Original Article
ISSN (Online): 2454-1907

International Journal of Engineering Technologies and Management Research
May 2025 12(5), 76–92

A COMPREHENSIVE REVIEW ON VIRTUAL TRIAL ROOMS: INTEGRATION OF AR, AI, AND 3D TECHNOLOGIES FOR ENHANCED E-COMMERCE EXPERIENCE

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Received 15 March 2025
Accepted 15 April 2025
Published 20 May 2025

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DOI
10.29121/ijetmr.v12.i5.2025.1615

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

Online shopping has become an everyday convenience, especially in the fashion and apparel industry. Yet, one persistent drawback remains—the inability for customers to try on clothes before making a purchase. This often leads to issues with fit, style mismatches, and high return rates, affecting both customer satisfaction and business operations. Virtual Trial Rooms (VTRs) have emerged as a promising solution, allowing users to virtually try on garments using technologies like Augmented Reality (AR), Artificial Intelligence (AI), and Computer Vision. This paper explores how VTRs work, the technologies behind them, and their real-world applications. It also looks at how VTRs are making online shopping more accurate, hygienic, and sustainable, especially after the COVID-19 pandemic. By comparing existing systems, we highlight their strengths and current limitations while pointing out key areas for future development. As this technology continues to evolve, it has the potential to significantly transform the way people experience fashion retail online.

Keywords: Virtual Trial Room, Augmented Reality, Virtual Reality, 3D Fitting, E-Commerce, Body Scanning

1. INTRODUCTION

The 21st century has witnessed a remarkable shift in consumer behaviour, largely driven by the proliferation of e-commerce platforms. With growing internet penetration, mobile device usage, and the rise of digital payment systems, online shopping has become a daily norm Jadhav et al. (2021), Ramesh et al, (2018). Market leaders like Amazon, Flipkart, and Myntra have revolutionized retail experiences by offering a vast product range, convenience, and competitive pricing, resulting in a steady consumer shift from physical stores to digital platforms Boonbrahm et al. (2015), Adikari et al. (2020).

Despite its popularity, one major limitation still persists in the e-commerce space—shoppers cannot physically try on apparel before purchasing. In contrast to physical stores where customers can assess a garment's size, fit, fabric, and appearance, online shoppers must rely on product descriptions, photos, and customer reviews. This gap in physical interaction frequently leads to dissatisfaction due to incorrect sizing, colour mismatches, and poor fit Wu and Kim (2022), Mehta et al. (2020). Consequently, the fashion and apparel sector continue to report the highest product return rates, often ranging between 30–40% in various regions Dias et al. (2022), Rajan et al. (2021). These returns result in logistical costs, inventory losses, and eroded consumer trust.

To mitigate this challenge, the concept of the Virtual Trial Room (VTR) has emerged as a groundbreaking innovation. A VTR is a digital interface that allows customers to try on clothes virtually using technologies such as Augmented Reality (AR), Artificial Intelligence (AI), and Computer Vision (CV). It aims to recreate the physical try-on experience in a digital space, offering customers a real-time, visual representation of how garments would look on them Erra et al. (2018), Shirsat et al. (2019).

1) Motivation Behind Virtual Trial Room Technology

The primary motivation for developing VTR systems is to enhance the online shopping experience while reducing return rates. In the fashion segment, the decision to buy is highly dependent on visual appeal and perceived fit, which cannot be fully captured through static images or videos. VTRs allow customers to preview garments on themselves or a 3D model in real time, thereby making more informed decisions Alzamzami et al. (2023), Kang (2013). This increases customer satisfaction, reduces post-purchase regret, and builds brand loyalty.

Moreover, reducing return rates also contributes to environmental sustainability. Reverse logistics, repackaging, and waste disposal due to returns significantly impact the carbon footprint of e-commerce. By facilitating better purchasing decisions, VTRs promote mindful shopping and reduce the environmental burden Verma et al(n.d.), Priyah and Vinod (2014).

2) Hygiene and Medical Perspective

In addition to convenience and sustainability, VTRs offer hygienic advantages over traditional fitting rooms. In physical stores, garments are often tried on by multiple customers, which increases the risk of transmission of skin infections or other communicable diseases. The COVID-19 pandemic amplified public concern over hygiene, and many consumers began avoiding physical try-ons due to fear of contamination Liu et al. (2024), Jayamini et al. (2021).

By eliminating the need to physically wear clothes before buying, Virtual Trial Rooms provide a contactless and safe alternative. For individuals with compromised immune systems or those concerned about hygiene, VTRs present a medically responsible innovation that aligns with post-pandemic retail practices Koppens (2021), Kedari et al. (2015).

3) Current Market Trends and Adoption of Virtual Trial Rooms

The retail industry is rapidly adopting VTR technology across both online and offline channels. Brands such as Zara, Adidas, Gucci, and H&M have already begun integrating AR-based try-on experiences in their mobile apps and smart mirrors Shirsat et al. (2019), Biswas et al. (2014). Amazon, for example, offers "Virtual Try-

On for Shoes," which allows users to visualize how footwear will look using their smartphone's camera Battistoni et al. (2022).

Beauty brands like L'Oréal, Sephora, and MAC have also implemented AR-based virtual makeup tools, which have proven successful in driving user engagement. These applications use AI-driven facial mapping and machine learning to personalize suggestions, increasing both sales and customer satisfaction Joshi et al. (2024), Sunan et al. (2023).

Startups such as Zeekit, Fit Analytics, and Metail are providing retailers with customizable virtual fitting solutions that incorporate AI, size recommendations, and body modelling technologies Moroz (2019). These platforms continuously learn from user behaviour and data inputs to improve fit prediction algorithms.

The demand for contactless shopping solutions surged during the pandemic, and VTR systems gained popularity as physical trial rooms became inaccessible Jayamini et al. (2021), Werdayani and Widiaty (2021). This has accelerated innovation in the space, motivating more brands to integrate VTRs into their omnichannel strategies.

4) Basic Idea and Working of a Virtual Trial Room

At its core, a Virtual Trial Room is a software system that allows a user to see how clothing items would look on them without physically wearing them. The system typically works using a combination of computer vision, augmented reality, and AI technologies. Here's a basic breakdown of how a typical VTR system works:

- **User Input:** The user either uploads a photo, enters body measurements, or uses their phone camera for live video input.
- Body Detection and Measurement: AI algorithms analyse the user's body structure, posture, and dimensions using pose estimation or depth sensing techniques.
- **3D Avatar Generation (optional):** Some VTR systems generate a 3D avatar based on the user's inputs for a more immersive and accurate trial experience.
- **Clothing Simulation**: The selected clothing item is rendered digitally and draped over the user's body or avatar. Advanced systems simulate how the garment would fall, stretch, and wrinkle in real life, offering a realistic look and feel.ddx
- **Visualization and Feedback:** The final output is displayed in real time, allowing the user to rotate the model, try different colours or sizes, and take screenshots.
- **Recommendation and Sharing:** Many platforms also recommend size or style variations and allow users to share their virtual try-on experience on social media or with friends.

Figure 1

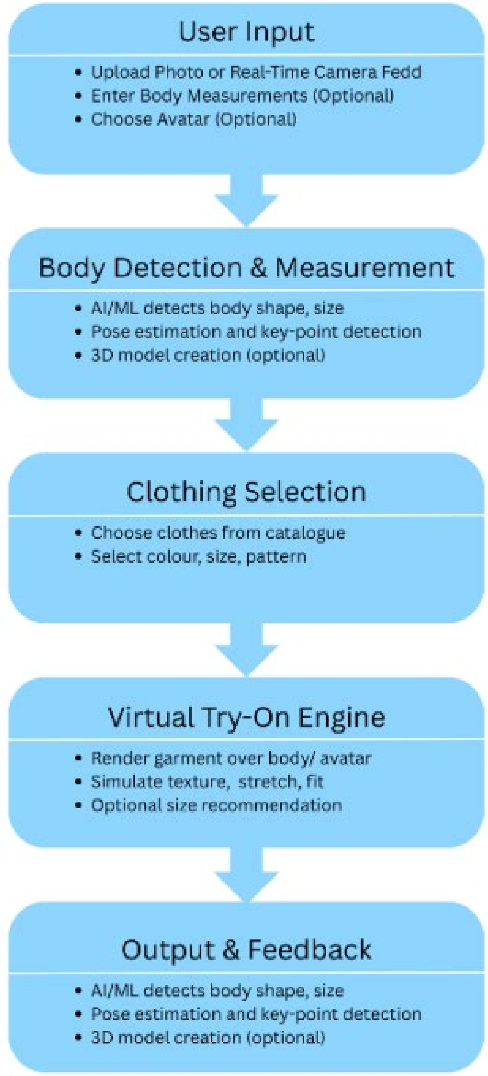

Figure 1 A General Workflow of a Virtual Trial Room System, Starting from User Input to Their Final Virtual Try on Experience Using Augmented Reality and 3D Simulation Techniques

VTRs can be implemented through mobile apps, web applications, or in-store smart mirrors, offering flexibility in use. With the rise of metaverse and virtual fashion shows, VTRs are also playing a crucial role in redefining how people experience and interact with fashion digitally.

2. PRELIMINARIES

In recent years, the convergence of immersive technologies and artificial intelligence has transformed the fashion and retail sectors. Among the most promising innovations is the Virtual Trial Room (VTR), a sophisticated solution that integrates a range of emerging technologies such as Augmented Reality (AR), Virtual Reality (VR), 3D modelling, body scanning, and artificial intelligence to simulate the in-store dressing experience from the comfort of home. This section provides the necessary background on the core technologies involved in the development and functionality of virtual trial rooms.

1) Augumented Reality (AR)

Augmented Reality (AR) refers to the technology that overlays virtual information—such as images, animations, or 3D models—onto the real world through devices like smartphones, tablets, or AR glasses El-Nahass (2021). In the context of virtual trial rooms, AR plays a pivotal role by allowing users to view digital clothing superimposed on their live image. This real-time interaction enhances the online shopping experience, making it more immersive and reducing uncertainty about the appearance of garments.

Figure 2

Figure 2 A User Interacting with a Smart Virtual Trial Mirror to Visualize Selected Garments Using Augmented Reality Technology.

AR-based virtual try-ons are developed using platforms such as Vuforia and Apple's ARKit, which enable object tracking, surface recognition, and marker-based AR features. ARKit, especially when used with Xcode 11, facilitates the development of iOS applications with seamless AR functionality. These platforms are integrated into mobile or web applications to allow users to rotate, resize, or change clothing with intuitive touch based gestures, bridging the gap between physical and online shopping.

2) Virtual Reality (VR)

Virtual Reality (VR) creates a fully immersive digital environment that users can explore using VR headsets. Unlike AR, which blends the virtual and physical worlds, VR transports users to entirely virtual spaces. In VTRs, VR is used to replicate the ambiance of high-end fashion boutiques or personalized dressing rooms. Users can walk through virtual stores, interact with garments, and try clothes in a 360-degree virtual mirror setup.

The development of such experiences relies heavily on game engines like Unity 3D and Unreal Engine. These platforms support high-fidelity 3D graphics, realistic lighting, and physics-based interactions, allowing for dynamic and lifelike virtual environments. Though VR adoption is limited due to hardware costs and user accessibility, it represents the future of experiential retail and digital personalization.

3) 3D Modelling and Simulation

The foundation of a VTR system lies in accurate and visually convincing 3D models of clothing. 3D modelling involves creating a virtual representation of garments using computer graphics software like Blender3D. Each model is carefully designed to replicate the texture, shape, and dimensions of actual clothing.

Simulation further enhances realism by replicating how fabric behaves under various physical conditions. Physics engines integrated with Unity 3D simulate gravity, friction, bending, and elasticity. These simulations ensure that the clothes drape and move naturally as the user moves their body. Parameters such as fabric stiffness, material density, and collision detection are adjusted to reflect different clothing types— from rigid jackets to flowing dresses.

The detailed 3D models are also rigged and skinned to a virtual avatar or a human figure, enabling interactive Tryon experiences. The level of detail in modelling directly influences the believability and user acceptance of the VTR experience.

4) Body Scanning

To personalize the try-on experience, the system must accurately detect and represent the user's body shape and size. Body scanning is the process of collecting body measurements using sensors or camera-based systems. Technologies like the Kinect V2 sensor and Asus Xtion provide depth-sensing capabilities that enable the system to understand the 3D structure of the user's body.

Figure 3

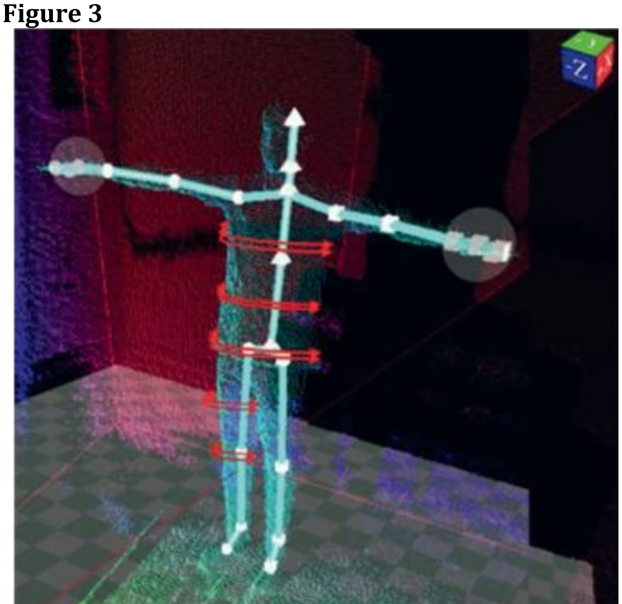

Figure 3 Complex 3Dgarment Measurements: Front Perimeters at Chest, Waist, Hip, Thigh, Knee, and Wrist.

Source Adopted from Adikari et al. (2020).

These sensors generate a point cloud or depth map, which is used to create a digital avatar or align virtual garments on the user's real-time image. More advanced scanning solutions utilize infrared light and structured light projection to enhance precision. Accurate body scanning ensures the clothing fits correctly in the virtual space, thereby reducing discrepancies and increasing consumer trust.

5) Artificial Intelligence & Machine Learning (Pose Detection)

AI and ML algorithms are central to real-time human pose estimation in virtual trial rooms Joshi et al. (2024). Pose detection allows the system to understand the position and orientation of the user's body, enabling the virtual garments to adapt and align dynamically.

Open Pose and Pose Net are two widely used frameworks for detecting body joints and skeletal structures. Open Pose, developed by the Carnegie Mellon Perceptual Computing Lab, can detect multiple body points (e.g., elbows, knees, shoulders) in real time. Pose Net is a lightweight deep learning model that can run efficiently on mobile devices, making it ideal for AR applications. Deep learning architectures such as ResNet-50 enhance pose estimation by capturing complex features and movements. These models are integrated into applications using Python and OpenCV. Flask is commonly used to serve these models as APIs in web-based systems. These AI-driven pose estimators ensure that the virtual clothes move in sync with the user's body, making the experience seamless and realistic.

6) Physics Engines for Cloth Fitting

Simulating realistic cloth behaviour is one of the most complex aspects of virtual try-on systems. Physics engines are responsible for modelling the interaction between the body and garments. These engines simulate fabric behaviour under various forces, such as gravity, wind, or user motion.

Unity's built-in physics engine, as well as third-party plugins, allow garments to exhibit natural movement— folding, stretching, or fluttering—just like real clothes. Three.js, a JavaScript library for 3D rendering, also supports basic physics for web-based applications. Parameters such as collision detection, soft body dynamics, and spring constraints are used to enhance realism.

Physics simulation not only improves visual appeal but also helps users evaluate how the garment will feel and look during different activities like walking or turning. This functionality is essential for sportswear and casual clothing brands that want to offer an interactive fit-testing experience.

7) Integration Platforms and Development Tools

A seamless VTR system requires integration across front-end interfaces, back-end servers, and machine learning components. Development tools like Flask serve as a bridge between ML models and the user interface, enabling real-time garment fitting and pose detection through APIs. Front-end frameworks incorporate libraries like Three.js to display interactive 3D visuals directly in web browsers.

Unity 3D remains the most preferred platform for building cross-platform virtual trial room experiences, as it supports scripting, physics, animation, and 3D rendering in one environment. On the other hand, mobile developers often rely on Apple's Xcode 11 and ARKit for building iOS-based AR applications.

Additional hardware platforms such as the Asus Xtion and Kinect V2 sensor support high-resolution depth sensing and skeletal tracking. These tools enable Realtime user interaction, depth detection, and avatar alignment, making them essential for accurate fitting and responsiveness.

3. RELATED WORK

The concept of Virtual Trial Rooms (VTRs) has evolved significantly over the past two decades, transforming the digital shopping landscape by providing customers the ability to try garments virtually before purchase. This evolution has been fuelled by technological advances in computer vision, 3D modelling, artificial intelligence (AI), and immersive technologies such as Augmented Reality (AR) and

Virtual Reality (VR). Initially grounded in 2D image processing, VTRs now offer real-time, interactive, and highly accurate simulations that replicate the experience of physically trying on clothing. A detailed review of the existing literature illustrates this transformation from rudimentary overlay techniques to sophisticated, intelligent systems.

Early systems primarily relied on 2D image overlays, where garments were superimposed on static images of users. These systems were simplistic and lacked realism, often leading to poor user experience and dissatisfaction. Despite their limitations, such systems laid the foundation for future enhancements by highlighting key technical challenges such as body alignment, scale matching, and cloth distortion Ramesh et al, (2018), Priyah and Vinod (2014). The need for more realistic garment visualization pushed researchers to explore 3D body modelling techniques, leading to a shift in approach. Notably, Boonbrahm et al. (2015) proposed a method to convert 2D images into 3D avatars, which allowed garments to be rendered with better fit accuracy and depth perception. This marked a pivotal change by enabling personalized avatars that could simulate the drape and flow of garments on a virtual body.

Figure 4

Figure 4 2D Virtual Try-on Interface Showing a Garment Overlaid on a User's Image Using Flask and OpenCV.

Source Adopted from Rajan et al. (2021)

As consumer expectations evolved, VTR systems began incorporating real-time interaction capabilities using devices such as RGB cameras, depth sensors, and motion detectors. Researchers like Singh et al. Verma et al(n.d.) and Rajan et al. (2021) integrated systems using Kinect sensors and OpenCV, enabling full-body tracking and movement detection. These systems allowed users to move, turn, and even simulate walking while virtually trying on clothes. Real-time fitting increased user engagement and made the experience more immersive. Further enhancements included the simulation of garment physics—such as cloth elasticity, wrinkle formation, and response to motion—through physics-based modelling approaches Erra et al. (2018), Sunan et al. (2023).

Figure 5

Figure 5 The User Interface of the Application and Some Examples of Clothing. The Green Arrow Icons on the Left and on the Right are Used to Browse the Clothing. A Click Is Simulated by Closing the Hand Over These Icons. A Restart Icon Is Located on the Top. This Icon Is Used When a New User Enters the Dressing Room

Source Adopted from Erra et al. (2018)

The introduction of AR into VTR systems revolutionized user interaction by overlaying digital clothing directly onto a user's real-time camera feed. This approach significantly enhanced realism and accessibility, especially through mobile platforms. Wu and Kim (2022) highlighted the effectiveness of AR in increasing user satisfaction and engagement. They found that the visual fidelity and natural interaction of AR-based trial rooms fostered greater trust in product selection. Similarly, Priyah and Vinod (2014) emphasized that markerless AR provided better garment alignment and improved usability. AR integration is now commonly seen in retail apps, allowing customers to visualize outfits using just their smartphones, thereby bridging the online-offline gap in shopping experiences.

Virtual Reality, although more immersive, remains less widespread due to its hardware demands. However, it offers a complete virtual shopping environment, often combined with haptic feedback and voice interaction. Studies like those by Dias et al. (2022) explored VR-based VTRs in metaverse environments, suggesting future retail could be conducted entirely within shared virtual spaces. Here, users can not only try on garments but also interact with virtual store assistants and other shoppers, enabling a social experience that mimics in-person retail.

AI has played a transformative role in the personalization and automation of VTR systems. Early research applied AI primarily for size prediction, based on manually entered body measurements. This approach was limited by user error and subjectivity. More recent systems utilize computer vision and deep learning to extract body dimensions from photos and videos, drastically improving accuracy and convenience. Studies by. Verma et al(n.d.) demonstrate how AI can estimate parameters such as shoulder width, waist circumference, and inseam length from 2D inputs, with promising results. In addition, AI-based recommendation systems help suggest clothing styles based on user preferences, body shape, and previous purchase data, creating a tailored experience for each user Liu et al. (2024), Jayamini et al. (2021).

The shift to web-based and mobile platforms has made VTR systems widely accessible. Researchers have developed frameworks using technologies like Three.js, Unity3D, and WebGL to ensure real-time performance across browsers Dias et al. (2022), Shirsat et al. (2019). Mobile-first designs prioritize responsive interfaces and low-latency rendering to deliver a seamless experience even on mid-range devices. Some solutions leverage cloud-based rendering to reduce computational load on client devices and provide scalable, platform-independent access Alzamzami et al. (2023), Verma et al(n.d.). This is particularly important for reaching global users and supporting diverse internet infrastructure conditions.

Figure 6

Figure 6 The Body Tracking Using 3D Skeleton
Source Adopted from Dias et al. (2022).

Several studies also explore the psychological and commercial implications of VTR systems. Liu et al. (2024) observed that users tend to trust the product more when they can virtually try it on, leading to increased purchase confidence and reduced return rates. Similarly. Jayamini et al. (2021) highlighted how VTRs improve decision-making and decrease cognitive dissonance in online shopping. Retailers have reported enhanced customer retention and optimized inventory management due to better-informed purchases, emphasizing the business value of integrating VTR technology.

Over time, researchers have proposed innovative enhancements such as gesture-based control, voice interaction, and fabric-specific simulations to further enrich the trial room experience. For instance, Iyer et al. Kedari et al. (2015) demonstrated a touchless trial room where users could navigate clothing options using hand gestures, which is particularly relevant in a post-pandemic, hygiene-conscious era. Other papers, like that by Yadav and Dias Ramesh et al, (2018), focused on replicating fabric behaviour under various lighting and motion scenarios to increase garment realism. As illustrated in Table I, modern systems differ widely in their underlying technologies,

ranging from basic 2D overlays to advanced AI-powered 3D simulations, enabling varying degrees of interactivity, realism, and accessibility.

Table 1

Table 1 Comparative Analysis of Existing Virtual Trial Room Methods Based on Methodology, Technologies Used, Strengths, and Limitations

Paper	Year	Methodology	Technology Used	Strength	Limitation
Boonbrahm et al. (2015)	2015	Reconstruction	Kinect2	Accessible for various applications	High Computing Resources

Ramesh et al, (2018)	2018	Augmentation	OpenCV	Cost-effective	Quality of camera and lighting conditions
Erra et al. (2018)	2018	User study with questionnaire-based surveys	Unity 4 Pro, Microsoft Kinect 2	Natural interaction with 3D models	Limited experience with augmented reality among participants
Shirsat et al. (2019)	2019	Use of Kinect sensor with Blender3D to create 3D VFR	OpenCV, Kinect V2, Blender3D	Realistic Fitting and display sizes along with price of the product	Limited Apparel Selection, Technical Constraints
Adikari et al. (2020)	2020	Non-contact body measurement	Kinect V2 Sensor, Unity3D	Real-time simulation	Relies on single depth sensor, not addressing varying body types or clothing styles
Mehta et al. (2020)	2020	Virtual dressing room implementation	OpenCV, hair's classifier, Unity, Vuforia	Enhances online shopping experience	High cost of sensors
Jadhav et al. (2021)	2021	Warping	CP-VITRON+, Open Pose, Pirus, Raytracing Algorithm	Realistic Virtual Try-On, Measurement Suggestions	Technical Complexity
Rajan et al. (2021)	2021	Real-time video processing for virtual dressing	Flask, OpenCV	Enhances online shopping experience with virtual fitting	Accuracy issues with fabric representation
Ramesh et al, (2018)	2022	Three-stage (Body Detection and Size, Reference Point Recognition, Clothes Superimposition) method for body detection	Unity3D, AR Core, Vuforia	Enhances online shopping experience, reduces returns	Smartphone hardware limits AR performance
Alzamzami et al. (2023)	2023	Unity3D is integrated with Xcode to build a mobile application for virtual try-on	Unity 2020.2 .4f and Xcode 11	Enhanced Shopping Experience by providing feedback and review system	Small Sample Size for Usability Testing
Verma et al(n.d.)	2023	Implementing PoseNet for pose estimation along with Three.js for real-time clothing animation	ResNet-50, PoseNet 2.0, Three.js, MS Kinect, ASUS Xtion	Providing personalized clothing recommendations, saves time and financial resources	Accuracy in pose estimation, dependence of technology

These studies collectively reveal a shift from basic 2D visualization approaches toward highly interactive, Realtime 3D virtual trial room systems. Researchers have experimented with various input mechanisms—ranging from depth sensors and webcams to advanced machine learning models—to improve virtual garment fitting accuracy and user interaction. Most of the earlier works focused on AR-based enhancements for visual appeal, whereas newer research emphasizes functionality, Realtime feedback, and personalized fitting.

4. CHALLENGES AND LIMITATIONS

While Virtual Trial Room (VTR) technologies are becoming more popular in fashion and retail, they still face several limitations. Although users enjoy the concept of trying outfits virtually, the experience isn't always seamless. Issues like poor alignment of clothes, lag in real-time movement, or inaccurate fitting often occur due to software or hardware limitations. Additionally, not all users have access to high-end devices or fast internet, which affects performance. One of the biggest challenges remains accuracy—what looks good virtually might not fit the same way in real life, leading to customer dissatisfaction and returns.

1) **Accuracy of Body Measurements and Fit Prediction:** One of the core challenges is accurately capturing users' body dimensions and predicting garment fit. Many VTR systems rely on depth sensors like Microsoft Kinect Adikari et al. (2020), but these tools can be sensitive to factors like poor lighting, limited space, or body posture, leading to inaccurate results Adikari et al. (2020), Biswas et al. (2014). Additionally, many systems still struggle to account for variations in body types, which limits their ability to offer truly personalized try-on experiences Boonbrahm et al. (2015), Joshi et al. (2024).
2) **Realistic Simulation of Clothing Behaviour:** Creating lifelike visualizations of how garments behave on the body—such as how they fold, stretch, or respond to movement—remains a complex problem. Most current systems simplify fabric behaviour due to hardware limitations or software constraints, which results in less convincing simulations Mehta et al. (2020), Battistoni et al. (2022). Real-time cloth simulation that captures fine details of different fabric types is computationally heavy and often not feasible for regular users on standard devices Shirsat et al. (2019), Sunan et al. (2023).
3) **Dependence on High-End Hardware:** Many virtual trial experiences, especially those using AR/VR, require high-performance devices with powerful processors, high-resolution cameras, and sometimes even specialized sensors. This hardware requirement limits access for a broader user base, especially in regions with lower smartphone penetration or limited internet infrastructure Dias et al. (2022), Kang (2013), Werdayani and Widiaty (2021).
4) **Privacy and Security Concerns:** Since these systems require capturing sensitive user data such as body scans or facial images, privacy becomes a major concern. Users may hesitate to engage with VTR platforms if they feel uncertain about how their data is being used or stored Wu and Kim (2022), Alzamzami et al. (2023), Moroz (2019). Unfortunately, many platforms lack clear privacy policies or adequate data protection measures, which impacts user trust.
5) **User Experience and Accessibility Issues:** For VTRs to succeed, the experience must be smooth, intuitive, and enjoyable. However, technical glitches, lagging visuals, or complex user interfaces can quickly discourage users Erra et al. (2018), Priyah and Vinod (2014), Douglas et al. (2017). Moreover, people with limited digital literacy or physical disabilities may find it hard to use these tools without guidance or accessibility support.
6) **Integration with Existing E-commerce Systems:** From a retailer's perspective, incorporating VTR solutions into current e-commerce websites is not always straightforward. Issues can arise with syncing 3D models of clothes with product listings, managing inventory updates, and maintaining platform compatibility Rajan et al. (2021), Koppens (2021). Such integration often demands substantial time, cost, and technical resources.
7) **Lack of Standards and Compatibility:** The fashion tech industry still lacks standardization in terms of digital garment formats, avatar sizes, and simulation protocols. This fragmentation makes it difficult to build systems that can work seamlessly across different brands, apps, or platforms Kedari

et al. (2015), El-Nahass (2021). As a result, customers may have to re-enter their data or adapt to new systems when switching between stores.

In essence, while Virtual Trial Room (VTR) technology has brought a fresh and interactive dimension to online shopping, it's still far from perfect. Users today want accuracy, realism, and convenience—but current systems often struggle to deliver all three at once. Whether it's the need for high-end hardware, challenges with body measurement precision, or concerns around data privacy, there are still quite a few bumps on the road. For VTRs to truly become a part of everyday online shopping, they need to be easier to use, more reliable, and built with user trust in mind. With continuous improvements and thoughtful design, VTRs have the potential to reshape the way we shop for clothes online making it not just more efficient, but also more enjoyable.

5. FUTURE SCOPE

As the demand for immersive and personalized online shopping experiences continues to grow, virtual trial rooms are expected to undergo significant advancements. Future research in this domain is likely to be shaped by technological evolution, user expectations, and the need for scalability, accuracy, and convenience.

One of the most promising directions lies in the enhancement of artificial intelligence (AI) models for more accurate body shape detection and cloth simulation. Current systems often face challenges in adapting to diverse body types and postures Adikari et al. (2020), Battistoni et al. (2022). The incorporation of advanced deep learning techniques— particularly generative adversarial networks (GANs) and transformer-based architectures—could enable highly realistic, dynamic fitting simulations that better reflect individual variations Joshi et al. (2024). These models would also benefit from large, diverse datasets to train on, reducing biases and improving generalization across global user bases.

Another key area is the seamless integration of Augmented Reality (AR) and Virtual Reality (VR) environments with high-definition graphics and intuitive interfaces. While AR overlays currently serve as useful visualization tools Jadhav et al. (2021), Wu and Kim (2022), future implementations may utilize VR environments that allow users to enter fully immersive digital fitting spaces Erra et al. (2018), Sunan et al. (2023). This would not only enhance the try-on experience but also enable social and interactive features, allowing users to shop collaboratively with friends or interact with AI-based virtual assistants in real time Alzamzami et al. (2023).

Cloud computing will also play a crucial role in scaling virtual trial rooms to a broader audience. Many current solutions rely on device-specific processing power, which limits accessibility Rajan et al. (2021). By offloading heavy computational tasks—such as real-time rendering, cloth physics simulations, and AI inference—to cloud platforms, applications can ensure smoother performance on low-end devices Shirsat et al. (2019), Biswas et al. (2014), thereby making virtual trial experiences more accessible and inclusive.

Moreover, the future of virtual trial rooms will likely include sophisticated personalization engines that utilize user preferences, body measurements, browsing history, and style choices to offer tailored recommendations Mehta et al. (2020), Liu et al. (2024). This level of personalization would significantly reduce product return rates and increase customer satisfaction Koppens (2021). Combining AI-based style advisors with user feedback mechanisms can further refine recommendation systems to better reflect individual tastes and shopping behaviours Priyah and Vinod (2014).

An emerging trend is the potential integration of virtual trial rooms into the broader ecosystem of the metaverse. As users increasingly engage in digital social spaces, avatars that accurately represent their body shapes and clothing styles could bridge the gap between online identities and physical presence Dias et al. (2022). In such environments, users might not only shop but also attend events, socialize, and experience brands in new, immersive ways Kang (2013), Jayamini et al. (2021). The virtual trial room could become a foundational service layer in such experiences Moroz (2019).

Real-time rendering technologies are another field poised for improvement. Reducing latency while maintaining high fidelity is a persistent challenge, especially for applications requiring real-time feedback Kedari et al. (2015). Techniques like edge computing, GPU optimization, and next generation rendering engines could be explored to deliver faster, high-quality visual outputs without compromising performance Douglas et al. (2017).

Additionally, future systems must address ethical and practical concerns such as data privacy and user security. With body measurements, personal preferences, and shopping history being stored and processed, it is essential to establish transparent data policies, consent mechanisms, and security protocols Verma et al(n.d.), El-Nahass (2021). Research may also focus on anonymization techniques and federated learning to ensure data is used responsibly without compromising user identity Werdayani and Widiaty (2021).

Future research in virtual trial rooms is not only about technological innovation but also about creating holistic, inclusive, and trustworthy systems. By advancing AI capabilities, enabling cloud-powered scalability, enhancing personalization, and integrating with larger virtual ecosystems, the next generation of virtual trial rooms has the potential to redefine how consumers engage with fashion in the digital era.

6. CONCLUSION

Virtual trial rooms (VTRs) have emerged as a transformative innovation in the fashion retail sector, offering an interactive and immersive alternative to traditional dressing methods. This paper has presented a

comprehensive review of existing literature, tracing the progression of VTRs from basic 2D overlays to sophisticated 3D simulations powered by augmented reality (AR), virtual reality (VR), and artificial intelligence (AI). Early models focused on simple visualization, but with advancements in depth sensing Adikari et al. (2020), real-time body modelling Boonbrahm et al. (2015), and AI-based garment fitting Joshi et al. (2024), the user experience has become significantly more accurate and personalized.

Several studies highlight that VTRs improve user satisfaction by offering better size recommendations, reducing return rates, and enhancing decision-making during online shopping Jadhav et al. (2021), Wu and Kim (2022), Liu et al. (2024). These systems also benefit retailers by streamlining inventory management and driving higher engagement through virtual interactivity. Notably, integration with game engines like Unity3D Dias et al. (2022) and AR toolkits has expanded deployment to mobile and web-based platforms, making the technology more accessible.

Despite promising progress, certain limitations persist— such as realistic cloth simulation, privacy concerns, and computational overhead. Nevertheless, ongoing research in metaverse integration, cloud-based rendering, and personalized AI recommendation systems indicates a strong future trajectory.

Finally, it can be concluded that VTRs are reshaping consumer interactions in the digital fashion ecosystem. With continued technological refinement, these systems are expected to become a core component of modern ecommerce platforms, driving a more engaging, efficient, and sustainable shopping experience.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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