Development of Virtual Environment with Dynamic Simulation of Colour, Texture and Design for Footwear

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Development of Virtual Environment with Dynamic Simulation

of Colour, Texture and Design for Footwear

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Abstract

The idea of the metaverse in footwear is a paradigm shift to an entirely digital environment, where customers can engage with these new and exciting footwear concepts in immersive and customized ways.” As digital ecosystem expands, top brands continue to venture into the world of digital footwear and not limit their marketing strategy to physical outlets. By virtue of such developments, the consumers are now able to simply gone through vast 3D virtual shoe collections and “fit” those virtual shoes onto their feet in interactive “magic mirror” systems based on advanced visualization technologies.

The aim of this research is to provide consumers with highly immersive, sensate virtual queries through AR technologies so that customers are able to see and use (customize & try) shoe models before buying and after-the-purchase. In this project, a virtual environment for the footwear retail outlet has been designed using 3D design software and rendered, which allows it to be viewed in Virtual Reality, with dynamic simulations of color, texture, and design. A space that closely resembles real life, with the feeling of being there, is created using advanced computer graphics and motion simulation, which enhance the user’s sense of immersion.

By empowering customers to interact with products in a digital simulated environment, it creates loyalty and

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retention for such products & brands. In conclusion, the advent of virtual footwear in the metaverse modernizes consumer behavior and develops new avenues for sustainable designing, lowering the footprints, minimized sampling cost, innovative business models in leather & footwear sector.

Keywords: Virtual Footwear, Meta verse, Digital Twin, VR/AR, 3D Scanning, Virtual Try-On, Immersive Experience, Footwear Design, Sustainability, Leather Sector Innovation.

1. Introduction

The metaverse represents an emerging digital paradigm that enables immersive online experiences by integrating Virtual Reality (VR), Augmented Reality (AR), artificial intelligence, and real-time 3D visualization. In this environment, users interact through avatars—threedimensional digital representations capable of engaging with virtual spaces, objects, intelligent agents, and other users. Access to the metaverse is typically facilitated through VR headsets, smart glasses, or AR-enabled devices, allowing seamless blending of digital and physical experiences.

Within the footwear industry, this technology offers significant potential to transform conventional retail, product development, and customer engagement models. Traditional footwear shopping relies heavily on physical inventory, repeated sampling, and in-store trials, which contribute to high operational costs and material waste.

Metaverse-based footwear platforms address these challenges by enabling digital exploration, customization, and evaluation of products before manufacturing or purchase.

Global brands such as Adidas, Gucci, and Clarks have demonstrated early adoption through digital collections, NFTs, and virtual showrooms. However, these initiatives

2. Research Gap

While existing studies demonstrate the potential of AR and VR technologies in footwear visualization and design communication, they remain limited to static, tool-based applications. There is a clear research gap in developing a metaverse-enabled, consumer-centric virtual footwear platform that integrates dynamic fit simulation, material behavior, immersive retail interaction, sustainability-driven design validation, and scalable industry adoption. This study addresses these gaps by proposing an immersive, platformbased virtual footwear ecosystem tailored to the leather and footwear industry.

3. Methodology

The proposed methodology (Fig. 1) adopts a modular, scalable, and industry-oriented digital workflow for the design and deployment of virtual footwear in a metaverseenabled retail environment. The framework is structured to ensure high visual realism, biomechanical relevance,

remain largely brand-centric and inaccessible to the broader Indian footwear ecosystem. This research addresses this gap by proposing a shared, technologydriven virtual footwear platform designed for scalable, sustainable, and user-friendly adoption across the Indian footwear value chain.

sustainability, and ease of adoption for footwear manufacturers and designers.

3.1 Digital Foot and Last Data Acquisition

Accurate foot–last geometry forms the foundation of realistic virtual footwear. Standardized footwear lasts representing Indian anthropometric data are digitized using 3D scanning techniques. The scanned data are cleaned, aligned, and parameterized to define critical dimensions such as foot length, girth, instep height, and toe allowance. This step ensures ergonomic correctness and supports size-wise scalability across footwear categories.

3.2 E-file of Basic Footwear Styles

Core footwear categories (casual, formal, sports, safety, and sandals) are converted into e-file as baseline models using footwear-specific CAD software. Upper patterns, sole units, and insole geometries are converted into digital assemblies, preserving construction logic such as stitching

lines, lasting allowances, and component overlaps. Construction constraints are embedded to ensure manufacturability.

3.3 Parametric 3D Footwear Modelling and Template Creation

Parametric modelling techniques are used to create reusable footwear templates, allowing rapid generation of new styles through controlled modification of parameters such as toe shape, sole thickness, heel height, and upper coverage. This approach supports mass customization while maintaining design consistency.

3.4 Virtual Material Library Development

A comprehensive virtual material library is developed for leather and non-leather materials. Each material is assigned physically based rendering (PBR) properties including albedo, roughness, normal maps, elasticity, thickness, and deformation response. Visual and tactile realism is enhanced through texture mapping and light interaction simulation.

3.5 Dynamic Fit and Motion Simulation

To simulate realistic wear conditions, dynamic fitting algorithms are implemented using foot–shoe interaction models. Real-time deformation of uppers and cushioning response of soles are simulated during basic gait cycles. Foot-tracking inputs and motion data enable users to visualize pressure zones and comfort-related deformation.

3.6 Virtual Retail Environment Design

A virtual footwear retail outlet is designed using Blender and game-engine-based rendering platforms. The environment includes display racks, interactive mirrors, and avatar-based navigation. Users can select footwear, customize design attributes, and instantly visualize changes in real time.

3.7 Metaverse Platform Integration

The finalized virtual footwear assets and retail environment are deployed on a metaverse- compatible platform supporting multi-user interaction. Avatars allow

users to try footwear collaboratively, while cloud-based asset management enables manufacturers to update collections dynamically.

Fig. 1 the Methodology of Virtual Footwear Integration

3.8 User Interaction and Feedback Loop

User interactions such as customization choices, fit preferences, and time spent on designs are recorded and analyzed. This data is used to refine designs, improve fit templates, and guide future product development decisions.

3.9 System Validation and Performance Evaluation

The system is evaluated based on visual realism, usability, rendering performance, and user satisfaction. Comparative analysis is conducted between physical sampling and virtual evaluation in terms of time, cost, and material savings.

4. Results and Discussion

The developed system demonstrates a high level of visual realism and functional interaction, enabling users to experience footwear products in a virtual retail environment comparable to physical stores. Dynamic fitting simulations and real-time customization significantly improve user confidence in product selection. From a sustainability perspective, the approach reduces the need for physical samples, minimizes material waste, and lowers carbon footprint associated with logistics and inventory handling.

The platform-based model introduces novelty by enabling multiple manufacturers and component suppliers to participate in a shared digital ecosystem, rather than isolated brand-specific solutions. Ease of application is ensured through template-driven modelling, cloud-based deployment, and compatibility with commonly used CAD and VR tools.

5. Conclusion

This research establishes a novel, sustainable, and industry-ready framework for virtual footwear development and retail in the metaverse. By combining digital twins, VR/AR technologies, and scalable design templates, the proposed system modernizes consumer engagement while supporting environmentally responsible product development. The intuitive interface allows seamless navigation, customization, and virtual try-on, making it accessible to both consumers and manufacturers. The study highlights the metaverse as a viable and transformative platform for the future growth of the Indian leather and footwear industry.

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