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Digital Transformation in Emerging Fashion Economies: A Qualitative Review of CAD/CAM Adoption and Its Implications for Design

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ABSTRACT

This study examines the role of Computer Aided Design and Computer Aided Manufacturing technologies in driving digital transformation within Bangladesh's apparel industry. The research adopts a systematic literature review approach based on existing academic and industry sources. The analysis focuses on three key areas. These are design transformation, production efficiency, and sustainability outcomes. The findings show that digital tools improve design flexibility and accuracy.

They also enhance production efficiency through faster processes and better coordination. In addition, these technologies support sustainability by reducing material waste and improving resource use. However, the impact of digital transformation depends on factors such as infrastructure, investment, and skill availability. The study highlights that adoption is uneven across firms in Bangladesh. Overall, the research provides an integrated understanding of how CAD and CAM technologies influence the apparel sector in an emerging economy. The study also offers insights for future research and industry practice.

Keywords: digital transformation, CAD/CAM technologies, apparel industry, Bangladesh, production efficiency, sustainable fashion, fashion technology, systematic review

INTRODUCTION

Background of the Study

The fashion industry is changing due to the growing use of digital technologies. These technologies influence both creative work and industrial production. In the past, designers depended on manual skills and repeated physical sampling. Today, digital systems support more accurate and flexible processes. Computer-Aided Design and Computer-Aided Manufacturing have become important tools in modern apparel development (Fletcher, 2010; Nayak & Padhye, 2018).

Computer-Aided Design allows designers to create and adjust patterns in a digital space. This reduces the need for repeated manual work. It also improves speed and accuracy. Computer-Aided Manufacturing supports automated production processes such as fabric cutting and material handling. These systems improve consistency and reduce errors. When combined, these technologies connect design and production more closely. Information moves more clearly between stages of the process.

Digital tools are also linked to sustainability in the fashion sector. Accurate pattern making can reduce fabric waste. Fewer physical samples can lower the use of materials and energy (Gwilt & Rissanen, 2011). Recent studies show that digital transformation can support better resource use and more informed production decisions (Kozlowski et al., 2019). These changes show that fashion systems are evolving due to both technological and environmental pressures.

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Research Problem

The adoption of digital technologies is not equal across all regions. This is especially true in emerging economies. Factors such as limited infrastructure, lack of technical skills, and high investment costs affect adoption. Bangladesh is one of the largest apparel-producing countries in the world. It plays an important role in global supply chains. However, the level of digital integration in its apparel industry is still uneven.

Most research on digital transformation in fashion focuses on developed countries. These regions have stronger technological systems. In contrast, studies on Bangladesh often focus on productivity or cost issues. They give less attention to design processes and sustainability outcomes. Because of this, the current understanding of CAD and CAM adoption remains incomplete.

There is a need for a more integrated analysis. Such analysis should connect technology with design, production, and sustainability. A qualitative review can bring together existing studies. It can provide a clearer understanding of how CAD and CAM technologies are shaping the apparel industry in Bangladesh.

Research Objectives

The main aim of this study is to examine the role of CAD and CAM technologies in digital transformation within Bangladesh's apparel sector. The study follows a qualitative review approach. The objectives are:

- To explore the influence of CAD and CAM on fashion design practices
- To assess the impact of these technologies on production efficiency
- To examine their contribution to sustainable production
- To integrate existing research for a better understanding of technology adoption in an emerging economy

Research Questions

This study is guided by the following questions:

- How do CAD and CAM technologies change fashion design processes?
- What effects do these technologies have on production efficiency and accuracy?
- How can CAD and CAM support sustainability in apparel production?
- How is digital transformation developing in Bangladesh's apparel industry?

Significance of the Study

This study provides an integrated view of CAD and CAM adoption in an emerging fashion economy. It connects design, production, and sustainability. This approach offers a broader understanding of digital transformation in the apparel sector.

The study also highlights Bangladesh as an important research context. This area has received limited attention in fashion technology studies. The findings may help designers, manufacturers, and policymakers. They can support better decisions related to digital adoption and sustainability. The study can also guide future research in similar industrial settings.

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Structure of the Paper

The paper is organized into several sections. Section 2 reviews literature on digital transformation, CAD and CAM technologies, and sustainability in fashion. Section 3 presents the conceptual framework. Section 4 explains the qualitative review method. Section 5 presents the findings. Section 6 discusses the results. Section 7 provides recommendations. Section 8 concludes the study.

LITERATURE REVIEW

Digital Transformation in the Fashion Industry

Digital transformation has become an important direction in the fashion industry. It changes how products are designed, developed, produced, and distributed. Earlier fashion systems depended mostly on manual work and physical samples. Current systems increasingly use digital platforms, data, automation, and virtual processes. These changes allow firms to improve speed, accuracy, communication, and decision making.

Casciani, Chkanikova, and Pal (2022) explain that digital transformation creates new opportunities for fashion supply chains, business models, and sustainability-oriented innovation. Their study shows that digital tools can support more flexible and responsive fashion systems. This is important because fashion companies now face pressure to reduce lead time, improve transparency, and respond quickly to buyer demand.

In Bangladesh, digital transformation is especially relevant because the apparel sector is highly connected with global buyers. The industry must meet strict demands related to quality, speed, compliance, and sustainability. However, the level of digital adoption is not equal across all firms. Large export-oriented factories are more likely to use advanced systems. Smaller factories often face barriers related to cost, training, and infrastructure. This makes digital transformation both an opportunity and a challenge for Bangladesh's apparel industry. In Bangladesh, the dominance of export-oriented production and cost-driven competition further shapes the pace and nature of digital transformation.

CAD and CAM Technologies in Fashion Design

Computer Aided Design and Computer Aided Manufacturing are central parts of digital fashion development. CAD helps designers create patterns, modify designs, and visualize garments in a digital environment. CAM supports production processes such as automated cutting and material handling. Together, these tools connect design and manufacturing more effectively.

Recent research on digital fashion innovation shows that digital technologies can change the way fashion products are imagined, tested, and produced. Sayem (2022) discusses how digital fashion innovations are expanding both real world and virtual fashion practices. This indicates that fashion design is no longer limited to physical development alone. Digital tools now shape creative thinking, product development, and technical execution.

In Bangladesh, CAD and CAM adoption is growing, especially in export focused factories. These technologies help firms reduce errors, improve pattern accuracy, and manage production more efficiently. However, adoption remains uneven. Many smaller firms still depend on traditional methods due to limited investment capacity and shortage of skilled workers. Therefore, CAD and CAM adoption in Bangladesh should be understood as a gradual transition rather than a fully completed transformation.

CAD and CAM and Production Efficiency

Production efficiency is one of the main reasons firms adopt CAD and CAM technologies. Digital pattern development reduces time in the design stage. Automated cutting improves accuracy in fabric use. Digital communication also reduces mistakes between design and production teams. These improvements are important in the apparel industry, where delays and errors can affect cost, quality, and buyer relationships.

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Studies on Industry 4.0 show that production efficiency depends on factors such as organizational readiness, technological capability, and infrastructure (Frank et al., 2019). The study shows that adoption is linked with issues such as organizational strategy, investment, infrastructure, information technology, skilled workers, smart operations, and smart factories. This shows that production efficiency does not depend only on machines. It also depends on management readiness, worker capability, and technological infrastructure.

For Bangladesh, this issue is very important. The apparel sector operates under strong pressure from international buyers. Factories must meet large orders within short production schedules. CAD and CAM can help improve speed, reduce waste, and increase consistency. Yet these benefits can only be achieved when firms invest in training, technical support, and proper system integration. In Bangladesh, the dominance of export-oriented production and cost-driven competition further shapes the pace and nature of digital transformation.

CAD and CAM and Sustainability in Fashion

Sustainability is now a major concern in fashion research and industry practice. The fashion sector uses large amounts of fabric, water, energy, and chemicals. It also produces significant waste during sampling, cutting, and production. Digital technologies can help reduce some of these problems by improving planning and resource use.

CAD and CAM technologies support sustainability through accurate pattern making and better material utilization. Digital pattern planning can reduce fabric waste. Virtual development can also reduce the need for repeated physical samples. This saves materials, time, and energy. Glogar (2025) notes that digital technologies in textile and fashion can support sustainable design and production when they are properly aligned with sustainability principles.

In Bangladesh, sustainability has become more important due to buyer requirements, environmental pressure, and global compliance standards. Many factories are now expected to improve resource efficiency and reduce environmental impact. CAD and CAM can support these goals, but they cannot solve sustainability challenges alone. Their value depends on how they are used within broader management, design, and production systems.

Technology Adoption in Bangladesh's Apparel Industry

Technology adoption in Bangladesh's apparel industry is shaped by both opportunity and constraint. The country has a strong position in global apparel production. At the same time, many firms still face challenges in adopting advanced digital systems. These challenges include investment cost, lack of skilled workers, weak infrastructure, and limited organizational readiness.

Alam (2023) studied ICT adoption in Bangladesh's apparel sector using the Technology Organization Environment framework. The study shows that technological, organizational, and environmental factors influence ICT adoption. It also highlights the need for better infrastructure, management commitment, and strategic alignment in the apparel sector.

This finding is useful for understanding CAD and CAM adoption. CAD and CAM are not only technical tools. They require trained users, supportive management, and suitable production systems. In Bangladesh, large firms may adopt these tools more successfully because they have better resources. Smaller firms may need policy support, training programs, and affordable access to technology.

Research Gap

The existing literature provides important insights into digital transformation, CAD and CAM technologies, production efficiency, and sustainability. However, many studies examine these issues separately. Some focus on digital innovation in global fashion. Others focus on Industry 4.0 or ICT adoption in Bangladesh. Fewer studies connect CAD and CAM adoption with design, production, and sustainability in one integrated review.

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This gap is important for Bangladesh. The country is a major apparel producer, but its digital transformation is still uneven. Existing studies often discuss technology adoption in general terms. They do not always explain how CAD and CAM reshape fashion design practice, production performance, and sustainability outcomes together.

Therefore, this study addresses a clear research gap. It offers a qualitative review of CAD and CAM adoption in Bangladesh's apparel industry. It connects digital transformation with design, production, and sustainability. This integrated approach can provide a stronger understanding of how emerging fashion economies respond to technological change.

This perspective suggests that CAD and CAM technologies should be understood not only as technical tools but also as integrative systems that reshape the relationship between design, production, and sustainability in emerging fashion economies.

Conceptual Framework

Theoretical Foundation

Digital transformation is widely understood as a process that reshapes design, production, and organizational systems through the use of advanced technologies. In the fashion industry, this transformation affects both creative practices and industrial operations. It changes how products are developed, how information is shared, and how decisions are made. Recent studies show that digital transformation also supports innovation and sustainability in fashion systems (Casciani et al., 2022).

Technology adoption in emerging economies follows a different pattern compared to developed contexts. It is influenced by factors such as infrastructure, financial capacity, and access to skilled labor. These conditions determine how effectively digital tools are implemented within production systems. Research on Bangladesh shows that organizational readiness and environmental factors play an important role in technology adoption (Alam, 2023).

Digital technologies are also linked to sustainability. They help improve efficiency, reduce waste, and support better resource management. In the fashion industry, these benefits are important because production processes often involve high material use and environmental impact. Recent research highlights that digital systems can support more sustainable design and production practices when they are properly integrated (Glogar, 2025).

Conceptual Relationships

The framework is based on the relationship between CAD and CAM adoption and three key outcome areas. These are design transformation, production efficiency, and sustainability outcomes.

CAD and CAM technologies influence fashion design by enabling digital pattern creation and modification. Designers can test and refine ideas more quickly. This improves flexibility and reduces dependence on manual processes.

These technologies also improve production efficiency. Automated systems increase accuracy in cutting and material handling. They reduce errors and improve coordination between departments. This leads to faster production and more consistent quality.

In addition, CAD and CAM support sustainability. Digital pattern making reduces fabric waste. Virtual development reduces the need for physical samples. These changes help lower resource use and environmental impact.

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Bangladesh Context as a Conditioning Factor

The impact of CAD and CAM adoption is influenced by the context in which these technologies are used. In Bangladesh, the apparel industry operates under specific economic and structural conditions. These include high production demand, cost pressure, and unequal access to technology.

Large export-oriented factories are more likely to adopt digital systems. Smaller firms often face barriers related to investment, training, and infrastructure. As a result, the outcomes of digital transformation vary across the industry.

Bangladesh is therefore considered a conditioning factor in this framework. It affects how strongly CAD and CAM technologies influence design, production, and sustainability. This allows the study to reflect real industry conditions.

Analytical Dimensions

The framework identifies three main analytical dimensions:

- Design transformation
- Production efficiency
- Sustainability outcomes

These dimensions guide the qualitative review. They are used to organize and interpret findings from the literature. Each dimension represents a key area where CAD and CAM technologies create impact.

Conceptual Framework Diagram

The conceptual framework is presented in Figure 1.

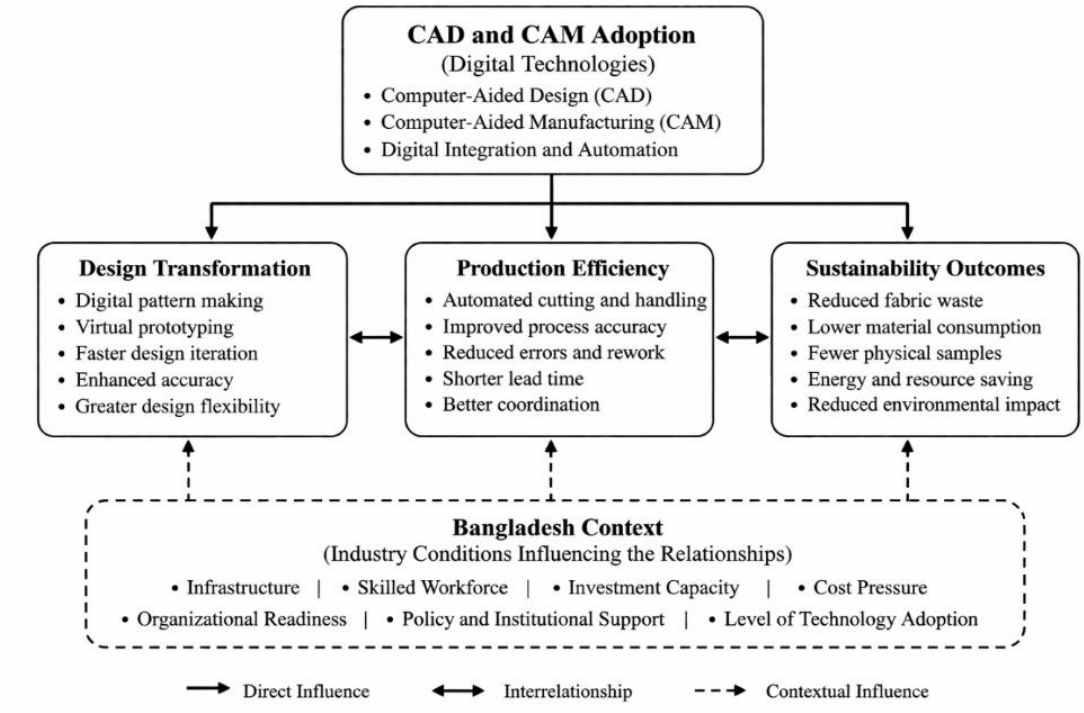

Figure 1. Conceptual framework of CAD/CAM adoption in Bangladesh apparel industry.

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Explanation of the Diagram

The conceptual framework places CAD and CAM adoption at the center. It acts as the main driver of change. This driver influences three outcome areas. These are design transformation, production efficiency, and sustainability outcomes.

Each of these areas represents a key function in the apparel industry. Design transformation focuses on creative processes. Production efficiency relates to industrial performance. Sustainability outcomes address environmental concerns.

The Bangladesh context surrounds these relationships. It represents the conditions under which digital technologies operate. These include infrastructure, skills, cost, and level of adoption. These factors influence how effective CAD and CAM technologies are in practice.

This framework provides a clear structure for the study. It connects theory with real industry conditions. It also guides the analysis of how digital transformation is shaping the apparel industry in Bangladesh.

METHODOLOGY

Research Design

This study adopts a systematic literature review approach to ensure a structured and transparent selection of sources. The aim is to understand how CAD and CAM technologies contribute to digital transformation in the apparel industry. The study does not use primary data. Instead, it relies on existing academic and industry sources. The review follows defined inclusion and exclusion criteria and uses multiple academic databases to identify relevant studies. This approach improves the reliability and rigor of the analysis and supports a more consistent interpretation of existing research.

Data Sources

The study uses secondary data collected from a range of academic and professional sources. These include peer reviewed journal articles, books, conference papers, and industry reports. Preference is given to recent publications to ensure relevance.

Key databases used for data collection include:

- Scopus
- Web of Science
- Google Scholar
- ScienceDirect

A systematic search strategy was applied using keywords such as “CAD”, “CAM”, “digital transformation”, “apparel industry”, and “sustainability”. Only peer-reviewed and high-quality sources were included to ensure the credibility of the review.

Selection Criteria

A set of criteria was used to select relevant sources. These criteria helped maintain consistency and quality in the review process.

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The inclusion criteria are:

- Studies published between 2010 and 2025
- Articles related to CAD, CAM, or digital transformation in fashion
- Research focusing on production efficiency or sustainability
- Studies relevant to emerging economies or Bangladesh

The exclusion criteria are:

- Studies not related to fashion or apparel
- Sources without academic or professional credibility
- Articles with insufficient relevance to the research objectives

This selection process ensured that only meaningful and reliable sources were included in the analysis.

Data Analysis Method

The study uses thematic analysis to interpret the collected data. This method helps identify patterns and key ideas across different sources. It allows the researcher to organize information into meaningful categories.

The analysis followed several steps:

First, selected articles were carefully read and reviewed.

Second, important concepts and recurring themes were identified.

Third, these themes were grouped into broader categories.

Finally, the findings were interpreted based on these categories.

Three main themes were used to guide the analysis:

1. **Design transformation**
2. **Production efficiency**
3. **Sustainability outcomes**

These themes are based on the conceptual framework of the study. They provide a clear structure for understanding the role of CAD and CAM technologies.

Reliability and Validity

To ensure reliability, the study uses multiple sources from different databases. This helps reduce bias and improves the consistency of findings. The use of recent and peer reviewed literature also strengthens the credibility of the study.

Validity is supported through careful selection of sources and clear analytical procedures. The themes used in the analysis are directly linked to the research objectives and conceptual framework. This ensures that the findings remain relevant and meaningful.

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Limitations of the Study

This study is based on secondary data. It does not include primary data from industry participants. As a result, the findings depend on the quality and scope of existing literature.

Another limitation is that the study focuses mainly on published research. Some practical industry insights may not be fully captured in academic sources. In addition, the context of Bangladesh is discussed based on available literature, which may not represent all industry conditions.

Despite these limitations, the study provides a comprehensive understanding of CAD and CAM adoption through a structured qualitative approach. This study does not include primary empirical data. Future research may incorporate interviews, case studies, or industry surveys to validate and extend the findings.

Ethical Considerations

The study follows standard academic practices in the use of secondary data. All sources are properly cited using APA style. No data is misrepresented or used without acknowledgment.

The research does not involve human participants or confidential data. Therefore, ethical risk is minimal. The study maintains transparency and integrity throughout the research process.

FINDINGS AND ANALYSIS

CAD and CAM and Design Transformation

The analysis shows that CAD and CAM technologies play a strong role in transforming fashion design practices. Digital tools allow designers to work in a more flexible and efficient way. Patterns can be created and modified quickly. This reduces the need for repeated manual work. It also improves accuracy in design development.

Designers are able to visualize garments before production. This helps them test ideas and make changes without using physical materials. As a result, the design process becomes faster and more controlled. The use of digital systems also supports better communication between designers and production teams.

In Bangladesh, this transformation is more visible in large export-oriented factories. These firms often use CAD systems to meet international standards. They can respond quickly to buyer requirements. However, many smaller firms still rely on manual methods. This creates a gap in design capability within the industry.

Overall, CAD and CAM technologies support a shift from traditional design practices to a more digital and responsive system. This change improves both creativity and efficiency in fashion design. This suggests that digital design transformation is not only a technical improvement but also a structural shift that redefines the role of designers within production systems.

CAD and CAM and Production Efficiency

The findings show that CAD and CAM technologies improve production efficiency by reducing processing time, minimizing material waste, and enhancing coordination between design and manufacturing stages. Digital pattern making reduces the time required for product development. Changes can be made quickly without restarting the process. This leads to shorter production cycles.

Automated cutting systems improve the use of materials. Fabric is used more efficiently, which reduces waste. These systems also improve accuracy and reduce errors during production. As a result, product quality becomes more consistent.

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Digital systems improve coordination between different departments. Information can be shared quickly between design and production teams. This reduces delays and improves workflow. Production becomes more organized and reliable.

In Bangladesh, production efficiency is a major concern due to high demand and tight deadlines. Large factories benefit more from digital technologies because they have better resources. Smaller firms often face challenges such as limited investment and lack of skilled workers. Despite these challenges, the use of CAD and CAM is increasing as firms try to improve productivity.

The findings suggest that digital technologies are essential for improving industrial performance in the apparel sector.

CAD and CAM and Sustainability Outcomes

The analysis indicates that CAD and CAM technologies contribute to sustainability in several ways. Digital pattern making allows better planning of fabric use. This reduces leftover materials during production. It also helps lower overall waste.

The use of virtual design reduces the need for physical samples. Designers can test and refine ideas digitally. This saves fabric, energy, and time. It also reduces environmental impact during product development.

Digital systems support better resource management. They help firms make more informed decisions about materials and production processes. This contributes to more efficient use of resources.

In Bangladesh, sustainability has become an important issue due to environmental pressure and international compliance requirements. Many factories are expected to reduce waste and improve efficiency. CAD and CAM technologies can support these goals. However, their impact depends on how widely they are adopted and how effectively they are used.

The findings show that digital tools support sustainability, but they are not a complete solution. Their effectiveness depends on broader industry practices and management decisions.

Integrated Analysis of Findings

The findings show that CAD and CAM technologies create interconnected effects across design, production, and sustainability. These areas are not separate. Improvements in one area often influence the others.

Better design processes lead to more efficient production. Efficient production supports reduced waste. Reduced waste contributes to sustainability. This shows that digital transformation works as a system rather than isolated changes.

In Bangladesh, these relationships are influenced by industry conditions. Factors such as infrastructure, skills, and investment affect how technologies are used. As a result, the impact of CAD and CAM is not uniform across all firms.

The analysis confirms that digital transformation in the apparel industry is a gradual process. It depends on both technological adoption and contextual factors. CAD and CAM technologies play a central role in this process by connecting design, production, and sustainability.

However, the adoption of CAD and CAM technologies is not uniform across firms. Smaller enterprises often face constraints related to cost, infrastructure, and skilled labor. This limitation indicates that digital transformation in Bangladesh is uneven and context-dependent. It also suggests that technological benefits cannot be fully realized without organizational readiness and strategic investment.

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DISCUSSION

The findings of this study confirm that CAD and CAM technologies play a central role in digital transformation within the fashion industry. The results support earlier research that highlights the importance of digital tools in improving design flexibility and production efficiency (Nayak & Padhye, 2018). The use of digital systems allows faster design development and more accurate production processes. This reflects the broader concept of digital transformation as a shift toward integrated and data-driven systems.

The study also aligns with recent literature that links digital technologies with sustainability. Improved material planning and reduced physical sampling contribute to lower resource use and waste. This supports the argument that digital innovation can assist in achieving sustainability goals in fashion (Kozlowski et al., 2019). However, the findings show that technology alone is not enough. Its effectiveness depends on how it is applied within production systems.

From a theoretical perspective, the results are consistent with technology adoption models in emerging economies. The impact of CAD and CAM technologies in Bangladesh is influenced by infrastructure, investment capacity, and skill availability. This supports the view that contextual factors shape the outcome of digital transformation (Alam, 2023). Large firms benefit more from digital systems, while smaller firms face limitations.

Overall, the discussion shows that CAD and CAM technologies create interconnected effects across design, production, and sustainability. These findings strengthen the conceptual framework of the study and confirm that digital transformation in Bangladesh's apparel industry is both technological and contextual.

This study contributes to the literature by integrating digital transformation, technology adoption, and sustainability within a single analytical framework. It extends existing theory by demonstrating how CAD and CAM technologies act as connecting mechanisms between design, production, and environmental performance in emerging economies.

RECOMMENDATIONS

The study suggests several practical steps for improving the use of CAD and CAM technologies in Bangladesh's apparel industry. First, training programs should be developed through industry–academic partnerships to ensure that workers gain practical skills in CAD and CAM systems. Without proper training, the benefits of these technologies cannot be fully achieved.

Second, policymakers should introduce targeted financial incentives and training programs to support small and medium apparel firms in adopting CAD and CAM technologies. Support from policymakers can also encourage technology adoption through incentives and industry programs.

Third, industry stakeholders should develop phased implementation strategies that include software acquisition, workforce training, and technical support systems. However, these tools must be used within a broader strategy that focuses on environmental responsibility.

Finally, collaboration between industry, education, and government institutions can support long-term digital transformation. Such collaboration can help reduce gaps between large and small firms.

CONCLUSION

This study examined the role of CAD and CAM technologies in digital transformation within Bangladesh's apparel industry. The findings show that these technologies improve design processes, increase production efficiency, and support sustainability outcomes. Digital systems allow faster development, better coordination, and more efficient use of materials.

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The study also shows that the impact of these technologies depends on the industry context. Factors such as infrastructure, investment, and skills influence adoption and effectiveness. As a result, digital transformation in Bangladesh is a gradual and uneven process.

Overall, the study provides an integrated understanding of how CAD and CAM technologies shape the apparel sector. It highlights the importance of combining technological adoption with organizational and contextual support. Future research can further explore practical implementation and industry specific challenges.

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