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# APPLICATION OF DIGITAL TWIN TECHNOLOGY IN APPAREL DESIGN, VIRTUAL TESTING, AND PRODUCTION PLANNING

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**Abstract**

The rapid advancement of Industry 4.0 technologies has significantly transformed manufacturing systems, including the apparel industry. Digital twin technology has emerged as an innovative tool for integrating virtual and physical production environments. This study investigates the development of a digital twin of a garment product for design, virtual testing, and technological preparation of production. The proposed framework combines three-dimensional garment modeling, anthropometric data processing, material simulation, and manufacturing process analysis within a unified digital environment. The research demonstrates that digital twin technology enables early detection of design inconsistencies, optimization of production parameters, reduction of material waste, and improvement of product quality. The findings indicate that the integration of digital twins into garment production contributes to greater efficiency, flexibility, and sustainability in apparel manufacturing.

**Keywords**: Digital twin, garment engineering, virtual prototyping, apparel manufacturing, Industry 4.0, digital fashion, production planning, simulation technologies.

## Introduction

The apparel industry is currently experiencing a profound digital transformation driven by advances in information technologies, artificial intelligence, and cyber-physical systems. Traditional garment development processes often involve multiple iterations of physical prototypes, extensive material consumption, and significant production costs. These challenges motivate the search for innovative approaches that can enhance efficiency while maintaining product quality.

Among the technologies associated with Industry 4.0, digital twin technology has attracted considerable attention. A digital twin can be defined as a dynamic virtual representation of a physical object, process, or system that continuously exchanges information with its real-world counterpart. Originally developed for aerospace and industrial engineering applications, digital twins are increasingly being adopted in manufacturing sectors where product complexity and customization requirements are high.

In garment production, the concept of a digital twin extends beyond simple three-dimensional visualization. It encompasses the virtual representation of garment geometry, fabric behavior, body measurements, manufacturing operations, and quality control procedures. By integrating these elements into a unified digital model, manufacturers can simulate product performance before physical production begins.

The growing demand for personalized clothing and rapid market responsiveness requires manufacturers to shorten product development cycles. Conventional methods based on physical sampling are no longer sufficient to meet modern market expectations. Consequently, digital twin technology offers an opportunity to transform garment development into a data-driven and highly efficient process.

The purpose of this study is to develop a conceptual framework for a garment digital twin that supports product design, virtual testing, and technological preparation of production. The research further examines the potential benefits of digital twin implementation for improving production efficiency and product quality.

## MATERIALS AND METHODS

Research Framework. The proposed digital twin architecture consists of four interconnected layers:

1. Physical garment layer;
2. Virtual garment model layer;
3. Data integration layer;
4. Decision-support layer.

The physical garment layer includes actual manufacturing resources, sewing equipment, fabrics, accessories, and finished products. The virtual layer contains digital representations of these components using three-dimensional modeling technologies.

The data integration layer serves as a communication bridge between physical and virtual environments. Information regarding material characteristics, body measurements, production parameters, and quality indicators is continuously transferred into the digital environment for analysis. The decision-support layer employs analytical algorithms to evaluate garment performance and optimize manufacturing processes.

Digital Modeling of Garments. A digital twin begins with the creation of an accurate three-dimensional garment model. Computer-aided design (CAD) software is used to generate garment patterns and construct virtual prototypes. The digital model incorporates detailed geometric parameters, including seam lines, fabric panels, allowances, and structural components.

To ensure realistic simulation, physical properties of textile materials are incorporated into the model. Parameters such as tensile strength, elasticity, bending rigidity, thickness, and weight are integrated into the simulation environment. This approach enables accurate prediction of fabric behavior under various conditions.

Anthropometric integration. Body dimensions significantly influence garment fit and comfort. Therefore, anthropometric datasets obtained through body scanning technologies are incorporated into the digital twin system.

The virtual human model serves as a platform for evaluating garment fit, pressure distribution, ease allowances, and ergonomic performance. Through simulation, designers can identify potential fitting problems before physical production.





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Virtual Testing Procedures. The digital twin environment enables comprehensive virtual testing of garment products. The testing process includes:

- Fit assessment;
- Stress and strain analysis;
- Mobility evaluation;
- Fabric drape simulation;
- Manufacturing feasibility analysis.

Advanced simulation algorithms calculate interactions between fabric surfaces and body geometry, allowing designers to observe garment performance under different conditions.

**RESULTS**

The implementation of the proposed digital twin framework demonstrated several advantages for garment development and production planning.

First, virtual prototyping significantly reduced the need for physical samples. Simulation results enabled designers to identify fitting defects during the early stages of product development. Common issues such as excessive tension, fabric distortion, and dimensional inaccuracies were detected before manufacturing.

Second, the integration of material properties improved prediction accuracy regarding garment behavior. Simulated drape characteristics closely matched expected physical performance, supporting more reliable design decisions.

Third, digital production planning enhanced manufacturing efficiency. By simulating sewing sequences, assembly operations, and workflow organization, the system identified potential bottlenecks and optimized production routes.

The implementation also improved communication between designers, technologists, and production managers. Because all stakeholders operated within the same digital environment, decision-making became faster and more transparent.

**DISCUSSION**

The findings confirm that digital twin technology has substantial potential for transforming garment manufacturing. Unlike traditional CAD systems that primarily focus on visualization, digital twins provide dynamic interaction between design, testing, and production stages.

One significant advantage of digital twins is their ability to support predictive decision-making. Instead of reacting to production problems after they occur, manufacturers can anticipate challenges through simulation and take preventive actions. This capability contributes to cost reduction and quality improvement.

Furthermore, digital twin implementation aligns with sustainability objectives. Reduced physical sampling lowers material consumption, decreases waste generation, and minimizes environmental impact. As sustainability becomes an increasingly important consideration within the fashion industry, digital twins offer a practical solution for responsible manufacturing.

Despite these benefits, several challenges remain. High implementation costs, data integration complexity, and the need for specialized expertise may limit adoption among small and



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medium-sized enterprises. Future research should focus on developing scalable and cost-effective digital twin platforms suitable for organizations of different sizes.
The integration of artificial intelligence, machine learning, and Internet of Things technologies may further enhance digital twin capabilities. Future systems could enable real-time monitoring of production processes and adaptive optimization of manufacturing parameters.

## CONCLUSION

This study explored the development of a digital twin of a garment product for design, testing, and technological preparation of production. The proposed framework integrates three-dimensional garment modeling, anthropometric data, material simulation, and manufacturing process analysis within a unified digital environment.
The results demonstrate that digital twins can improve product quality, reduce development time, minimize material waste, and support efficient production planning. Moreover, the technology facilitates collaboration among stakeholders and contributes to sustainable manufacturing practices. As Industry 4.0 technologies continue to evolve, digital twins are expected to become an essential component of future apparel production systems. Their implementation may significantly enhance competitiveness, flexibility, and innovation within the garment industry.

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