to properly deploy IR 4.0 in the local context, lifecycle reengineering and new technology adoption across the entire value chain are required, which are not covered in this research. This study will demonstrate that the garment industry needs to view IR 4.0 as a new business model instead of restricting its vision to introducing information and communication technologies. The study concludes that more research needs to be performed before IR 4.0 can be applied in the textile and apparel sectors. There are many areas where more research could be conducted in the future concerning IR 4.0 in the RMG sector of Bangladesh. IR 4.0 implementation-identified challenges can be further analyzed in the case of small and large industry aspects.

Ethical approval and consent to participate

This study topic, questionnaire, dataset, and results were reviewed and approved by the Department of Textile Engineering Management, Bangladesh University of Textiles, Bangladesh. Participants for the survey were selected based on their experience level in industrial manufacturing processes and each participant was properly (verbally) described with all the questions included in the survey. The participants provided their proper consent to participate in the study specifying their voluntary participation, confirming that information about themselves and their organization will remain confidential as well as in any report of the study results, their identity will remain anonymous. They were verbally informed that the research findings will be published in the renowned journal.

Data availability statement

The data and calculations presented in this study come from software directly. So, there is no other data available to share.

CRediT authorship contribution statement

IsratZahan Mim: Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Md. Golam Sarower Rayhan:** Software, Formal analysis, Data curation. **Md. Syduzzaman:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e32044.

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