3D CLOTHING VISUALIZATION AS AN INNOVATIVE TOOL FOR THE FASHION INDUSTRY

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Summary

The study focuses on the integration of three-dimensional (3D) visualization as an innovative tool for transforming design practices in the fashion industry. The increasing digitalization of manufacturing processes and the globalization of the economy present new challenges for the personalization of clothing. 3D design and printing technologies enable the creation of removable decorative elements, facilitating the customization of standard clothing models. *This study aims* to conduct a comprehensive analysis of the use of three-dimensional visualization as an innovative tool for transforming design practices in the fashion industry, taking into account aesthetic, technological, and socio-cultural factors. *The methodological* framework is based on an interdisciplinary synthesis of visual semiotics and the conceptual foundations of virtual materialism, enabling a multifunctional approach to the analysis of the phenomenon. Particular attention is given to the application of 3D visualization in creating virtual prototypes that allow designers to evaluate the shape, texture, and materials of future garments. This approach optimizes the design process, reduces time and material costs, and minimizes textile waste, aligning with the principles of sustainable development. The study examines the technological aspects of 3D modeling, including the use of software such as Marvelous Designer and ZBrush for developing digital patterns, sculpting surface details, and material texturing.

The analysis explores the impact of aesthetic, technological, and socio-cultural factors on the adoption of 3D technologies. Using the case of the Limerense_com brand, the research highlights innovative approaches to producing digital clothing analogues that function as both commercial products and conceptual artifacts. The findings underscore the epistemological shifts in materializing aesthetic narratives within the postmodern fashion industry, where physicality is supplanted by digital simulations offering high perceptual fidelity, commercial viability, and artistic expressiveness.

Key words: digital prototyping, garment customization, sustainable design, virtual modeling, textile simulation, material optimization, design automation, creative industries, fashion digitalization.

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1. Introduction

The development of science and innovative technologies has become a powerful driver for the adoption of 3D design and printing in the apparel industry.The widespread digitalization of manufacturing and the globalization of the economy–aimed at accelerating and intensifying the growth of the fashion industry–have complicated the implementation of personalized models. Consumers are increasingly being offered fast fashion clothing in the budget price segment to diversify their wardrobes. Research has shown that the accessibility of digital 3D graphic software, integrated with 3D printers, has facilitated the introduction of additive printing

technologies in garment production. These technologies enable the printing of removable decorative elements, the flexible combination of which allows consumers to individualize standard clothing models. Since 2011, the fashion industry has been promoting innovative products–fashion items such as clothing, external corsets, costumes, footwear, headwear, accessories, and jewelry–created using volumetric (3D) printing techniques *(Hu et al., 2023).*

Three-dimensional visualization is currently one of the most promising information technologies used across various industries. Its applications are quite extensive, as the representation of spatial objects in a 3D environment is the most familiar, intuitively understandable, and visually accessible form for human perception. There are various types of 3D visualization and virtual reality systems that provide users with the ability to perceive information about an object in a volumetric and objective manner. 3D visualization systems serve as an effective tool for designing and evaluating garment constructions in the apparel industry, through the use of an informational 3D model – a virtual prototype of the product that contains a comprehensive set of data on the properties and characteristics of the designed object.

Visualization of a product in a 3D editor enables the realistic rendering of shape, color, and material texture, thereby offering specific functional advantages in the field of apparel design and manufacturing, such as: visual formulation of the product's appearance; use of the 3D model to adjust the external shape and construction of the garment; virtual fitting on a specific body figure.

Key priorities in the development of visualization methods for the garment shaping process include: studying the geometric features of the object's form and defining the methods for its generation and display; analyzing the topographic features of the object's surface and determining methods for their representation and visualization *(Chittaro & Corvaglia, 2003).*

At present, research into the factors influencing garment shaping has selectively focused on individual properties and specific product categories, leaving many issues related to the visualization of spatial garment forms with complex surface topographies underexplored. Such garments include:

1) items made from fabrics like drape or bouclé, whose surfaces exhibit irregular textures and complex fabric structures that affect visual perception of form;

2) multi-layered garments, where surface shape is influenced by the properties of the material package and the degree of contact with areas of the human body *(Choi, 2019).*

The objective of this scholarly inquiry is to undertake a comprehensive and multi-tiered analysis of the application of three-dimensional visualization as an innovative instrument for the transformation of design practices within the fashion industry, taking into account the syncretic interplay of aesthetic, technological, and socio-cultural factors. Within the framework of this aim, the following research tasks are delineated: the identification of key paradigms conditioning the integration of 3D visualizations into fashion design processes; the elucidation of cognitive and communicative mechanisms underlying visual construction of fashion products in digital environments; and the extrapolation of innovative practices toward forecasting market dynamics in the context of digitalization. The methodological foundation rests upon an interdisciplinary synthesis of aesthetic-philosophical hermeneutics, visual semiotics, and the conceptual framework of virtual materialism, thus enabling a polyfunctional approach to the study of the phenomenon. The logic of material presentation is determined by a gradual unfolding of discourse: from the ontological premises of visuality in fashion to the applied analysis of digital case studies that allow for a critical reflection on the prospects of post-physical clothing within the realm of virtualized aesthetic communication.

2. Technological Foundations of 3D Clothing Visualization

In today's environment, the success of entrepreneurs largely depends on their ability to collect and process information. Across the globe, there is a rapid increase in computerization within manufacturing. The implementation of computer technologies enhances both efficiency and labor productivity. Lagging behind in high-tech development can result in significant economic setbacks. One of the key demands of the apparel market for garment enterprises is high mobility and efficiency in design processes. Rapid technological advancements, market saturation with goods, and the fast pace of changing fashion trends have led to evolving consumer expectations regarding product variety and pricing. These requirements can be addressed more quickly and with higher quality through the use of automated design systems (CAD) *(Kolosnichenko et al., 2020: 137)*. A sharp leap in product quality and competitiveness is achieved through the adoption of new design technologies. Therefore, improving the design process of garment construction is of primary importance for enhancing product quality.

Among the most advanced and promising technologies in clothing design and manufacturing is 3D visualization. This approach enables the creation of digital prototypes without the need for physical samples, significantly reducing time and resource consumption. Through 3D modeling, designers can observe in real time how a garment will appear on a virtual mannequin, assess fit, proportions, fabric drape, and easily alter colors, textures, or decorative elements *(Park, 2018)*. This allows for a swift response to changing fashion trends and individual customer preferences, while also fostering effective communication between all participants in the garment development process – from designer to manufacturer. The application of 3D visualization in the garment industry also contributes to the implementation of sustainable development principles, as it reduces the amount of materials used for sample creation and minimizes textile waste *(Liu, 2022)*.

Research has shown that the primary direction for improving the garment design process is its automation. The process of creating garments – particularly those with decorative elements – is highly resource-intensive and laborious, often requiring multiple sample iterations and artistic board reviews based on quality indicators. This limits the potential for fully automated end-to-end design. The complexity of the design object is driven by several factors, including: the need to analyze sketch defects on a mannequin; rapid fashion changes; a wide variety of sewing materials with differing properties; a broad spectrum of creative tasks.

An automated system equipped with modern technology is capable of performing nearly all stages of the design process. However, technical equipment alone depends on the manufacturer's objectives, the specifics of the production facility, the structural complexity of the model, and the intellectual capabilities and skills of the workforce. Basic pattern construction, structural modeling according to body measurements, application of decorative elements in line with consumer and market requirements, pattern grading, fabric consumption calculations, and other aspects of garment construction can all be effectively carried out within automated design systems.

Three-dimensional (3D) clothing visualization constitutes a technologically intensive domain wherein heterogeneous engineering and mathematical constructs coalesce, encompassing topoinvariant modeling, biharmonic surface approximation, and variational mapping of the physico-mechanical attributes of textile fibers within a virtualized environment. The integration of complex three-dimensional geometric structures–particularly polygonal decomposition with multilevel level-of-detail (LOD) optimization–facilitates hyper-detailed shape formation of simulated garments, taking into account quasistatic deformations and the nonlinear responses

of textile substrates to dynamic vector fields *(Choi, 2022).* Within the framework of digital three-dimensionality, a synchronized interface is established between the parametric mesh of the avatar and the kinematically conditioned surface topography of the garment, modeled in real time through energetically informed methods such as branched-vector skinning or positional retargeting based on harmonic functions. Thus, 3D clothing visualization transcends mere visual representation, evolving into a high-fidelity simulational paradigm capable of emulating the nuanced behavioral characteristics of fabric under the influence of complex emergent interactions with the body and ambient environment.

3. Innovative Applications of 3D Visualization in the Fashion Industry

In the context of transformational shifts characterizing post-industrial society, the integration of three-dimensional visualization into the fashion sector represents a symbiosis of technological progress and aesthetic experimentation *(Porterfield & Lamar, 2017).* This phenomenon not only expands the boundaries of traditional perceptions of the creative process but also initiates a metamorphosis in conceptual approaches to the development, production, and presentation of textile and design products.

– three-dimensional visualization introduces fundamental changes to the methodological foundations of the fashion industry, particularly in the aspect of product development. Through comprehensive tools such as parametric fabric modeling and interactive testing of material properties, designers can achieve a high degree of analytical precision in garment design. This ensures harmony between functionality and aesthetics, minimizing anthropometric inaccuracies and production risks;

– the application of three-dimensional technologies enables a radical optimization of resources through the digitization of preliminary stages of clothing creation. This significantly reduces the volume of physical prototyping, which in traditional practice is exceedingly costly in both material and temporal dimensions. Thus, innovations promote not only cost rationalization but also a reduction of the carbon footprint within the production cycle;

– modern interactive platforms integrating 3D visualization create new modalities of interaction between manufacturers and end-users. Through digital showrooms and virtual presentations, consumers can assess multidimensional aspects of products, including their textural characteristics, fabric dynamics, and ergonomic design in a virtual environment, significantly enhancing brand trust and engagement;

– the use of 3D visualization is a decisive factor in shaping the paradigm of sustainable development within the fashion industry. Virtual model testing and their digital refinement prevent excessive material waste, substantially reducing ecological impact. This, in turn, fosters the popularization of conscious consumption concepts and circular economy principles;

– by employing 3D technologies, designers can incorporate multicultural motifs and symbolism into fashion collections without the constraints of technical or economic limitations. The virtual space serves as a laboratory for synthesizing aesthetic traditions and innovative techniques, stimulating the expansion of creative thinking horizons *(Li et al., 2024; Tuan et al., 2021).*

3D clothing visualization represents the future of fashion. With current advancements in this technology, there is a vast array of opportunities for creating impressive new products and materials. 3D visualization is primarily used for accessories and conceptual sculptural pieces. Despite their originality and depth, these developments are not always functional, wearable, or easy to move in *(Papachristou & Anastassiu, 2022).* The described tools for developing design

concepts in costume design are rooted in architectural design traditions and enable the production of relevant and original fashion models tailored for the mass market. This is expected to significantly impact online retail and the fashion industry as a whole in the near future *(Ma et al., 2021)*. Thus, maintaining standards while pushing the boundaries of design activity is the result of interdisciplinary collaboration based on the convergence of fashion design, architecture, and industrial design. Collections by many costume designers are increasingly noted for their use of these technologies and for incorporating parametric design.

Within the framework of a transdisciplinary analysis of the synergistic interplay between visual technologies and contemporary modalities of material design, 3D visualization emerges not merely as a tool of projective display but as a paradigmatic construct of post-metaphysical conceptualization, wherein clothing is apprehended as a phenomenon situated at the intersection of digital ontology, aesthetic affect, and cognitive modeling *(McQuillan, 2020; Waymouth et al., 2021)*. Accordingly, the table below serves as an analytic-categorical framework intended to structure the complex dynamics of techno-aesthetic implementations within the fashion industry, elucidating their capacity to transgress traditional notions of corporeality, authorship, and materiality through the lens of simulacral, interface-driven, and hermeneutic methodologies (Table 1).

Categorical Domain	Techno-aesthetic Implementation	Epistemological Implications
Virtual Morphogenesis of Garments	Integration of parametric 3D models with mutable topology into fashion design, aiming at a reflexive deconstruction of canonical textile configurations.	Initiates a decorporealized perception of form as a fluctuating category, unconstrained by material paradigms.
Hyperrealistic Texturization of Fabrics	Application of spectroscopic light-reflection models to achieve hyperrealistic simulation of textile surfaces in digital prototypes.	Provokes an ontological erasure of the boundary between material and simulated, whereby fabric becomes a metaphysical illusion.
Algorithmic Customization of Silhouettes	Utilization of adaptive visual environments responsive to anthropometric vectors, representing corporeality as a dynamic, multimodal phenomenon.	Leads to a radical reconfiguration of standardized sizing systems toward post-industrial individuation.
Transmedia Presentation of Collections	Audiovisual conversion of 3D fashion imagery into VR/AR environments to establish immersive narratives that de-technologize conventional fashion shows.	Catalyzes the emergence of a new consumer aesthetics where clothing exists more as an emotional event than a functional artifact.
Cognitive Modeling of Design Processes	Implementation of neuroevolutionary 3D systems for generative fashion construction based on empirical, semiotic, and behavioral consumer patterns.	Generates epistemological ambiguity of authorship in design, wherein the boundary between creator and simulator becomes conceptually unfixed.

In conclusion, three-dimensional visualization in the fashion sector is not only a technological breakthrough but also a means of conceptual reflection that defines new trajectories

for its development. With the unique potential of this technology, the industry is empowered to transform the process of garment creation into a harmonious symbiosis of art and science, responding adeptly to the challenges of a globalized society.

4. Current Challenges and Strategic Prospects for the Development of 3D Visualization Technologies

In the context of the relentless dynamics of post-industrial society and the pervasive digitalization of the creative industries, the phenomenon of 3D visualization within the fashion design sector emerges not merely as a factor of modernization, but as a paradigmatic shift in the methodology of design, prototyping, and product presentation. Of particular interest is the implementation of virtual modeling practices by the innovative fashion brand Limerense_com, which utilizes advanced visualization platforms to create digital clothing analogues functioning simultaneously as conceptual artifacts and commercial entities *(Limerense_com, 2025).*

The initial stage in the development of such a digital product involves the construction of electronic patterns using Marvelous Designer software, which, due to its topological precision, allows for the modeling of fabric structures with a high degree of realism and consideration of material properties. During this phase, two-dimensional design elements are structured and subsequently transformed into a virtual space, ensuring the structural fidelity of the prospective garment *(Limerense_com, 2025).* This approach facilitates a preemptive understanding of the final silhouette, thereby minimizing production errors at the conceptualization stage (Figure 1.).

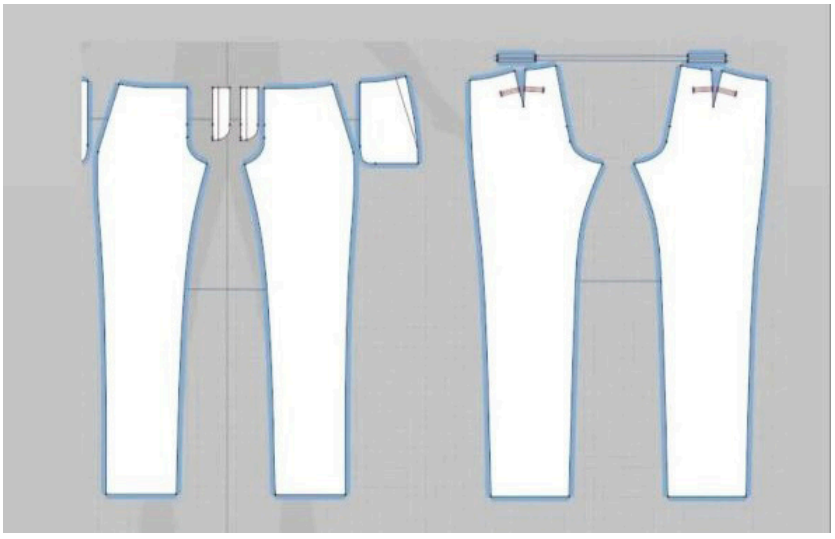

Figure 1. Digital Pattern Drafting in Marvelous Designer: Initial Construction Phase

The next phase consists of fitting the constructed patterns onto a virtual mannequin an operation that emulates the real-world fitting process while simultaneously transcending the boundaries of physical materiality. The virtual mannequin, functioning as an algorithmic model of the human body, enables the detection of potential conflicts in fabric layering and ensures the a priori adaptation of the garment's form to the morphological characteristics of the target wearer (Figure 2).

Figure 2. Virtual Fitting on a Parametric Mannequin: Simulation of Garment Behavior

This methodology optimizes the development of customized apparel within mass production frameworks, reducing material and temporal resources. In terms of surface detailing, ZBrush is employed as a digital sculpting environment wherein folds, tension lines, and other fabric nuances are articulated. It is within this environment that the mimetic rendering of textile behavior is achieved through the topological layering of fragments that simulate the dynamic interaction of fabric under gravity, motion, and bodily contact. The result is a hyper-realistic visual output capable of rivaling high-resolution photography or physical samples. Simultaneously, ZBrush is used to construct a prototype model of trousers, which functions as the foundational template for subsequent texture mapping. This step is crucial for the application of prints and the encoding of material properties such as glossiness, transparency, and roughness. Essentially, the model serves as a UV map framework, ensuring the precise positioning of graphical elements in accordance with the anatomical structure of the garment. This phase represents the culmination of both artistic intent and technical execution (Figure 3;4) *(Limerense_com, 2025).*

In the final outcome, the virtual model is initially presented in its raw, textureless form, and subsequently in its fully rendered state, adorned with a designer print. This transformational continuum from digital drafting to photorealistic visualization enables the interactive engagement of potential consumers, opening new horizons in digital marketing and bespoke design. Thus, 3D visualization within the Limerense_com brand stands not only as a technological instrument, but also as a medium of profound aesthetic transformation in the very conception of clothing (Figure 5) *(Limerense_com, 2025).*

Thus, the integration of three-dimensional visualization into the processes of garment modeling, visual representation, and conceptual articulation as exemplified by the case of Limerense_com reveals not only the heuristic potential of digital tools as representational mediators between ideation and realization, but also signifies an epistemological shift in the modalities of materializing aesthetic narratives within the postmodern fashion industry; for what occurs is a peculiar denaturalization of traditional production paradigms through the simulacral transformation of textile objects, whereby physical presence is supplanted by a hyperreal analogue capable of rivaling the material prototype in terms of perceptual verisimilitude, commercial efficacy, and artistic expressiveness.

Figure 3. Sculptural Detailing of Fabric Folds in ZBrush: Trousers Prototype (Stage I)

Figure 4. Advanced Drapery Modeling in ZBrush: Preparation for Texture Application (Stage II)

Figure 5. Final Visualization of the 3D Garment Model: a) Without Texture, b) With Applied Print Design

5. Conclusions

Thus, the effectiveness of researching the quantitative and qualitative characteristics of a garment's three-dimensional form depends not only on the complexity of the surface topography of the studied items but also on the accuracy of digital information in the virtual environment and the technical capabilities of the equipment used. It is worth noting that the use of 3D scanning technology to determine the magnitude and location of projection allowances in fur garment constructions can be recommended for designing models where the fur is positioned on the inner side of the garment specifically, shearling coats and garments with fur linings. The current level of development in additive technologies, along with the wide range of 3D printers and advanced filaments, is expanding the possibilities of 3D printing applications and enabling the creation of unique products for the garment industry. Research has demonstrated the promising potential of using additive technologies in the production of clothing items. Printed objects with complex spatial forms are in demand across various areas of apparel manufacturing from everyday and formal wear to headgear, as well as products with specialized or rehabilitative purposes. Increasing user competence and the growing proficiency of industry professionals in graphic design software not only simplify and expand the production of garments created using three-dimensional technologies and 3D printing but also contribute to shaping a new aesthetic for the society of the future.

References

1. Chittaro, L., & Corvaglia, D. (2003). 3D virtual clothing: From garment design to Web3D visualization and simulation. In Proceedings of the Eighth International Conference on 3D Web Technology. Retrieved from https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=3cf2c95a3362e3669f96892b577f1b82fa1763af

2. Choi, K.-H. (2019). Digitalized dynamic fashion illustration, using motion graphics. In Proceedings of International Conference on Fashion Communication: Between Tradition and Future Digital Developments (pp. 9–20). Switzerland.

3. Choi, K.-H. (2022). 3D dynamic fashion design development using digital technology and its potential in online platforms. Fashion and Textiles, 9(1). Retrieved from https://link.springer.com/content/pdf/10.1186/s40691-021-00286-1.pdf

4. Hu, Z., et al. (2023). Physically realizable natural-looking clothing textures evade person detectors via 3D modeling. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition. Retrieved from https://openaccess.thecvf.com/content/CVPR2023/papers/Hu_Physically_Realizable_Natural-Looking_Clothing_Textures_Evade_Person_Detectors_via_3D_CVPR_2023_paper.pdf

5. Kolosnichenko, M. V., Chuprina, N. V., Krotova, T. F., & Olishevska, T. M. (2020). Designing fashion clothing based on the principles of parametric design. Art and Design, 1(09), 129–141.

6. Li, Z., et al. (2024). An analysis of the status and trend of visualization research in 3D fashion design. Journal of the Balkan Tribological Association, 30(2). Retrieved from https://openurl.ebsco.com/EPDB:gcd:16:31020128/detailv2?sid=ebsco:plink:scholar&id=ebsco:gcd:178373718&crl=c&link_origin=scholar.google.com.ua

7. Limerense_com. (2025). Instagram page. Retrieved from https://www.instagram.com/limerense_com?igsh=eWhqa2ZjZmtvMXJz

8. Liu, H. (2022). Computer 5G virtual reality environment 3D clothing design. Mobile Information Systems, 2022(1), 8024453. Retrieved from https://onlinelibrary.wiley.com/doi/pdf/10.1155/2022/8024453

9. Ma, Q., et al. (2021). The power of points for modeling humans in clothing. In Proceedings of the IEEE/CVF International Conference on Computer Vision. Retrieved from https://openaccess.thecvf.com/content/ICCV2021/papers/Ma_The_Power_of_Points_for_Modeling_Humans_in_Clothing_ICCV_2021_paper.pdf

10. McQuillan, H. (2020). Digital 3D design as a tool for augmenting zero-waste fashion design practice. International Journal of Fashion Design, Technology and Education, 13(1), 89–100.

11. Papachristou, E., & Anastassiu, H. T. (2022). Application of 3D virtual prototyping technology to the integration of wearable antennas into fashion garments. Technologies, 10(3). Retrieved from https://www.mdpi.com/2227-7080/10/3/62

12. Park, J. (2018). Emotional reactions to the 3D virtual body and future willingness: The effects of self-esteem and social physique anxiety. Virtual Reality, 22, 1–11.

13. Porterfield, A., & Lamar, T. A. (2017). Examining the effectiveness of virtual fitting with 3D garment simulation. International Journal of Fashion Design, Technology and Education, 10(3), 320–330.

14. Tuan, T. T., et al. (2021). Multiple pose virtual try-on based on 3D clothing reconstruction. IEEE Access, 9, 114367–114380.

15. Waymouth, B., et al. (2021). Demonstrating cloth folding to robots: Design and evaluation of a 2D and a 3D user interface. In 2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN). IEEE. Retrieved from https://arxiv.org/pdf/2104.02968