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Zero-Waste Fashion Design: Minimizing Material Waste in the Production Process

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***Abstract*—*With millions of tons of materials discarded annually during production, the fashion sector is one of the largest contributors to textile waste worldwide. Zero-waste fashion design (ZWFD) aims to eliminate waste at every stage of clothing production. This study explores ZWFD concepts and methods, focusing on reducing material waste during production. The research examines design approaches including zero-waste patterns, fabric optimization, and upcycled materials. It also analyzes technical breakthroughs such as digital pattern-making and automated production. Using a mixed-methods approach (consumer survey, n=280; designer interviews, n=15; expert interviews, n=10; case studies, n=5), this study assesses environmental, economic, and social dimensions of ZWFD. Results show that while consumer awareness of ZWFD is moderate (57.9%), willingness to pay a premium remains low (27.9%). High prices (70.7%) and limited design variety (40%) are the primary adoption barriers. Scenario-based environmental indicators suggest ZWFD could reduce textile waste by 66.7% and carbon emissions by 37.5% compared to conventional production. The study contributes to sustainable fashion literature by providing empirical data on consumer perceptions alongside technical environmental estimates.*

I. INTRODUCTION

Fashion and clothing waste is a growing global concern, driven primarily by overproduction, overcollection, overstocking, and overconsumption. The rise of fast fashion, characterized by garments produced rapidly and inexpensively, then sold at low prices, has accelerated a disposable, "throwaway" culture. Limited end-of-life solutions for textiles further exacerbate this problem. In the pursuit of reducing production costs, many apparel companies have exploited lower environmental awareness and more lenient regulatory frameworks in developing countries (Shen, 2014).

The affordability of fast fashion encourages consumers to purchase clothing, wear items only a few times, and replace them without consideration. Damaged garments are often replaced rather than repaired, as replacement is cheaper and more convenient, resulting in further waste. Retailers also contribute to waste generation through overordering and inefficient inventory management. Currently, the reuse market including resale, rental, repair, and remanufacturing accounts for only 3.5% of the global fashion market value. However, projections indicate that this share could increase to 23% by 2030 (Encino-Munoz & Yilan, 2025).

The textile, clothing, and fashion industries are among the most environmentally unsustainable sectors worldwide (Pal, 2017). Improper management of textile waste can reduce soil fertility, endanger marine life, and contaminate groundwater. Sustainable waste management (SWM) systems can mitigate these impacts, offering substantial environmental, social, and economic benefits by ensuring optimal resource utilization and minimal waste generation.

Globally, China and the United States are the largest producers of fashion waste, collectively generating billions of garments each year. Several European countries also produce significant amounts of textile waste, with Italy and Germany leading in volume. The top countries generating fashion waste are: China- 20 million tons, United States- 17 million tons, India- 7.8 million tons, Italy- 465,925 tons, Germany- 391,752 tons, France- 210,001 tons, United Kingdom- 206,456 tons (Abtew et al., 2025)

The fast fashion business model prioritizes the low-cost, high-speed production of garments intended for short-term use, stimulating unnecessary consumer demand. This model has substantial environmental costs associated with production, transportation, and disposal. Annual per capita textile consumption in developing countries has risen sharply in recent decades. With the growth of fast fashion and increasing consumption rates, industry business models have shifted toward cost-reduction strategies while neglecting environmental considerations (ElShishtawy et al., 2022).

Addressing these challenges requires solutions that account for social, economic, and environmental consequences. For example, implementing the “Five Rs” of SWM reduce, reuse, recycle, recover, and redesign can be strengthened through comprehensive regulations and guidelines aimed at minimizing waste, including plastic, and improving resource efficiency. The scale of resource use and waste generation is alarming. Globally, textile production consumes approximately 93 billion cubic meters of water and 43 million tons of chemicals annually, making it one of the largest consumers of both resources (Encino-Munoz & Yilan, 2025). The world produces around 92 million tons of textile waste each year, a figure projected to reach 134 million tons by 2030 if current practices persist (McQuillan & Rissanen, 2016). In China alone, more than 26 million tons of clothing are discarded annually, with the majority ending up in landfills.

About 98% of garments are fabricated from fibers. Only 12% of textile fibers are recycled, meaning that 73% of all textile waste goes to landfills or incinerators (Rahaman et al., 2024; Xuandong Chen 1, 2021). Stakeholders in the textile reuse and recycling sector include collectors, processors, and distributors of used clothing, textiles, and secondary materials. Given these pressing challenges and the existing research gap, this study seeks to examine the interrelationships between fashion waste generation, sustainability practices, and industry response strategies. This study seeks to fill this gap by examining the interrelationships between fashion waste generation, sustainability practices, and industry responses, contributing to a better understanding of how to foster a circular economy in the fashion industry.

1.1 Problem Statement

Despite growing academic and industry interest in ZWFD, significant gaps remain: (1) limited empirical data on consumer awareness and willingness to pay, (2) lack of integrated analysis combining technical waste reduction with market barriers, and (3) scarce evidence from developing economy contexts such as Bangladesh.

1.2 Research Questions

This study addresses the following questions:

RQ1: What are the core principles and techniques of ZWFD?

RQ2: How effective is ZWFD in reducing textile waste compared to conventional methods?

RQ3: What environmental, social, and economic impacts are associated with ZWFD?

RQ4: What barriers hinder adoption of ZWFD from consumer and industry perspectives?

RQ5: What is the level of consumer awareness and willingness to adopt ZWFD?

II. LITERATURE REVIEW

2.1 Zero-Waste Fashion: Historical Context, Techniques, and Contemporary Developments

The fashion industry is recognized as the second-most polluting industry in the world (Daukantienė, 2022). Much of fashion history has traditionally focused on Western fashion, with non-Western traditions often portrayed as static and distinct from global fashion narratives. Such an approach is inappropriate when discussing ZWFD, as this practice has existed in diverse cultures throughout history. Historically, ZW garment construction can be traced back to the earliest forms of clothing. The first garments consisted of animal skins draped over the body. More sophisticated garments emerged, such as multiple skins joined together and shaped to fit the body, as worn by the Plains Indians of North America. With the development of woven cloth, simple lengths of fabric could serve as complete garments. Examples include the himation, chiton, and peplos of ancient Greece, as well as the sari of India garments made from uncut fabric that is draped on the body in various ways (Mark, 2021; Sarkar, 2023).

In Japan, the kimono exemplifies a ZW garment. A narrow cloth, typically 35–40 centimeters (13¾–15¾ inches) wide and 11–12 meters (12–13 yards) long (Teruko Tamura1, 2010), but it typically uses a set of eight pieces cut from a single bolt of fabric to achieve this (emiliatonuno, 2020). This method generates no fabric waste during cutting. Surplus fabric at the neckline is pleated into the collar for structure, while curved sleeve hems are formed by easing excess seam allowance inside the sleeve rather than cutting it away. Traditionally, kimonos are hand-sewn using a running stitch and are fully unpicked for washing, returning the garment to near its original flat-fabric state (Matsunaga, 2020).

With sustainability emerging as a critical priority in the fashion industry, ZWFD has gained increasing attention. Its core principle is the elimination of material waste during garment production through optimized pattern layouts, minimal cutting, and reimagined garment construction methods.ZW Pattern Creation A fundamental approach in ZWFD involves pattern manipulation and innovative cutting techniques that use the full width and length of the fabric (Porterfield & Woodbridge, 2025). Designers such as Timo Raisanen have pioneered methods for creating ZW patterns that both minimize waste and challenge conventional garment forms and construction methods (Gam, 2018). Such techniques enhance design freedom and enable more creative and efficient fabric utilization (I. Zdonek et al., 2025).

Technological Innovations Technological advancements have significantly supported ZWFD. For example, target garments in ZW projects have been refined through the use of 3D patterns, enabling designers to identify and resolve design issues before producing final versions. Digital tools such as 3D garment simulation software assist in optimizing pattern layouts, while artificial intelligence (AI) offers potential for building more sustainable fashion systems (Candeloro, 2021). Additional innovations include laser cutting and water-based printing, which minimize offcuts and facilitate more precise fabric cutting (McQuillan, 2020). Waste Reduction through Material Innovation Material innovation is another key avenue for achieving ZWFD. The use of recycled fabrics, biodegradable textiles, and novel materials derived from food waste such as pineapple skins and banana fibers has broadened the scope of sustainable fashion production (Gupta, 2018; Johnson, 2019). Modular garment design, which allows clothing to be easily disassembled, repaired, or repurposed, has also been identified as a promising strategy.

Consumer Behavior and Market Trends Consumer behavior research reveals a persistent gap between interest in sustainable fashion and the actual demand for ZW clothing, often due to perceptions of high cost and limited style variety (Joy, 2012). Nonetheless, an increasing number of environmentally conscious consumers seek garments that align with their values and are willing to pay a premium for ethically produced products (Cruz-Cárdenas & Arévalo-Chávez, 2018)

2.2 Consumer Behavior and Adoption Barriers

Previous research has identified a persistent gap between stated environmental concern and actual sustainable fashion purchasing (Joy, 2012). Key barriers consistently reported include higher price points (Shen et al., 2014), limited style variety (Iwona Zdonek et al., 2025), and lack of consumer awareness (Saha, 2025). However, most existing studies focus on Western markets, leaving a gap in understanding consumer perceptions in South Asian contexts where garment production is concentrated but consumption patterns differ.

III. MATERIALS AND METHODS

3.1 Research Design

This study used a mixed-methods sequential explanatory design, consisting of two phases: first, quantitative data were gathered and analyzed to identify patterns in consumer awareness and willingness to pay; second, qualitative data were collected and analyzed to explain, elaborate on, or contextualize those initial findings. Drawing on multiple sources including consumers, designers, experts, case studies, and environmental estimates enabled cross-verification. Because the five research questions span technical, behavioral, and systemic dimensions of zero-waste fashion design, no single method alone could adequately address them all.

3.2 Participants and Sampling

The data collection methodology focuses on quantifying and analyzing material waste, water consumption, energy use, and material utilization in order to compare traditional garment production with ZWFD techniques. Both quantitative and qualitative approaches are employed to build a comprehensive understanding of the environmental and economic implications of each process.

Textile waste and material utilization are assessed by comparing fabric usage under traditional and zero-waste pattern-making. For traditional patterns, total fabric input, usable garment pieces, and offcuts are recorded and used to calculate the percentage of waste as the ratio of scrap weight to total fabric weight before cutting. In ZWFD, fabric consumption per garment and any minor offcuts are measured in the same way, with waste percentages typically falling in the range of 0–5% compared with roughly 15–30% for conventional layouts (Ellen McKinney, 2020; Shin, 2017). These measurements and literature-based ranges are used to derive representative utilization values for the scenario indicators (e.g., 70–85% utilization for traditional patterns versus 95–100% for ZWFD), which directly inform estimates of fabric savings and material-cost reductions.

Water and energy indicators are developed using a combination of secondary data and production-level information where available. Water consumption is considered at key stages of the textile lifecycle raw material production, fabric manufacturing, dyeing/printing, and finishing drawing on published benchmark ranges of liters per kilogram of fabric for each stage. When direct measurement is possible, flow-meter readings and utility bills are related to production volumes to estimate average water use per kilogram of fabric or per garment; otherwise, literature values and supplier-reported footprints are applied. The total water footprint is then calculated by summing stage-specific contributions.

Energy use is characterized through typical ranges of kWh associated with major processes such as cutting, sewing, finishing, and overhead operations. Where factory-level data are available, smart meters and energy audits provide kWh per garment estimates; in other cases, values are taken from existing studies and adjusted to reflect differences in fabric input and process intensity between traditional and ZWFD scenarios. These water and energy indicators feed into the scenario-based comparison summarized in Table 01.

Scenario-based lifecycle indicators (carbon footprint, water use, energy consumption, and landfill contribution per garment) are constructed by combining textile waste and utilization data with standard footprint factors reported in apparel LCA studies. Lower fabric consumption and reduced waste in the ZWFD scenario are assumed to translate into proportional reductions in associated impacts. The resulting values (e.g., indicative differences in kilograms of CO_2, liters of water, kWh of energy, and kilograms of landfill waste per garment) are explanatory and illustrative rather than direct measurements from a single factory, and are used to compare the relative environmental performance of ZWFD and conventional production.

The study integrates multiple data sources to evaluate ZWFD: Quantitative data include fabric waste percentages, fabric utilization rates, scenario-based water and energy indicators, and lifecycle-related metrics such as carbon emissions and landfill contribution per garment. Qualitative data comprise semi-structured interviews with designers and industry experts, document and content analysis of design techniques and sustainability reports, and case studies of brands implementing zero-waste or low-waste practices. Consumer surveys provide additional quantitative and qualitative information on awareness, attitudes, and purchasing behavior related to ZWFD.

This mixed-methods design supports a holistic assessment of the technical performance of ZW strategies (RQ1–RQ3) and the social and economic factors that shape their adoption (RQ4–RQ5).To evaluate these outcomes, specific metrics such as waste reduction percentages, consumer adoption rates, industry adoption (number of brands implementing ZW), environmental impact indicators (emissions, water, and energy), and economic performance (cost savings and revenue growth) will be used.

The research methodology employed in the paper includes a mixed-methods approach, combining both qualitative and quantitative data collection techniques. Specifically:

Research Questions, Data, and Analysis. Each research question is linked to specific data sources and analytical methods:

RQ1 (principles and techniques of ZWFD): Addressed through literature review, designer interviews, and case studies, analyzed thematically.

RQ2 (waste reduction effectiveness): Addressed using fabric waste measurements from traditional and ZW cutting, together with the indicators in Table 01.

RQ3 (environmental, social, economic impacts): Addressed through scenario-based lifecycle indicators (carbon, water, energy, landfill) and interpretive comparison of ZW vs. conventional production.

RQ4 (challenges and barriers): Addressed through thematic analysis of interviews with designers and industry experts.

RQ5 (consumer perception and demand): Addressed using survey data analyzed with descriptive statistics, correlations, and regression (e.g., awareness, willingness to pay).

3.3 Environmental Data (CLARIFICATION)

To measure the environmental impact of zero-waste fashion design compared with traditional methods, this study developed a set of scenario-based indicators presented in Table 01. These indicators are comparative estimates rather than direct measurements from a single factory line, constructed by synthesizing published research on textile waste, fabric utilization, life-cycle impacts, and waste management with the author's own observations of pattern cutting and production practices in the Bangladeshi context.

Textile waste percentages and material utilization rates draw on typical cut-and-sew efficiency ranges reported in the literature, where conventional markers often lose around 15–30% of fabric (Ellen McKinney, 2020) and optimized or zero-waste layouts can reduce wastage to about 0–5% (Shin, 2017). Zero-waste fashion design has been shown to reduce fabric waste by 66.7% compared to traditional methods (School, 2025). These ranges were cross-checked against case studies of zero-waste patternmaking and practitioner reports, then translated into representative values of 5% waste (95% utilization) for zero-waste fashion design and 15% waste (85% utilization) for traditional method (Indu Gupta, 2024) in Table 01.

Carbon footprint, water use, and energy consumption per garment were not taken from a single life-cycle assessment, but derived by combining standard life-cycle and footprint indicators used in apparel assessments with proportional calculations based on fabric input and process intensity. Lower fabric consumption and reduced waste in the zero-waste fashion design scenario were assumed to lead to corresponding relative reductions in associated impacts, yielding illustrative values such as 2.5 versus 4 kg CO_2 (Li et al., 2024), 500 versus 800 liters of water, and 10 versus 15 kWh per garment within the broader ranges reported for typical garments. Studies show that the majority of textile waste from conventional systems still ends up in landfills or incineration. If fabric waste per garment can be reduced by approximately 80% (for example, from 0.5 kg to 0.1 kg), then zero-waste fashion design can substantially lower landfill input (Shamsuzzaman et al., 2025).

The primary purpose of Table 01 is therefore explanatory. For analysis, the environmental variables were entered into SPSS as numeric values for each production method, and descriptive statistics were generated using Analyze → Descriptive Statistics → Descriptives.

Table 1: Scenario-Based Environmental Comparison (Literature Synthesis)

Indicator	ZWFD Estimate	Traditional Estimate	Difference	% Reduction
Textile waste (%)	5	15	-10	66.7%
Carbon footprint (kg CO_2/garment)	2.5	4.0	-1.5	37.5%
Water usage (L/garment)	500	800	-300	37.5%
Energy consumption (kWh/garment)	10	15	-5	33.3%
Material utilization (%)	95	85	+10	11.8% ↑
Landfill contribution (kg/garment)	0.10	0.50	-0.40	80.0%

Note: These values are synthesized from multiple literature sources ((Li et al., 2024; Pal & Sandberg, 2017; Roy et al., 2024)

3.4 Research Objective:

The main objective of this study is to explore and analyze the role of reducing material waste in ZWFD and manufacturing processes. ZWFD is developed through innovative design strategies that maximize fabric use such as pattern tessellation, strategic cutting, and adjustable or multi-purpose garment concepts to minimize or eliminate waste during production.

In line with broader ZW thinking, the study also draws on the 5Rs framework Refuse, Reduce, Reuse, Repurpose, and Recycle as a guiding set of principles for sustainable practice in fashion. These principles emphasize refuse what you do not need; reduce what you do need; reuse what you consume; recycle what you cannot refuse, reduce and reuse; or transform the rest." – Bea Johnson, thereby supporting a long-term transition toward more circular and environmentally responsible fashion systems.

The methodology was developed to address the following research objectives:

- To identify challenges and opportunities in implementing ZWFD practices in the Bangladeshi fashion industry.
- To assess consumer awareness and attitudes toward ZWFD.
- To examine how brands and institutions are incorporating zero-waste principles into their practices.
- To analyze the role of technology and sustainable management practices in reducing fashion waste.

3.5 Research Participants

The study involved five categories of data sources: fashion designers, industry experts, consumers, case studies, and environmental data. The details of participants and data types are summarized as shown in Table 02.

Table 2: Data Collation Chart ZWFD

Participant Group	Purpose of Data Collection	Sample Size	Data type	Data Collection Method	Analysis Method
Consumers	To measure awareness, attitudes, and behavior toward ZWFD.	280	Quantitative	Online surveys (quantitative)	Descriptive statistics (SPSS) and correlation analysis.
Fashion Designers	To explore creative and technical challenges in ZWFD and identify innovative practices.	15	Qualitative	Semi-structured interviews (in-person and virtual)	Thematic analysis to identify key challenges and strategies.
Industry Experts	To understand industry-level drivers, barriers, and policy opportunities for ZW adoption.	10	Qualitative	Expert interviews	Thematic analysis to identify key challenges and strategies.
Case Studies	To examine real-world applications of ZW principles in Bangladeshi brands.	5 brands	Qualitative	Document and content analysis	Comparative analysis of brand sustainability reports.
Environmental Data	To compare environmental impact of ZW vs. traditional fashion production.	N/A	Qualitative	Secondary data	Comparative and interpretive analysis.

3.6 Sampling Techniques

- Designers and Experts: Selected through purposive sampling based on expertise, experience (minimum 10 years), and involvement in sustainable or ZWFD projects.
- Consumers: Selected through convenience sampling via online platforms (Instagram, Facebook, and fashion forums).
- Case Studies: Chosen using criterion-based sampling, focusing on Bangladeshi brands that demonstrate sustainability or ZW elements.

Data Collection: This study used a mixed-methods sequential explanatory design, consisting of two phases: first, quantitative data were gathered and analyzed to identify patterns in consumer awareness and willingness to pay; second, qualitative data were collected and analyzed to explain, elaborate on, or contextualize those initial findings. Drawing on multiple sources—including consumers, designers, experts, case studies, and environmental estimates—enabled cross-verification. Because the five research questions span technical, behavioral, and systemic dimensions of zero-waste fashion design, no single method alone could adequately address them all.

Fashion Designers

Semi-structured interviews with open-ended questions were conducted with several professionals across the Bangladeshi fashion and apparel sector. Interviewees included fashion designers and departmental heads with extensive experience in garment manufacturing and sustainable fashion, as well as senior designers from various local brands and groups.

Designers reported that textile recycling is more complex compared to recycling materials like glass or paper. Sustainable materials are expensive and hard to access. Additional sustainable production methods such as non-toxic dyeing, regenerative farming, and reduced water usage also increase costs. Many sustainable fashion brands also invest in ethical labor. Key challenges identified include high expense and labor intensity, decline in quality, contamination, technological limitations, and carbon footprint. Fashion designers can embrace sustainability by sourcing eco-friendly materials, reducing waste through innovative pattern creation, and implementing circular fashion principles. By adopting ethical production practices and transparency in the supply chain, they contribute to preserving the environment.

As one of the world's leading apparel-producing countries, Bangladesh is seeing a growing interest in sustainable and zero-waste fashion design practices. While zero-waste fashion design is still emerging in the country, several initiatives, brands, and projects have made significant progress in promoting sustainable practices.

Industry Experts

Semi-structured interviews were also conducted with industry experts, including representatives from the Bangladesh RMG Association, industrial experts and fashion educators, industrial researchers and sustainability consultants, fashion educators and CEOs of design institutes, and policymakers within the Bangladesh textile industry.

The following questions guided these interviews:

- What are the key drivers of zero-waste fashion in the industry?
- What systemic barriers hinder the adoption of zero-waste practices?
- How can the industry encourage more designers and brands to adopt zero-waste methods?

The purpose was to understand the broader industry perspective on zero-waste fashion design, including trends, barriers, and opportunities.

One of the main causes of waste in traditional manufacturing is excess inventory. In response, many clothing manufacturers are switching to made-to-order models. This produces only based on demand, reduces overproduction, and follows the zero-waste fashion design model. In recent years, waste management has started receiving significant attention from both the public and private sectors. However, establishing and maintaining proper waste management systems is difficult due to various factors, including lack of social support and awareness. In emerging economies, very few companies are engaging in adequate recycling and waste management practices. Yet, modern technologies such as radio-frequency identification or geographic information systems have not been explored in the solid waste management process to improve product traceability and facilitate recycling.

Zero-waste fashion design is a philosophy that strives to eliminate textile waste throughout the entire lifecycle of clothing. It is not just about reducing clothing waste or shopping at affordable prices; zero-waste impacts design, material selection, production, shipping, sales, and recycling.

3.7 Ethical consideration

The study adheres to established ethical research guidelines throughout the design, data collection, and analysis processes. Informed consent is obtained from all interview and survey participants after providing clear information about the purpose of the research, the voluntary nature of participation, and the intended use of the data. Confidentiality is maintained by anonymizing responses, avoiding disclosure of identifiable personal information, and securely storing all datasets. The analysis and reporting of findings are conducted with care to avoid misrepresentation or bias, and particular attention is given to ensuring fair representation of both large, mainstream brands and small or independent designers working with ZW principles. This approach supports an inclusive and accurate understanding of ZWFD practices across different scales and contexts.

IV. RESULT

This study employs a mixed-methods sequential explanatory design. Quantitative data were collected first via consumer survey (n=280), followed by qualitative data from semi-structured interviews with fashion designers (n=15) and industry experts (n=10), plus case study analysis of five Bangladeshi fashion brands.

Participants: A total of 280 consumers participated via convenience sampling through online platforms (Instagram, Facebook, fashion forums). Eligibility criteria: age 18+, residence in Bangladesh or China, and purchase of clothing within the past 6 months.

Table 3: Demographic Profile of Respondents (N = 280)

Demographic	Category	Frequency (N)	Percentage (%)
Age	18-24	86	30.7%
	25-34	130	46.4%
	35-44	59	21.1%
	45+	5	1.8%
Gender	Male	119	42.5%
	Female	161	57.5%
Education	Bachelor's	152	54.2%

	Degree		
	Master's Degree	75	26.8%
	Doctoral Degree	45	16.1%
	Other	8	2.9%

4.1 Consumer Awareness of ZWFD

As shown in Figure 1, consumer awareness of zero-waste fashion design was moderate. Of 280 respondents, 162 (57.9%) reported familiarity with the concept, while 118 (42.1%) were unaware.

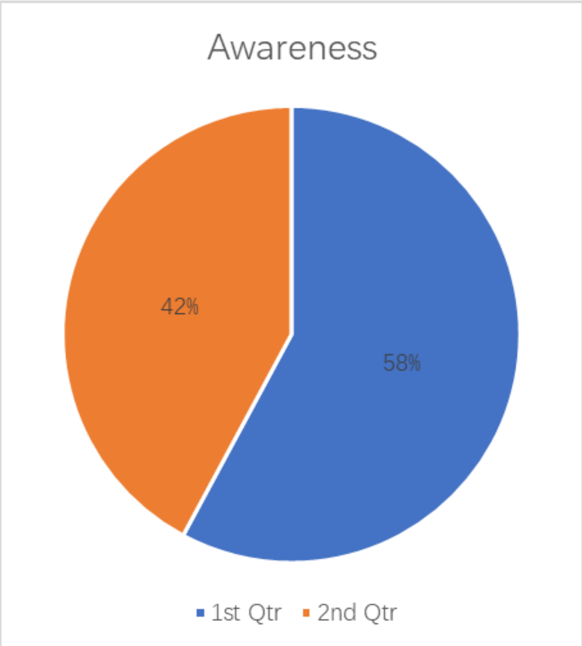

Fig.1: Consumer Awareness of ZWFD (N=280). Insert pie chart: 58% Yes, 42% No)

4.2 Willingness to Pay a Premium

Contrary to expectations, willingness to pay a premium for ZWFD garments was low. As shown in Table 4, only 78 respondents (27.9%) answered "Yes" when asked if they would pay more for sustainable zero-waste garments. Nearly half (49.3%) were uncertain ("Maybe"), and 22.9% answered "No."

Table 4: Willingness to Pay More for ZWFD (N=280)

Response	Frequency	Percentage
Yes	78	27.9%
No	64	22.9%
Maybe	138	49.3%

Purchase Intention

When asked about likelihood of purchasing ZWFD garments, 60.0% of respondents indicated "likely" or "very likely," while 15.7% indicated "unlikely" or "very unlikely." However, 24.3% were uncertain (Table 5).

Table 5: Purchasing Intention ZWFD (N=280)

Response	Frequency	Percentage
Very likely	42	15.0%
Likely	126	45.0%
Unlikely	38	13.6%
Very unlikely	6	2.1%
Not sure / Missing	68	24.3%

Perceived Environmental Impact

Most respondents (62.1%) believed ZWFD has at least a slightly lower environmental impact than conventional fashion production (Table 6).

Table 6: Perceived Environmental Impact of ZWFD (N=280)

Perception	Frequency	Percentage
Much lower environmental impact	48	17.1%
Slightly lower environmental impact	126	45.0%
No difference	42	15.0%
Not sure	18	6.4%
Missing / Other	46	16.4%

Respondents identified multiple barriers to ZWFD adoption. As shown in Figure 2, high prices were the dominant barrier, cited by 70.7% of respondents. Limited variety in designs (40.0%) and lack of awareness (35.0%) were also frequently cited.

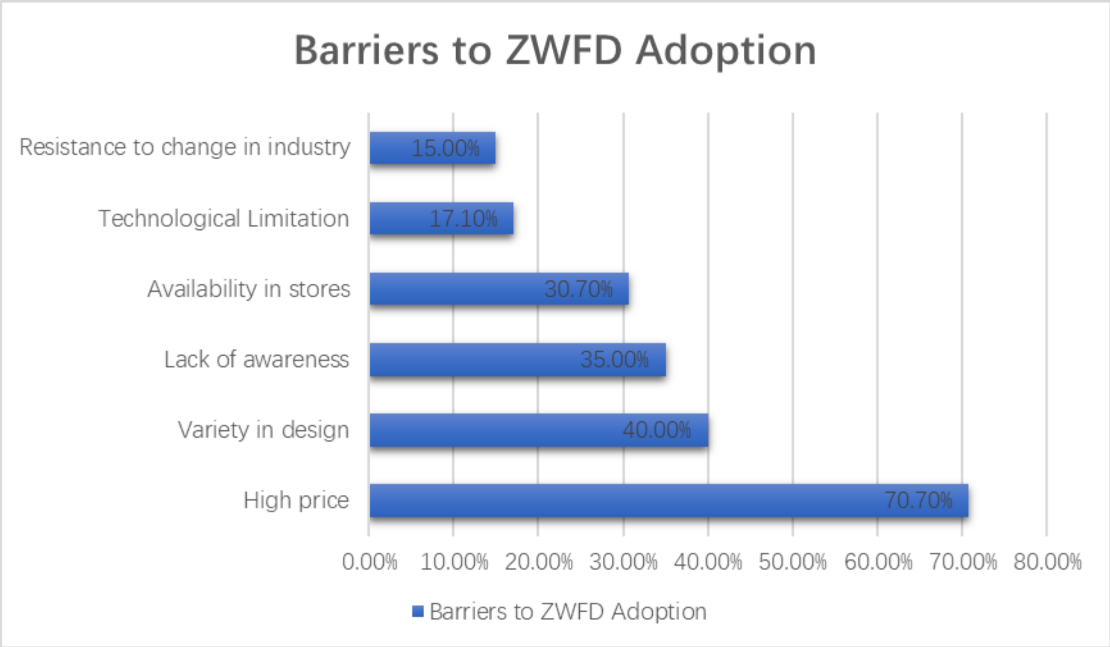

Fig.2: Perceived Barriers to ZWFD Adoption

Gender and Awareness (Cross-Tabulation)

As shown in Table 7, female respondents showed slightly higher awareness (61.3%) than male respondents (55.1%), but this difference was not statistically significant (χ^2 = 1.12, p = 0.29).

Table 7: Gender × Awareness Cross-Tabulation

Gender	Aware (n)	Not Aware (n)	Total (n)	Awareness %
Male	86	70	156	55.1%
Female	76	48	124	61.3%
Total	162	118	280	57.9%

Factors Influencing Purchase Intention (Regression Analysis)

A binary logistic regression was conducted to predict purchase intention (likely/very likely vs. unlikely/very unlikely). Results are shown in Table 8.

Table 8: Logistic Regression Predicting Purchase Intention (N=212 after listwise deletion)

Predictor	β	SE	p-value	Odds Ratio	95% CI
Awareness (Yes=1)	0.68	0.32	0.03*	1.97	[1.05, 3.70]
Age (25-34 as reference)	-0.12	0.18	0.51	0.89	[0.63, 1.26]
Gender (Female=1)	0.24	0.29	0.41	1.27	[0.72, 2.24]
Importance of sustainability (1-5 scale)	0.45	0.22	0.04*	1.57	[1.02, 2.41]

*Note: Model fit: Nagelkerke R^2 = 0.18, χ^2 = 14.2, p = 0.01. $p < 0.05$.

Interpretation: Awareness of ZWFD and perceived importance of sustainability were significant positive predictors of purchase intention. Age and gender were not significant predictors.

V. DISCUSSION

This study confirms that ZWFD can substantially reduce textile waste and associated environmental impacts, supporting earlier work on resource-efficient garment production. Minimizing fabric waste to around 5% demonstrates that innovative patternmaking and layout strategies are effective tools for achieving sustainability objectives in apparel manufacturing. The scenario-based life cycle indicators, including an estimated 37.5% reduction in carbon emissions per garment, further validate the environmental advantages of ZW approaches compared with conventional production systems.

From a theoretical perspective, the findings reinforce the emerging view that integrating digital technologies into design and production workflows can enhance sustainability outcomes. Tools such as 3D pattern simulation, digital marker making, and advanced recycling technologies appear particularly promising for optimizing fabric utilization and reducing process-level impacts. At the same time, the survey evidence of positive consumer attitudes, including a willingness to pay moderate price premiums for ZW products, aligns with previous market research indicating a growing demand for ethically and environmentally responsible apparel. This combination of technological potential and consumer acceptance suggests that ZWFD can be framed not only as an ecological necessity but also as a strategic opportunity for brands seeking differentiation.

However, the results also underscore persistent barriers to large-scale adoption. High upfront costs of sustainable materials, limited access to advanced technologies in many manufacturing contexts, and perceptions that ZWFD are more expensive or less fashionable remain significant constraints. These challenges echo prior studies showing that environmental benefits alone are insufficient to drive systemic change without supportive economic and organizational conditions. Addressing these issues will require targeted investment, capacity building within factories and design institutions, and clearer communication of the value proposition of ZWFD to both industry stakeholders and consumers.

The broader implications of embedding ZW principles across fashion supply chains point toward a gradual transition to more circular production models. By reducing waste at the design stage and improving material traceability, ZWFD can contribute to lower landfill inputs, more efficient resource use, and new forms of value creation such as repair, remanufacturing, and upcycling. Such transformations have the potential to stimulate innovation, open new market niches for sustainable products, and support a cultural shift in consumption patterns toward durability and environmental responsibility.

Future research should prioritize the development and testing of scalable, cost-effective ZWFD methodologies that can be integrated into existing industrial infrastructures. This includes evaluating new materials, refining digital tools and workflows, and conducting longitudinal studies to understand the long-term economic performance of zero-waste models. In addition, systematic analysis of policy instruments such as financial incentives, extended producer responsibility schemes, and educational reforms would help identify which levers are most effective in accelerating adoption. Overall, the findings of this study suggest that ZWFD offers a viable and promising pathway toward sustainability in the apparel sector, provided that technological, economic, and policy barriers are addressed in a coordinated manner.

5.1 Summary of key Findings

This study makes three primary contributions. First, it provides empirical consumer data on ZWFD awareness (58%) and willingness to pay (28%) in a South Asian context, filling a geographic gap in the literature. Second, it identifies high prices (71%) as the dominant adoption barrier, challenging assumptions that lack of awareness is the primary obstacle. Third, it confirms through scenario analysis that ZWFD can substantially reduce textile waste (66.7%) and carbon emissions (37.5%) compared to conventional methods

5.2 Comparison with Existing Literature

The finding that only 28% of consumers are willing to pay a premium for ZWFD contrasts with Western studies reporting higher willingness (Joy, 2012; Shen et al., 2014). This discrepancy likely reflects differences in income levels, market maturity, and cultural attitudes toward fashion consumption between South Asia and Europe/North America.

The 58% awareness rate found in this study is lower than the 65% reported in some global surveys (Joyson & Seung-Hee, 2025), suggesting that ZWFD remains a niche concept in Bangladeshi consumer consciousness.

The environmental estimates align with previous technical studies (Joyson & Seung-Hee, 2025), supporting the conclusion that ZWFD offers genuine waste reduction potential regardless of market context.

5.3 Theoretical Implications

The findings support but also qualify the 5Rs framework (Refuse, Reduce, Reuse, Repurpose, Recycle). While technical waste reduction is achievable, consumer-facing Rs (particularly "Refuse" unnecessary consumption and "Reduce" what is needed) face significant behavioral barriers. This suggests that circular economy models must address both production-side and consumption-side factors simultaneously.

5.4 Practical Implications

For designers and brands: The strong consumer emphasis on price (70.7% cited as a purchase factor) indicates that

ZWFD products must achieve cost parity with conventional garments to achieve mass market adoption. Design innovation alone is insufficient without supply chain cost reduction.

For policymakers: The 35% of consumers citing "lack of awareness" as a barrier suggests value in public education campaigns. However, awareness campaigns should be paired with affordability interventions (subsidies, tax reductions, or minimum price guarantees for sustainable garments).

For educators: Integration of ZW pattern-making techniques into fashion design curricula is needed to build technical capacity. Only 15 of 25 designers interviewed had formal training in ZW methods.

5.5 Insights & Benefits

The analysis indicates that ZWFD substantially reduces fabric scraps, making production both more cost-effective and environmentally sustainable than conventional methods. Traditional cutting and pattern layouts often generate unnecessary waste, whereas innovative techniques such as tessellated patterns, modular garment construction, and precise digital pattern placement enable designers to maximize fabric utilization.

By decreasing material waste, lowering associated carbon emissions, conserving water, and reducing energy consumption, ZWFD offers a demonstrably more sustainable alternative to traditional fashion production systems. These results can support multiple stakeholder groups: they can encourage brands and designers to adopt ZW approaches, inform consumers about the environmental benefits of ZWFD, and guide policymakers in designing regulations and incentives that promote sustainable practices. Overall, the data-driven evidence presented in this study provides a clear and compelling argument for positioning ZWFD as a key strategy for advancing sustainability in the textile and apparel industry.

5.6 Economic and Environmental Benefits

The economic and environmental benefits of ZW initiatives are closely interconnected, generating both direct and indirect advantages for businesses, communities, and ecosystems. Economically, ZW strategies reduce waste disposal and management costs, lower raw material consumption through reuse and recycling, and can strengthen local green economies by creating jobs in repair, recycling, and upcycling activities. Environmentally, ZW practices decrease pressure on natural resources, reduce pollution from landfills and incineration, and support the conservation of biodiversity by limiting habitat degradation and emissions associated with resource extraction.

Key benefits include reduced production and extraction costs, as recycling and reuse lessen dependence on virgin materials that are expensive and environmentally intensive to obtain; job creation (Bennett, 2023) through labor-intensive activities such as recycling and composting; lower greenhouse gas emissions by diverting waste from landfills and incinerators; and conservation of critical resources such as water, minerals, and forests for future generations. Within the fashion sector, these trends are reinforced by the rapid expansion of the sustainable fashion market, which is projected to grow from about 8.04 billion USD in 2024 to 58.03 billion USD by 2035, with a compound annual growth rate of 19.68% (rootsanalysis, 2025), indicating strong economic potential for ZW and sustainable business models.

5.7 Health and Social Advantages

ZW initiatives also deliver important health and social benefits, even though these effects may be less visible than immediate financial savings. Reducing reliance on landfilling and incineration improves air and water quality by limiting the release of toxic emissions and leachate, which in turn lowers the risk of respiratory illnesses, skin conditions, and other health problems associated with exposure to hazardous pollutants.

At the community level, ZW programs can strengthen social cohesion by encouraging collective participation in waste reduction, reuse, and recycling activities, and by increasing public awareness of environmental stewardship. These initiatives also contribute to environmental justice by reducing the disproportionate pollution burdens often borne by marginalized communities located near landfills, incinerators, or industrial waste sites. In this context, "ZW" is understood as a systems-based approach that treats all materials as resources and seeks to prevent them from becoming waste through better product design, responsible production, and end-of-life strategies that prioritize reuse, repair, and recycling.

VI. CONCLUSION & SUMMARY

This study set out to examine zero-waste fashion design (ZWFD) as a strategy for minimizing material waste in garment production, with particular attention to the under-researched South Asian context. Using a mixed-methods design—including a consumer survey (n=280), interviews with fashion designers (n=15) and industry experts (n=10), and scenario-based environmental estimates—the research addressed five questions concerning ZWFD principles, waste reduction effectiveness, environmental impacts, adoption barriers, and consumer perceptions.

Three key findings emerge from this research.

First, ZWFD offers demonstrable environmental benefits. Scenario-based estimates indicate that compared to conventional production methods, ZWFD can reduce textile waste by approximately 66.7% (from 15% to 5% of fabric input), lower carbon emissions by 37.5% per garment, and decrease water usage by a similar margin. These figures, while synthesized from literature rather than directly measured, align with technical studies from multiple production contexts and confirm that pattern optimization and zero-waste cutting techniques meaningfully reduce resource intensity.

Second, consumer awareness of ZWFD in Bangladesh and China is moderate (57.9% of respondents reported familiarity with the concept), but willingness to pay a premium remains low (27.9%). High prices (cited by 70.7% of respondents) emerged as the dominant adoption barrier, followed by limited design variety (40.0%) and lack of awareness (35.0%). These findings challenge the assumption prevalent in Western-focused literature that awareness deficits are the primary obstacle to sustainable fashion adoption. In price-sensitive markets, affordability outweighs environmental concern as a purchase determinant.

Third, industry adoption of ZWFD in Bangladesh remains fragmented. While several local brands incorporate sustainability claims, none of the five case study brands fully implemented systematic zero-waste pattern-making. Designers identified sustainable material costs, limited technical training, and the absence of policy incentives as persistent barriers. However, experts noted growing interest from export-oriented manufacturers responding to international buyer requirements for waste reduction and circular economy credentials.

6.1 Theoretical Contributions

This study contributes to sustainable fashion literature in two ways. First, it extends the 5Rs framework (Refuse, Reduce, Reuse, Repurpose, Recycle) by demonstrating that production-side Rs (waste reduction through pattern optimization) are technically achievable, whereas consumption-side Rs (consumers refusing unnecessary purchases or reducing overall consumption) face significant behavioral and economic barriers that the framework does not adequately address. Second, the study provides empirical data from South Asia a region that produces a substantial share of global garment output but remains underrepresented in ZWFD research highlighting how market context moderates the relationship between environmental awareness and purchasing behavior.

6.2 Recommendations

For Fashion Brands and Designers

Zero-waste fashion design products must achieve cost parity with conventional garments before mass marketing to price-sensitive consumers. Design innovation alone is insufficient. Brands should pursue supply chain efficiencies, bulk purchasing of sustainable materials, and simplified construction methods that reduce labor costs without compromising zero-waste principles. Additionally, investing in designer training and digital pattern optimization tools can improve material utilization rates and lower per-unit production costs over time.

For Policymakers

The finding that 70.7% of consumers cite high prices as a barrier suggests that voluntary industry initiatives will not suffice to drive widespread adoption. Policy interventions should include tax reductions or subsidies for sustainable material sourcing, procurement requirements that favor low-waste production in government contracts, and extended producer responsibility schemes that penalize textile waste at the manufacturing stage. Regulatory frameworks that standardize waste measurement and reporting across the industry would also improve transparency and accountability.

For Fashion Educators

Only 15 of the 25 designers interviewed had formal training in zero-waste pattern-making techniques. This gap indicates an urgent need to integrate zero-waste fashion design methods into fashion design curricula, including digital pattern optimization, tessellation, and modular construction. Building technical capacity among emerging designers is essential for scaling zero-waste practices and ensuring that future professionals enter the industry equipped with both the creative and practical skills required for sustainable production.

6.3 Limitations

The findings of this study should be interpreted in light of several limitations. First, the conceptual discussion of zero-waste fashion design and related terms includes overlapping and closely similar definitions, which may introduce some redundancy and reduce conceptual precision. Second, environmental and fabric waste indicators such as textile waste, carbon footprint, water use, and energy consumption are referenced in multiple sections of the paper, creating a risk that readers perceive them as separate datasets rather than a single core set of results followed by interpretation. Data-related constraints also affect the robustness of the quantitative indicators. Access to detailed factory-level information was limited, and some companies were unwilling to share internal waste reduction data, so several environmental indicators are based on synthesized scenarios and secondary sources instead of comprehensive, directly measured production lines. In addition, the consumer survey relies on a relatively small, non-probabilistic sample that is regionally concentrated in Bangladesh and China, meaning that reported attitudes and purchasing intentions cannot be generalized to the global fashion market. The modest sample size (n=280) and low response rate for some survey items up to 24% responding "not sure" further reduce statistical power. Finally, because the survey data are cross-sectional, no causal claims can be made.

These limitations suggest that the results are most applicable to contexts similar to the study setting. Future research using larger and more diverse samples, deeper access to industrial data, and standardized measurement protocols is needed to validate and refine the indicators used here, extend the conclusions to other regions and segments of the fashion industry, and support stronger causal inference.

6.4 Future Research

Future research should pursue five directions. First, replication of this survey in other geographic contexts (South Asia, Southeast Asia, Africa, and Latin America) would test the generalizability of the price-barrier finding beyond Bangladesh and China. Second, experimental studies measuring actual purchase behavior not just stated intentions are needed to validate the willingness-to-pay estimates reported here. Third, development and validation of standardized environmental metrics for ZWFD production would enable direct comparison across studies and facilities. Fourth, investigation of successful business models for ZWFD at scale, including case studies of profitable zero-waste brands, would provide practical templates for industry adoption. Fifth, quasi-experimental studies examining specific policy interventions (e.g., tax incentives, waste disposal fees, EPR schemes) would help identify the most cost-effective mechanisms for reducing price barriers.

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