Journal of Textile Engineering & Fashion Technology

Literature Review

Open Access

Technical evaluation of men's T-shirt development in a CLO3D virtual environment

Abstract

This study presents a technical analysis of men's T-shirt development within a CLO3D virtual environment, focusing on the integration of digital pattern development, fabric simulation, avatar customization, and virtual fit evaluation into a unified apparel development workflow. Unlike previous studies that primarily discuss the general advantages of 3D virtual prototyping, this research provides a garment-specific technical investigation of men's T-shirt simulation and evaluates the practical effectiveness of CLO3D in improving workflow efficiency, fit accuracy, and sustainable product development. A simulation-based experimental methodology was adopted, incorporating digital pattern construction, sewing simulation, fabric parameter assignment, strain and stress mapping, and real-time visualization. The results demonstrate that CLO3D enables structurally accurate garment development with realistic drape behavior and effective fit assessment through iterative virtual simulation. The study further confirms that digital prototyping significantly reduces physical sampling requirements, material dependency, and development time while improving design communication and workflow flexibility. However, simulation accuracy remains highly dependent on correct fabric parameter calibration and user expertise. The findings contribute to a clearer technical understanding of CLO3D-based apparel development and support the broader adoption of digital garment engineering in sustainable apparel production.

Keywords: CLO3D, men's T-shirt, virtual prototyping, digital garment development, apparel CAD, 3D simulation, pattern design, sustainable fashion

Volume 12 Issue 3 - 2026

Md. Ahshan Habib, Khadija Khanom Mesu, Md Jaynal Abdin Jihad, Sarmin Akhter Beauty

Department of Fashion Design & Technology (FDT), Sonargaon University (SU), Dhaka, Bangladesh

Correspondence: Md Ahshan Habib, Department of Fashion Design & Technology (FDT), Sonargaon University (SU), Dhaka, Bangladesh

Received: May 09, 2026 | **Published:** June 09, 2026

Introduction

The global apparel industry is experiencing a significant transformation driven by digital innovation, automation, and the increasing demand for efficiency in product development.[1–3] Traditional garment development processes rely heavily on manual pattern drafting, multiple rounds of physical sampling, and iterative modifications.[1] These practices are often time-consuming, resource-intensive, and prone to inconsistencies, particularly when addressing fit and design accuracy. As market competition intensifies and consumer expectations evolve, the need for more efficient, precise, and sustainable development methods has become increasingly important.[4] The transition from conventional apparel development to digital garment simulation has significantly changed modern apparel production workflows. Figure 1 illustrates the major differences between traditional garment development processes and CLO3D-based virtual apparel development workflows.

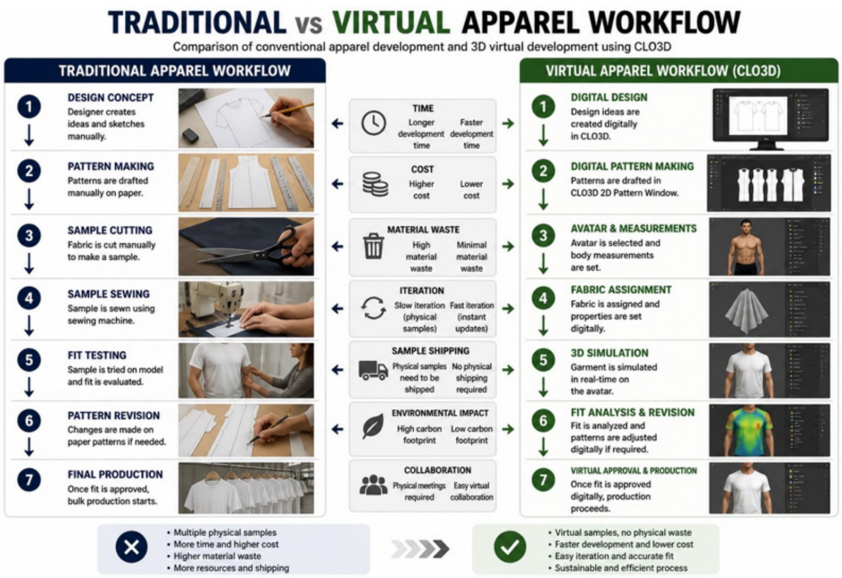

Figure 1 Comparison of traditional and virtual apparel development workflows.

Source: Author's own illustration.

In response to these challenges, digital technologies have been widely adopted to enhance apparel design and production workflows. Among these advancements, three-dimensional (3D) virtual garment simulation has emerged as a key tool for improving visualization, fit evaluation, and communication throughout the development process.[5] By enabling designers to create and evaluate garments in a virtual environment, 3D simulation reduces dependence on physical prototypes and allows for faster design iteration. This shift not only streamlines development timelines but also contributes to more informed decision-making at early stages.[6]

CLO3D is one of the leading software platforms for 3D garment simulation, offering comprehensive tools for digital pattern creation, material assignment, and realistic garment visualization. The software allows designers to construct garments using precise pattern dimensions and simulate their behavior on customizable avatars that reflect specific body measurements. This capability supports accurate evaluation of fit, drape, and structural details prior to production. Additionally, real-time rendering enables immediate feedback on design adjustments, facilitating a more dynamic and interactive development process.[7,8] T-shirts represent a fundamental category in the apparel market, particularly within men's wear, due to their widespread use and continuous demand.

Despite their relatively simple construction, achieving optimal fit, comfort, and aesthetic quality requires careful consideration of pattern design, fabric properties, and body measurements. Variations in sizing systems and consumer preferences further increase the complexity of developing well-fitting garments. Therefore, applying digital tools such as CLO3D to T-shirt development provides an opportunity to standardize processes and enhance consistency while maintaining design flexibility.[9,10]

The integration of CLO3D into garment development supports a structured workflow that combines pattern construction, fabric simulation, and fit assessment within a unified platform.[11,12] Digital pattern creation enables precise control over garment dimensions, while fabric property assignment replicates key physical characteristics such as weight, elasticity, and drape. Avatar customization based on anthropometric data ensures that virtual fit evaluation closely represents the intended target group. Together, these features allow designers to identify potential issues early and refine designs without the need for repeated physical sampling.[13,14] In addition to improving technical efficiency, virtual prototyping contributes to sustainability in the apparel industry. The reduction of physical samples minimizes fabric waste, lowers energy consumption, and decreases the environmental impact associated with transportation and production processes. Digital workflows also enhance collaboration among designers, pattern makers, and manufacturers by facilitating the exchange of accurate visual and technical information across different stages of development.[15]

However, the implementation of 3D simulation technologies is not without challenges. The accuracy of virtual garments depends on the correct input of fabric parameters and the ability of the software to replicate complex material behaviors.[16] Furthermore, effective use of CLO3D requires a certain level of technical expertise, and aligning virtual outputs with real-world production standards demands careful validation.[17] Addressing these limitations is essential for ensuring reliable integration of digital tools into conventional apparel development practices.

This study provides a technical overview of men's T-shirt development within a CLO3D virtual environment, focusing on the application of digital pattern making, fabric simulation, and avatar-based fit evaluation. By examining each stage of the workflow, the research aims to demonstrate how virtual prototyping can enhance development efficiency, improve design accuracy, and support sustainable practices in contemporary apparel production.

Problem statement

Despite the increasing adoption of 3D garment simulation technologies in apparel development, there remains limited garment-specific technical analysis regarding how digital workflows influence fit evaluation, simulation accuracy, and development efficiency in practical apparel production. Existing studies primarily focus on the general advantages of virtual prototyping, while comparatively little research systematically investigates the complete workflow of men's T-shirt development within a CLO3D environment. Furthermore, the relationship between fabric parameter calibration, avatar customization, and virtual fit reliability remains insufficiently explored. As a result, there is a need for a structured technical investigation that evaluates the effectiveness, limitations, and practical implications of CLO3D-based virtual prototyping in men's T-shirt development.

Objectives of the study

General objective

To provide a technical analysis of men's T-shirt development within a CLO3D virtual environment, with emphasis on workflow efficiency, simulation accuracy, and sustainable design practices.

Specific objectives

1) To examine the process of digital pattern development for men's T-shirts using CLO3D.
2) To analyze the role of avatar customization based on male anthropometric data in achieving accurate garment fit.
3) To evaluate the impact of fabric property assignment on drape behavior and simulation realism.
4) To assess the effectiveness of 3D visualization in identifying and resolving design and fit issues during development.
5) To compare virtual prototyping with conventional physical sampling in terms of time, cost, and material efficiency.
6) To investigate the contribution of CLO3D to sustainable apparel development through the reduction of material waste and sample production.
7) To identify key limitations and technical challenges associated with the application of CLO3D in men's T-shirt development.

Research gap

Although existing studies highlight the advantages of 3D garment simulation in enhancing visualization, efficiency, and sustainability, there remains a lack of detailed, garment-specific technical analysis within the literature. In particular, limited research has systematically examined the complete workflow of men's T-shirt development in a CLO3D environment, integrating digital pattern construction, fabric simulation, and avatar-based fit evaluation into a cohesive framework.

Furthermore, prior studies tend to emphasize conceptual benefits rather than providing in-depth evaluation of how virtual tools influence design accuracy, workflow optimization, and decision-making during product development. There is also insufficient comparative analysis between virtual outputs and traditional physical prototyping, especially in terms of reliability and practical implementation.

Additionally, the challenges associated with fabric parameter accuracy, simulation limitations, and the alignment between virtual and real-world production outcomes are often underexplored. This gap highlights the need for a structured and technical investigation that bridges theoretical understanding with practical application. Therefore, this study addresses these limitations by offering a comprehensive technical overview of men's T-shirt development using CLO3D, contributing to a clearer understanding of its capabilities, constraints, and relevance in modern apparel production.

Unlike previous studies that focus primarily on conceptual discussions of virtual prototyping, this study contributes a structured garment-specific technical workflow for men's T-shirt development using CLO3D. The research integrates digital pattern construction, fabric simulation, avatar-based fit evaluation, strain and stress analysis, and rendering evaluation into a unified analytical framework. In addition, the study critically examines how simulation accuracy depends on fabric parameter calibration and virtual fit interpretation, thereby providing practical insights for both academic research and industrial apparel development.

Literature review

Evolution of digital technologies in apparel development

The adoption of digital technologies in apparel development has significantly reshaped traditional design and production practices.[18] Early computer-aided design (CAD) systems primarily focused on two-dimensional (2D) pattern drafting and grading, offering improvements in precision and efficiency over manual methods. However, these systems provided limited capabilities for visualizing garments in a realistic context. As a result, designers still relied heavily on physical prototypes to evaluate fit, appearance, and construction details.[19]

Advancements in computing power and simulation algorithms have enabled the development of three-dimensional (3D) garment visualization systems, which allow for more comprehensive digital representation of apparel products.[20] These technologies integrate pattern design, fabric behavior, and body measurements into a single environment, enabling designers to assess garments prior to physical production. The transition from 2D to 3D systems represents a significant milestone in apparel engineering, as it enhances both the analytical and creative aspects of the design process.[21]

Recent studies emphasize that digital transformation in apparel development is not limited to design visualization but extends to workflow integration, data management, and collaborative communication. Digital platforms facilitate seamless information exchange among designers, pattern makers, and manufacturers, thereby reducing errors and improving overall productivity. As a result, the integration of advanced simulation tools is increasingly recognized as essential for maintaining competitiveness in the global apparel industry.[22]

3D garment simulation and virtual prototyping

3D garment simulation has emerged as a critical component of modern apparel development, enabling the creation of virtual prototypes that closely replicate real-world garments. Virtual prototyping allows designers to evaluate garment structure, fit, and aesthetics without the need for multiple physical samples. This approach significantly reduces development time and associated costs while enhancing design flexibility.

The effectiveness of 3D simulation largely depends on its ability to accurately represent fabric behavior and garment construction. Research indicates that simulation systems utilize physics-based modeling techniques to replicate properties such as drape, elasticity, and collision behavior. These capabilities allow garments to interact realistically with virtual avatars, providing valuable insights into fit and movement.[23] The overall workflow of digital garment simulation integrates multiple stages, including pattern creation, avatar customization, fabric assignment, simulation, and fit evaluation. Figure 2 presents the complete workflow of 3D garment simulation and virtual prototyping within a CLO3D environment.

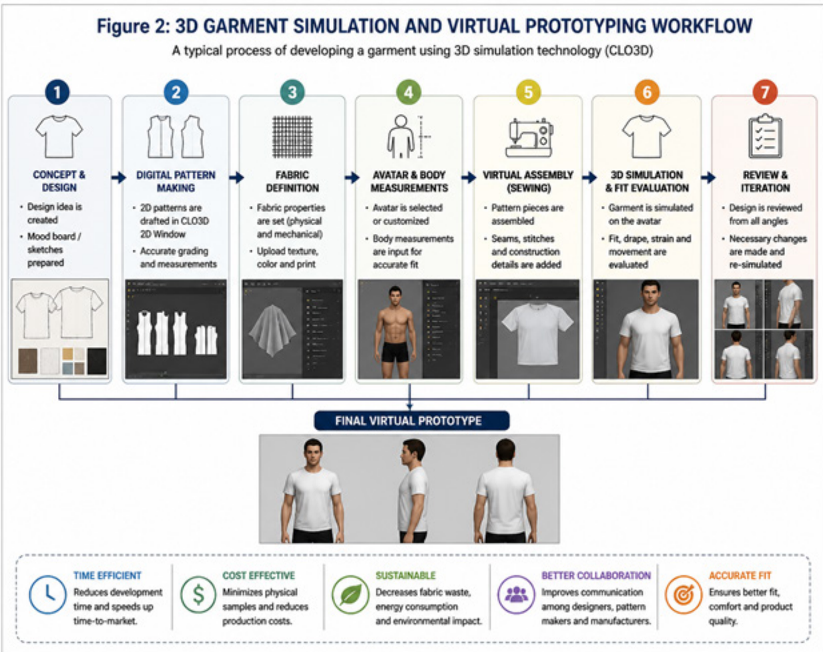

Figure 2 Workflow of 3D garment simulation and virtual prototyping.

Source: Author's own illustration.

Several studies highlight the role of virtual prototyping in improving decision-making during the early stages of product development. By enabling rapid design iteration, 3D simulation reduces the risk of costly errors and facilitates experimentation with different styles, materials, and constructions.[24] Moreover, virtual prototypes can be easily shared across teams, supporting collaborative evaluation and feedback.

Despite these advantages, the reliability of virtual prototyping remains dependent on the accuracy of input parameters and system calibration. Inaccurate fabric data or simplified simulation models can lead to discrepancies between virtual and physical outcomes. Therefore, ongoing research focuses on improving simulation accuracy and validating digital results against real-world measurements.[24]

Application of CLO3D in garment design

CLO3D is widely recognized as one of the leading software solutions for 3D garment simulation, offering a comprehensive set of tools for digital apparel development.[25]

The platform enables users to create patterns, assign fabric properties, and simulate garments on customizable avatars within an interactive environment. Its user-friendly interface and advanced simulation capabilities have contributed to its widespread adoption in both academic and industrial settings.[26] Research on CLO3D applications demonstrates its effectiveness in enhancing design visualization and improving workflow efficiency. Designers can quickly modify patterns and observe the impact of changes in real-time, allowing for more precise control over garment construction. Additionally, CLO3D supports the integration of technical specifications, enabling accurate communication between design and production teams.[27]

Studies also highlight the importance of CLO3D in supporting remote collaboration and digital sampling. Virtual garments can be shared with stakeholders across different locations, reducing the need for physical sample transportation and accelerating the approval process. This capability has become particularly relevant in the context of globalized supply chains and distributed production systems.

However, some limitations have been identified in the use of CLO3D, particularly regarding the simulation of complex fabrics and intricate garment details. While the software performs well for standard materials and basic constructions, achieving high levels of realism for specialized fabrics may require additional calibration and expertise. These challenges underscore the need for continued refinement of simulation tools and methodologies.

Fabric simulation and material properties

Accurate representation of fabric behavior is a fundamental requirement for effective 3D garment simulation. Fabric properties such as weight, thickness, elasticity, bending stiffness, and friction significantly influence how a garment drapes and fits on the body. Therefore, precise input of these parameters is essential for generating realistic simulation results.[28]

Existing literature emphasizes the use of both experimental and digital methods for determining fabric properties. Physical testing methods, such as tensile and bending tests, provide reliable data but may be time-consuming and resource-intensive. Alternatively, digital estimation techniques offer greater convenience but may lack the same level of accuracy. As a result, a combination of approaches is often recommended to ensure optimal simulation outcomes. Research also explores the relationship between fabric properties and perceived garment quality. Studies indicate that even small variations in material parameters can significantly affect the visual appearance and performance of a garment in a virtual environment. Consequently, improving the accuracy of fabric simulation remains a key area of focus in apparel technology research.

Avatar customization and fit evaluation

The accuracy of garment fit in 3D simulation depends largely on the representation of the human body. Avatar customization allows designers to create digital models based on specific body measurements, enabling more precise fit evaluation. Anthropometric data plays a crucial role in this process, as it ensures that virtual garments are tested against realistic body dimensions.[29] Recent studies highlight the importance of incorporating population-specific anthropometric data to improve fit accuracy. Standard sizing systems often fail to account for variations in body shape and proportions across different demographic groups. By using customized avatars, designers can better address these variations and develop garments that meet the needs of target consumers.[2,30]

Fit evaluation in a virtual environment involves analyzing factors such as garment ease, tension distribution, and alignment with body contours.[31,32] Advanced simulation tools provide visual indicators, such as strain maps, which help identify areas of tightness or looseness. These features enable designers to make informed adjustments and optimize garment fit before production. Nevertheless, challenges remain in accurately capturing dynamic body movement and soft tissue behavior. While current avatar models provide a static representation of the human body, ongoing research aims to incorporate more realistic motion and deformation to enhance fit analysis.[33]

Sustainability in digital apparel development

Sustainability has become a central concern in the apparel industry, driven by increasing awareness of environmental and social impacts. Traditional garment development processes contribute to significant material waste, energy consumption, and carbon emissions, particularly due to repeated sampling and transportation.[34,35]

Digital apparel development offers a promising solution to these challenges by reducing reliance on physical prototypes. Virtual prototyping minimizes fabric waste and decreases the need for sample production, thereby lowering resource consumption. Additionally, digital workflows reduce the environmental impact associated with shipping samples between different locations.

Studies indicate that the adoption of 3D simulation technologies can contribute to more sustainable design practices by enabling efficient resource utilization and reducing production waste. Furthermore, digital tools support the exploration of alternative materials and design strategies, promoting innovation in sustainable fashion.[36]

However, the environmental benefits of digital technologies must be considered alongside their energy requirements and technological limitations. While virtual systems reduce physical waste, they rely on computational resources that may have their own environmental impact. Therefore, achieving sustainability in digital apparel development requires a balanced and holistic approach.

Summary of literature

The reviewed literature demonstrates that 3D garment simulation and virtual prototyping have become integral components of modern apparel development. Technologies such as CLO3D offer significant advantages in terms of design efficiency, visualization, and sustainability. At the same time, challenges related to simulation accuracy, fabric representation, and fit evaluation highlight the need for continued research and development.

Overall, existing studies provide valuable insights into the potential of digital tools in apparel design but reveal a gap in detailed, garment-specific technical analysis. This underscores the importance of further investigation into structured workflows and practical applications, particularly in the context of men's T-shirt development within a CLO3D environment.

Methodology

This study adopts a simulation-based experimental approach to analyze the development of a men's T-shirt within a CLO3D virtual environment. The methodology is organized through a structured digital workflow that systematically replicates the major stages of apparel product development, beginning with digital pattern construction and ending with final garment visualization and rendering. The entire workflow was conducted within a controlled virtual simulation environment to maintain consistency in garment construction, fit evaluation, fabric behavior analysis, and rendering conditions.

The research methodology integrates digital pattern making, avatar customization, fabric property assignment, sewing simulation, fit analysis, and virtual prototyping into a unified workflow. This approach enables efficient design modification, real-time visualization, and iterative fit correction while minimizing dependency on physical sample production (Table 1).

Table 1 Workflow stages and evaluation parameters in CLO3D-based men's T-shirt development

Workflow stage	Input/data required	Output/evaluation
Digital pattern development	Chest, shoulder, sleeve, and garment length measurements; seam allowance and ease values	Front, back, and sleeve pattern components
Avatar customization	Male anthropometric measurements and target body size	Measurement-based virtual avatar model
Fabric assignment	Cotton jersey GSM, thickness, stretch, bending, shear, and friction parameters	Realistic drape and surface behavior
Simulation	Sewing relationships and arrangement points	Simulated T-shirt draped on avatar
Fit analysis	Strain map, pressure/tension indicators, and visual inspection	Pattern adjustment and fit correction decisions
Final rendering	Lighting settings, camera view, and material appearance	Final digital garment prototype for documentation

Source: Author's own compilation

Materials and equipment

The virtual development and simulation process was conducted using CLO3D Version 7.0, a three-dimensional apparel design and virtual prototyping software widely utilized in digital garment engineering and apparel product development. The software was used for digital pattern drafting, sewing simulation, avatar customization, fabric property assignment, fit analysis, and final garment rendering.

A standard male avatar available within the CLO3D avatar library was customized according to medium-size anthropometric measurements to ensure realistic fit evaluation. The avatar dimensions were adjusted using standard men's apparel sizing measurements relevant to T-shirt development.

A single jersey knitted cotton fabric commonly used in men's casual knitwear was selected for simulation. Fabric parameters were assigned and calibrated through the CLO3D material editor to achieve realistic drape behavior and simulation accuracy. The selected fabric properties included fabric composition, weight, thickness, elasticity, and surface behavior.

The technical specifications used in the simulation process are summarized in Table 2.

Table 2 Materials and equipment specifications used in the study

Component	Specification
Software	CLO3D Version 7.0
Garment type	Men's basic T-shirt
Fabric construction	Knit
Fabric composition	100% Cotton
Fabric type	Cotton jersey
Fabric weight	180.808 g/m^2
Fabric thickness	0.78 mm
Stretch behavior	Medium stretch
Avatar gender	Male
Avatar size	Medium (M)
Chest circumference	96.52 cm
Waist circumference	82.55 cm
Across shoulder	44.13 cm
CB neck to waist	48.58 cm
Neck to wrist	87.31 cm
Bicep circumference	32.39 cm
Hand circumference	19.65 cm
Height	187.96 cm
Sizing standard	Standard men's apparel sizing

Accurate fabric parameter assignment is essential for achieving realistic garment drape and simulation behavior.

Figure 3 illustrates the cotton jersey fabric properties configured within the CLO3D material editor for the virtual T-shirt simulation.

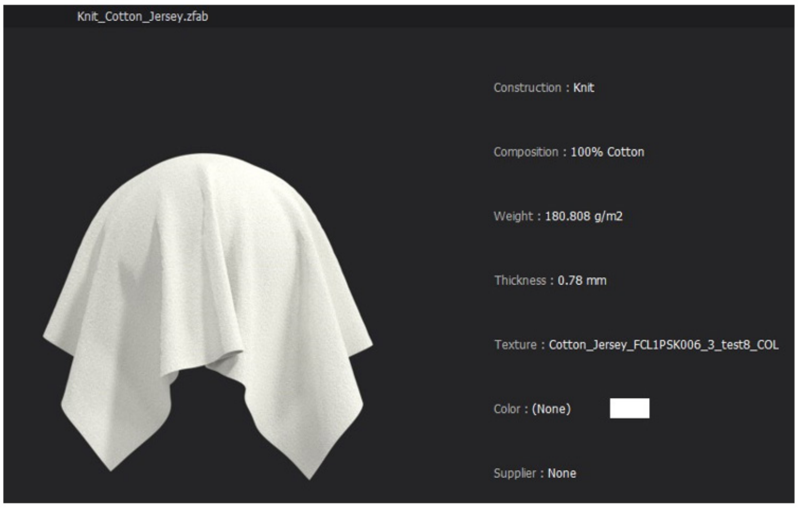

Figure 3 Fabric property configuration in CLO3D.

Source: Author's own screenshot from CLO3D Version 7.0.

Avatar customization based on anthropometric measurements plays an important role in realistic virtual fit evaluation.

Figure 4 shows the customized male avatar measurements used in the simulation environment.

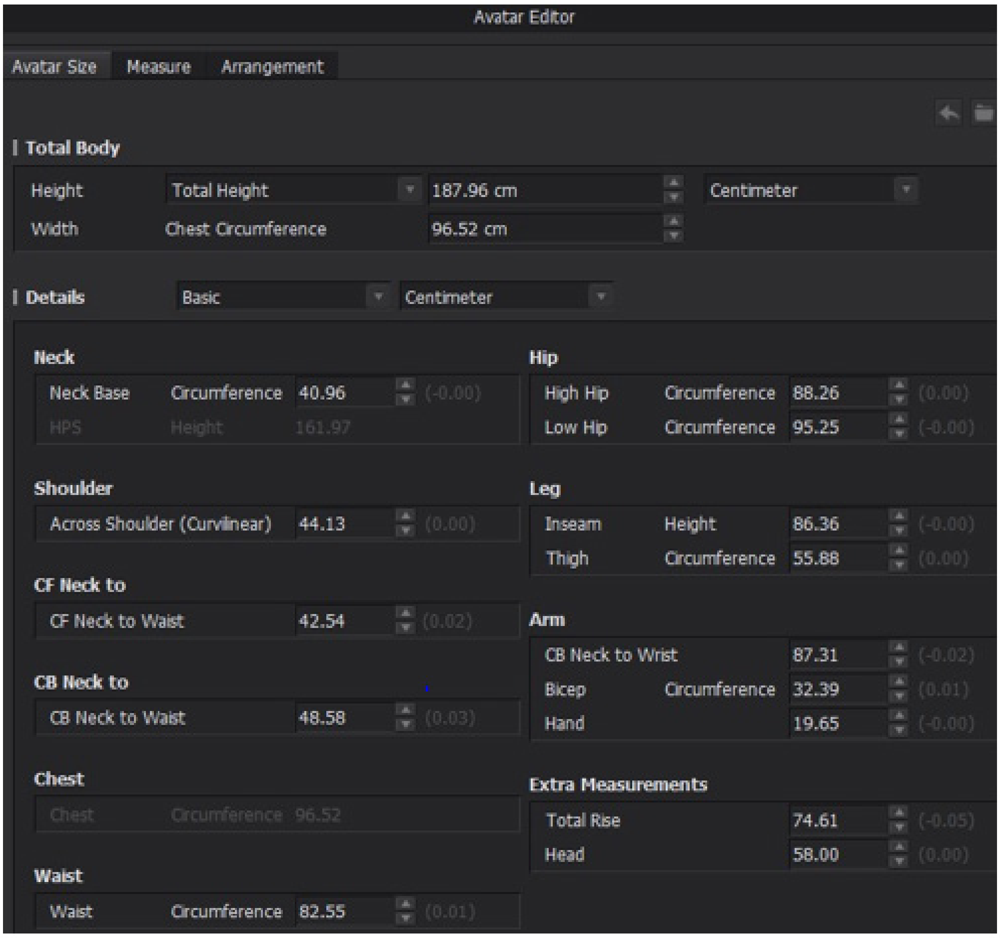

Figure 4 Customized male avatar measurements in CLO3D.

Source: Author's own screenshot from CLO3D Version 7.0.

Citation: Habib A, Mesu KK, Jihad JA, et al. Technical evaluation of men's T-shirt development in a CLO3D virtual environment. *J Textile Eng Fashion Technol.* 2026;12(3):215–226. DOI: 10.15406/jteft.2026.12.00467

The digital T-shirt pattern was developed based on standard medium-size block measurements commonly used in men's apparel production. The key pattern dimensions used for digital pattern construction in CLO3D are presented in Table 3.

Table 3 Block measurements for men's T-shirt. Unit System: Centimeter (cm)

POM	Measurement Name	M
HC	Half Chest	52
HBO	Half Bottom Opening	52
HPSF	Front Length from HPS	73
FND	Front Neck Drop	10
BND	Back Neck Drop	3
SD	Shoulder Drop	4
AHS	Arm Hole Straight	24
NW	Neck Width	19
FS	Full Shoulder	46
AF	Across Front/Back	42
SSL	Sleeve Length	23
SSO	Half Sleeve Opening	18.5
SW	Half Sleeve Width	22
SCH	Sleeve Cap Height	13.5
NRL	Neck Rib Length	48
NH	Neck Rib Height	2

Digital pattern development

The initial stage involved the development of a basic men's T-shirt pattern using the 2D Pattern Window in CLO3D. Standard block pattern construction techniques were applied based on established men's sizing systems. Key measurements such as chest circumference, shoulder width, garment length, sleeve length, and neckline dimensions were incorporated during the drafting process.

The primary pattern components, including the front, back, neck rib and sleeves, were drafted separately and refined through the addition of seam allowances and appropriate ease values. These adjustments ensured realistic garment fit and balanced silhouette formation during simulation. The digital pattern drafting process provided precise control over garment dimensions and facilitated efficient modification during subsequent stages. The digital pattern development stage involves drafting the major garment components required for T-shirt construction. Figure 5 presents the digital pattern pieces created using the CLO3D 2D Pattern Window.

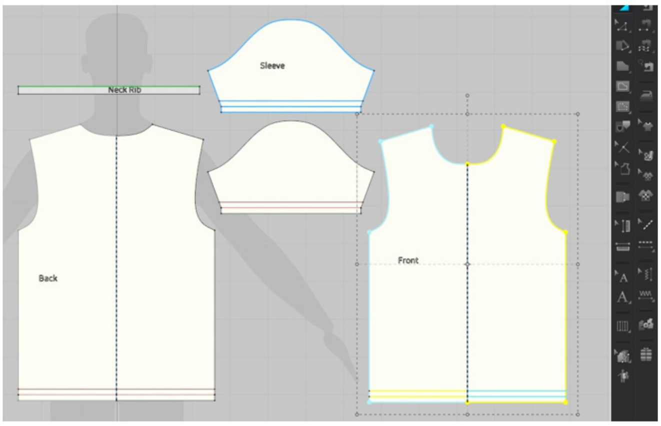

Figure 5 Digital pattern development in CLO3D.

Source: Author's own screenshot from CLO3D Version 7.0.

Pattern arrangement and sewing

Following pattern development, the individual pattern components were arranged around the avatar within the virtual workspace using arrangement points and positioning tools. Sewing relationships were established by assigning stitching lines between corresponding pattern edges through CLO3D's sewing functions.

Structural garment connections, including shoulder seams, side seams, neckline attachment, and sleeve assembly, were configured to replicate conventional garment construction techniques. Accurate sewing alignment ensured structural integrity and prevented simulation instability during the draping process. Following pattern development, the garment components were arranged and virtually stitched within the simulation workspace. Figure 6 illustrates the arrangement and sewing configuration used for assembling the digital T-shirt.

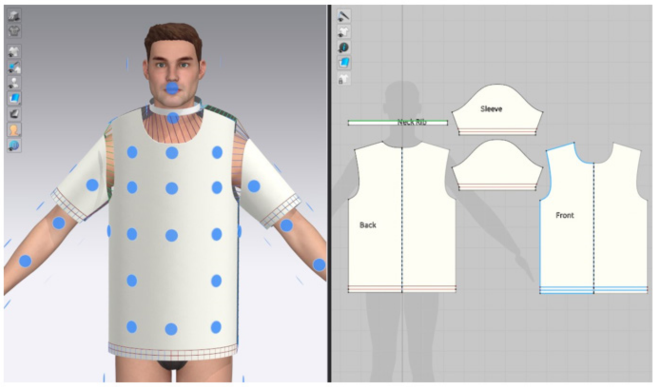

Figure 6 Digital pattern development and arrangement in CLO3D.

Source: Author's own screenshot from CLO3D Version 7.0.

Avatar selection and body measurement input

A male avatar was selected from the CLO3D avatar library and customized according to standard anthropometric measurements representative of the target consumer group. Body dimensions including chest circumference, waist circumference, shoulder width, arm measurements, and height were adjusted to create a realistic virtual fit model.

The use of measurement-based avatar customization provided a reliable foundation for evaluating garment fit, silhouette balance, and proportional accuracy within the simulation environment.

Fabric property assignment

A cotton jersey knit fabric commonly used in men's T-shirt manufacturing was assigned to the digital garment. Material parameters were defined within the CLO3D material editor to replicate realistic fabric behavior during simulation. Key fabric properties included weight, thickness, elasticity, bending stiffness, shear resistance, and surface friction. These parameters significantly influenced garment drape, wrinkle formation, stretch behavior, and overall visual realism. Accurate material calibration was essential for achieving reliable simulation results consistent with physical garment behavior.

3D simulation and real-time evaluation

The garment simulation was activated within the 3D workspace, allowing the assembled digital garment to drape naturally over the customized avatar. Real-time simulation enabled continuous observation of garment behavior under static conditions. Evaluation criteria included wrinkle distribution, tension balance, silhouette

Citation: Habib A, Mesu KK, Jihad JA, et al. Technical evaluation of men's T-shirt development in a CLO3D virtual environment. *J Textile Eng Fashion Technol.* 2026;12(3):215–226. DOI: 10.15406/jteft.2026.12.00467

formation, fit conformity, and garment alignment relative to body contours. The interactive simulation environment increased the effectiveness of iterative clothing development and made it easier to see design changes instantly. To assess the garment drape and fit behavior on the personalized avatar, the assembled garment was simulated within the 3D environment. Figure 7 depicts the men's T-shirt simulation in the CLO3D virtual workspace.

Figure 7 3D garment simulation in CLO3D.

Source: Author's own screenshot from CLO3D Version 7.0.

Fit analysis and pattern adjustment

Fit evaluation was conducted using both visual inspection and analytical tools available in CLO3D, including stress maps, strain maps, and pressure/tension indicators. Critical garment regions such as the neckline, shoulder area, armhole, chest region, and torso balance were analyzed to identify fitting inconsistencies. Minor fitting discrepancies observed during simulation were corrected through iterative pattern adjustment within the 2D workspace. The modified patterns were re-simulated until an acceptable balance between fit, comfort, and appearance was achieved. This iterative process demonstrated the flexibility and efficiency of virtual prototyping compared to traditional physical sampling methods. Strain mapping tools were used to identify tension distribution and fitting conditions during garment simulation. Figure 8 presents the strain map analysis of the simulated T-shirt.

Figure 8 Fit analysis using strain mapping.

Source: Author's own screenshot from CLO3D Version 7.0.

Stress mapping was applied to identify localized pressure areas and fitting inconsistencies during virtual fit evaluation.

Figure 9 illustrates the stress map analysis generated within the CLO3D environment.

Figure 9 Fit analysis using stress mapping.

Source: Author's own screenshot from CLO3D Version 7.0.

Combined strain and pressure mapping tools were utilized to evaluate garment balance, comfort, and fitting accuracy.

Figure 10 demonstrates the integrated fit analysis performed during simulation.

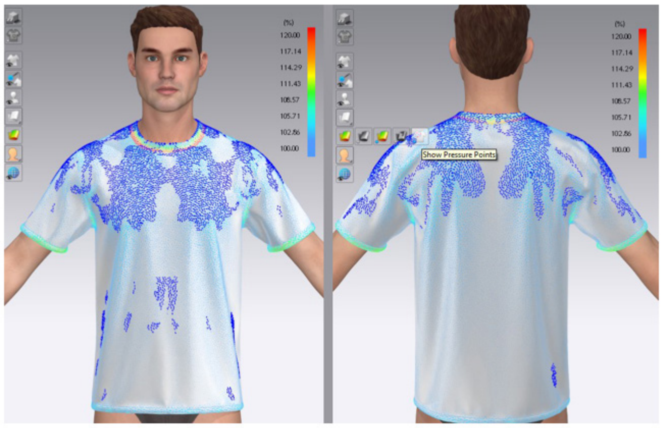

Figure 10 Fit analysis using strain and pressure mapping.

Source: Author's own screenshot from CLO3D Version 7.0.

Visualization and final rendering

In the final stage, high-resolution rendered outputs were generated for documentation and evaluation purposes. Multiple garment perspectives, including front, back, and side views, were captured to analyze overall garment appearance and fit consistency.

Rendering parameters such as lighting, shading, camera angle, and material appearance were optimized to improve visual clarity and realism. The final rendered outputs served as digital prototypes for technical evaluation, communication, and presentation purposes. Final rendering was conducted to generate high-resolution visual outputs for documentation and evaluation purposes. Figure 11 presents the final rendered digital prototype of the men's T-shirt developed in CLO3D.

Citation: Habib A, Mesu KK, Jihad JA, et al. Technical evaluation of men's T-shirt development in a CLO3D virtual environment. *J Textile Eng Fashion Technol.* 2026;12(3):215‒226. DOI: 10.15406/jteft.2026.12.00467

Figure 11 Final rendered men's T-shirt prototype.

Source: Author's own rendering from CLO3D Version 7.0.

Limitations of simulation

Although CLO3D provides realistic visualization and efficient virtual prototyping capabilities, certain limitations remain within the simulation environment. The accuracy of garment behavior depends heavily on the precision of fabric parameter input and avatar configuration. Additionally, dynamic body movement and complex fabric interactions may not be replicated perfectly in virtual simulations. Therefore, physical validation remains important for final production accuracy and quality assurance.

Summary of method

The methodology integrates digital pattern construction, virtual assembly, avatar customization, fabric simulation, fit analysis, and high-resolution rendering within a unified CLO3D environment. By replacing conventional physical sampling with a virtual prototyping workflow, the study enables efficient design iteration, improved technical accuracy, and reduced material dependency.

The structured simulation-based workflow demonstrates the effectiveness of digital garment development in enhancing apparel design efficiency, supporting sustainable practices, and improving communication during men's T-shirt product development.

To improve the reliability of the simulation workflow, garment fit and drape behavior were evaluated through repeated iterative simulation cycles using strain mapping, stress mapping, and visual fit inspection tools available within CLO3D. The simulation outcomes were compared against standard apparel construction principles and expected physical garment behavior to ensure technical consistency throughout the development process.

Results and discussion

Overview of simulation outcomes

The application of the CLO3D-based workflow resulted in the successful development of a virtual men's T-shirt prototype. Each stage of the methodology, including pattern creation, assembly, fabric assignment, and simulation processes, was executed systematically allowing for continuous observation and evaluation of garment behavior. The digital environment enabled immediate visualization of design changes, supporting an efficient and controlled development process.

The final simulated garment demonstrated stable construction, realistic drape, and satisfactory alignment with the avatar's body structure. No major structural distortions or simulation errors were observed, indicating that the workflow was technically consistent and suitable for garment development analysis.

Pattern accuracy and garment construction

The digital pattern developed in the initial stage produced a structurally balanced garment. The front and back panels aligned correctly at the shoulder and side seams, while sleeve attachment was executed without distortion. The inclusion of appropriate seam allowance and ease values contributed to proper garment shaping and ensured that the T-shirt maintained its intended silhouette during simulation. The sewing configuration within the virtual environment accurately replicated conventional garment construction logic. This confirms that digital pattern-making tools in CLO3D are capable of producing technically viable garment structures comparable to physical prototypes.

Fabric simulation and drape behavior

The assigned knit fabric (cotton jersey) exhibited realistic drape characteristics within the simulation. The garment conformed naturally to the avatar's body, showing smooth surface flow and appropriate wrinkle formation in areas such as the underarm and waist region. Fabric parameters such as elasticity and bending stiffness significantly influenced the final appearance of the garment. Higher elasticity contributed to improved body conformity, while appropriate stiffness ensured structural stability without excessive deformation. These findings highlight the importance of accurate material parameter input in achieving reliable simulation results. The observed drape behavior indicates that fabric elasticity and bending resistance are among the most influential parameters affecting simulation realism in knit garment development. This finding supports previous research emphasizing the importance of accurate mechanical fabric characterization in virtual garment simulation systems.

Fit evaluation and adjustment

Fit analysis revealed that the initial simulation provided a generally acceptable fit, with minor adjustments required in specific areas. Slight tension was observed around the shoulder and armhole regions, indicating the need for increased ease. After iterative pattern modification, the garment achieved improved balance and comfort. The iterative correction process demonstrates the practical advantage of virtual prototyping over conventional sampling workflows, where repeated physical corrections would require additional production time, fabric consumption, and labor cost. Strain visualization tools were effective in identifying localized stress areas, allowing for targeted adjustments. The iterative process of modifying pattern dimensions and re-simulating the garment demonstrated the flexibility of the digital workflow and its capability to refine fit without the need for physical sampling.

Visualization and design communication

The final rendered outputs provided high-quality visual representations of the garment from multiple perspectives. Front, back, and side views clearly illustrated the garment's fit, proportion, and overall aesthetic. These visualizations enhance communication between designers and stakeholders by providing accurate and detailed representations of the final product. Compared to traditional sketches or 2D patterns, 3D renders offer a more comprehensive understanding of garment appearance and performance.

Efficiency of virtual prototyping

The use of CLO3D significantly reduced the time required for garment development. Design modifications were implemented and visualized instantly, eliminating delays associated with physical sample production. The virtual workflow also minimized material usage, as no physical fabric or sample garments were required during the development process. This demonstrates the potential of digital prototyping to improve efficiency while reducing production costs and environmental impact.

Comparison with traditional methods

Compared to conventional garment development, the CLO3D-based approach offers several advantages. Traditional methods require multiple physical samples to achieve an acceptable fit and design accuracy, resulting in increased time and resource consumption. In contrast, the digital workflow enables rapid iteration and immediate feedback. However, the study also identified limitations in virtual simulation. The accuracy of results depends heavily on the correct input of fabric properties, and certain complex material behaviors may not be fully replicated. Additionally, while virtual fit evaluation is effective, final validation in physical form remains necessary for production (Table 4).

Table 4 Comparison between traditional and CLO3D-based T-shirt development

Parameter	Traditional method	CLO3D workflow
Sample development	Multiple physical samples	Virtual simulation
Time consumption	High	Reduced
Material usage	High fabric consumption	Minimal physical material
Fit correction	Manual repeated adjustment	Real-time iterative correction
Communication	2D sketches/sample dependent	3D visualization
Sustainability	Higher waste generation	Reduced waste
Design flexibility	Limited	High

Key findings

The analysis of the simulation results highlights several important findings:

1) Digital pattern development in CLO3D can produce structurally accurate garments.
2) Fabric properties play a critical role in determining simulation realism.
3) Virtual fit evaluation tools enable efficient identification and correction of fitting issues.
4) The iterative simulation process enhances design flexibility and reduces development time.
5) Virtual prototyping significantly decreases material waste and supports sustainable practices.

Discussion

The findings demonstrate that CLO3D provides an effective digital environment for integrating garment design, simulation, and fit evaluation within a unified workflow. Similar observations were reported by Jevšnik et al.,[24] who emphasized that virtual prototyping significantly improves iterative garment development efficiency while reducing dependence on repeated physical sampling. The ability to perform real-time visualization and iterative pattern modification significantly improves development efficiency compared to traditional sampling-based workflows. These findings are consistent with previous studies that identified virtual prototyping as a valuable tool for reducing development time and improving communication during apparel product development. However, this study further reveals that simulation reliability is strongly influenced by the accuracy of fabric parameter calibration and avatar customization. Minor variations in elasticity, thickness, and bending stiffness produced noticeable differences in garment drape and fit behavior during simulation. This indicates that virtual garment realism is not solely dependent on software capability, but also on the technical precision of input data and user expertise.

Compared with conventional garment development methods, the CLO3D workflow demonstrated substantial advantages in iterative fit correction and visualization efficiency. Traditional product development often requires multiple physical samples to evaluate garment balance and fitting performance, whereas the digital workflow enabled immediate adjustment and re-simulation without material consumption. This highlights the practical value of digital prototyping in reducing both development cost and environmental impact.

Nevertheless, the study also identified several limitations associated with current simulation technologies. Although CLO3D effectively replicated static garment behavior, the system showed limitations in representing complex fabric deformation, dynamic body movement, and certain localized pressure behaviors. Therefore, physical validation remains necessary before final production implementation.

The study contributes to existing literature by providing a structured garment-specific technical analysis rather than a purely conceptual overview of virtual prototyping. The integration of strain mapping, stress analysis, avatar-based fit evaluation, and digital pattern correction offers practical insight into how CLO3D can support technically accurate and sustainable apparel development workflows.

Practical implications

The findings of this study demonstrate the practical applicability of CLO3D in contemporary apparel product development. The integration of virtual prototyping can support faster product approval processes, reduced physical sampling costs, improved fit evaluation, and enhanced communication among designers, manufacturers, and other stakeholders.

Furthermore, the adoption of digital garment simulation technologies contributes to sustainable apparel development by minimizing material waste, reducing sample production, and decreasing resource consumption during product development. These advantages support the transition toward more efficient, sustainable, and digitally integrated apparel production systems.

Conclusion and recommendations

Conclusion

This study provides a comprehensive technical analysis of men's T-shirt development within a CLO3D virtual environment, demonstrating the effectiveness of digital technologies in modern apparel design. By implementing a structured workflow that integrates pattern development, virtual assembly, fabric simulation, and fit evaluation, the research highlights the practical capabilities of 3D garment simulation in replicating real-world production processes.

The findings confirm that CLO3D enables the creation of structurally accurate and visually realistic garment prototypes. Digital pattern construction, combined with precise fabric property assignment, allows garments to exhibit natural drape behavior and appropriate fit on a customized avatar. The use of simulation tools, such as strain and tension analysis, further enhances the ability to identify and resolve fitting issues during the development stage.

One of the key outcomes of this study is the demonstration of improved efficiency in the design process. The ability to perform real-time adjustments and instantly visualize results significantly reduces development time compared to traditional methods. Furthermore, the elimination of repeated physical sampling contributes to reduced material consumption, supporting more sustainable production practices.

Despite these advantages, the study also identifies certain limitations associated with virtual garment simulation. The accuracy of results is highly dependent on the correct input of fabric parameters and the user's technical expertise. Additionally, while CLO3D provides a reliable platform for preliminary design and fit evaluation, physical validation remains necessary to ensure production accuracy.

The study extends existing research by presenting a garment-specific technical evaluation of CLO3D-based men's T-shirt development rather than a generalized overview of virtual prototyping. The findings demonstrate that effective integration of fabric simulation, avatar customization, and digital fit analysis can significantly improve technical decision-making during apparel product development.

Overall, the study concludes that CLO3D is a powerful tool for enhancing efficiency, accuracy, and sustainability in men's T-shirt development. Its integration into apparel workflows represents a significant advancement in digital garment engineering and offers valuable potential for future industry adoption. Future advancements in digital garment simulation and AI-assisted apparel development are expected to further enhance the accuracy, efficiency, and sustainability of virtual apparel production systems.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

Integration of digital prototyping in industry: Apparel manufacturers and designers should adopt CLO3D and similar 3D simulation tools as part of their standard development process. Integrating digital prototyping can reduce dependency on physical samples, improve workflow efficiency, and enhance communication across production stages.

Improvement of fabric data accuracy: To enhance simulation reliability, greater emphasis should be placed on the accurate measurement and input of fabric properties. The use of standardized testing methods and fabric databases can help ensure consistency between virtual simulations and physical outcomes.

Skill development and training: Effective use of CLO3D requires technical expertise in pattern making, fabric simulation, and digital tools. Training programs and academic curricula should incorporate 3D garment simulation to equip designers and engineers with the necessary skills.

Hybrid development approach: While virtual prototyping offers significant advantages, it should be combined with limited physical sampling for final validation. A hybrid approach ensures both efficiency and accuracy in the production process.

Further research on complex garments: Future studies should extend the application of CLO3D to more complex garment types, including multi-layered or structured designs. This would provide deeper insight into the capabilities and limitations of 3D simulation technologies.

Advancement of simulation technology: Software developers should focus on improving the accuracy of fabric behavior modeling, including dynamic movement and complex material interactions. Enhancements in simulation algorithms will further strengthen the reliability of virtual garment development.

Expansion of anthropometric data usage: Incorporating diverse and population-specific anthropometric data can improve fit accuracy and support inclusive design practices. Future research should explore customization based on different body types and regional sizing variations.

Acknowledgements

None.

Funding

None.

Conflicts of interest

The authors declare no conflict of interest.

References

1. Habib MA. Advancing sustainable fashion through 3D virtual design for reduced environmental impact. *J Textile Eng Fashion Technol*. 2025;11(3):135–142.
2. Choi KH. 3D dynamic fashion design development using digital technology and its potential in online platforms. *Fashion and Textiles*. 2022;9(9):1–28.
3. Power J. *Integrating 3D scanning data & textile parameters into virtual clothing*. Lugano; 2011.
4. Zangue FC. Key steps in the development of production guidelines for 3D garment simulations. *Communications in Development and Assembling of Textile Products*. 2024;5(2):131–139.
5. Ren X. Research on 3D simulation design and dynamic virtual display of clothing flexible body. *AUTEX Research Journal*. 2024;24(1):1–18.
6. Xiao Y. *Application of clothing design and production based on clothing 3D simulation technology*. 2021.
7. CLO. CLO3D resources notice 1020. 2025.
8. Singh RN, Jyoti R. The role of CLO 3D in high-end virtual fashion design. In: *Technology-Driven Market Transformations for Digital Fashion and Smart Luxury*. 2026:227–254.

9. Habib MA. A comparative study of 3D virtual pattern and traditional pattern making. *Journal of Textile Science and Technology*. 2023;10(1):1–24.

10. Fontana M. 3D virtual apparel design for industrial applications. *Computer-Aided Design*. 2005;37(6):609–622.

11. Habib MA. From sketch to garment: a digital–first workflow for women's trouser development utilizing CLO3D. *Journal of Textile Engineering & Fashion Technology*. 2026;12(3):134–143.

12. Widiyawati IN. Application of Clo3d technology in fashion vocational education in vocational schools: a systematic literature review. *International Journal of Education & Curriculum Application*. 2024;7(3):268–278.

13. Kim J. Efficient representation of garment fit with elastane fibers across yoga poses in 3D fashion design software: a preliminary study using CLO 3D software. *Applied Sciences*. 2025;15(19):1–18.

14. Style3D. What is 3D garment design and how does it transform fashion? *Style3D Blog*. 2026.

15. Salim I. Integration of digital pattern making in garment designing: a step forward towards effectiveness, accuracy and sustainability in fashion industry. *International Journal of Innovative Science and Research Technology*. 2025;10(10):549–552.

16. Sabantina L. *Enhancing realism in cloth simulation: a review of methods and issues*. 2024.

17. Hu Y. Application of CLO3D software in the teaching of garment structure drawing. *Journal of Apparel Structure*. 2022;4:14.

18. Wang Z, Tang X, Zhang X, et al. Design of customized garments towards sustainable fashion using 3D digital simulation and machine learning-supported human–product interactions. *International Journal of Computational Intelligence Systems*. 2023;16(16):1–20.

19. The Cut Design Academy. The future of fashion: how 3D apparel design is revolutionizing the industry. 2026.

20. Marzia F. 3D virtual apparel design for industrial applications. *Computer--Aided Design*. 2005;37(6):609–622.

21. Güney S. Virtualization of clothing thermal comfort in 3D simulations. *European Journal of Science and Technology*. 2021;28:29–33.

22. Xu X. Color analysis and performance optimization of 3D virtual simulation knitted fabrics. *AUTEX Research Journal*. 2025;25(1):1–9.

23. Papachristou E. A methodological framework for the integration of 3D virtual prototyping into the design development of laser-cut garments. *Journal of Engineered Fibers and Fabrics*. 2023;18:1–11.

24. Jevšnik S. 3D virtual prototyping of garments: approaches, developments and challenges. *Journal of Fiber Bioengineering and Informatics*. 2017;10(1):51–63.

25. Istituto di Moda Burgo Milano. CLO3D course: the future of digital fashion. 2026.

26. Li X. Dress-1-to-3: single image to simulation-ready 3D outfit with diffusion prior and differentiable physics. *ACM Journals*. 2025;44(4):1–16.

27. Dreamzone. CLO 3D: a complete overview and new features breakdown. 2025.

28. Dai X. Fabric mechanical parameters for 3D cloth simulation in apparel CAD: a systematic review. *Computer-Aided Design*. 2024;167.

29. Fung YW, Lim KH. Review on three-dimensional clothing modelling and digital human reconstruction for virtual try-on applications. *Multimedia Tools and Applications*. 2026;85(359).

30. Yu H. On generating realistic avatars: dress in your own style. *Multimedia Tools and Applications*. 2011;59:973–990.

31. Dustin J. Advancements in virtual garment simulation and digital fit analysis for custom fashion design. *International Journal of Fashion Design Research and Development*. 2025;2(1):1–7.

32. Lagė A. Comparative study of real and virtual garments appearance and distance ease. *Materials Science (Medžiagotyra)*. 2019;26(2):233–239.

33. Zhang M. Dynamic neural garments. *ACM Transactions on Graphics*. 2021;40(6):1–15.

34. Geneva Environment Network. Sustainable fashion updates. 2025.

35. Khan Z. Sustainable fashion trends and purchasing pattern analysis for textiles and apparel: an encouragement for eco-innovation. *Sustainable Futures*. 2025;9:1–10.

36. Zhu XJ. An interactive clothing design and personalized virtual display system. *Multimedia Tools and Applications*. 2018;77:27163–27179.