Journal of Design Intelligence
https://www.ffspub.com/index.php/jdi
ISSN 3104-9001 (print)
E-mail: jdi.office@ffspub.com

Article

Design and Research of a Virtual Clothing Store Based on VR Technology

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Received: April 23, 2026 / Revised: June 8, 2026 / Accepted: June 15, 2026 / Published online: June 25 2026

Abstract: To address the lack of immersive experience and intuitive perception in conventional online apparel shopping, a problem associated with a high rate of returns and exchanges, this study proposes a design and implementation method for a virtual clothing store based on virtual reality (VR) technology. First, through field investigations of physical apparel stores and a comparative analysis of existing virtual display platforms, the design requirements of a virtual clothing store were identified, and design principles for spatial layout, interaction, merchandise display, and lighting were established. Second, digital garment models, including T-shirts, shirts, trousers, and dresses, were created using Style 3D, with visual details refined through wrinkle adjustment, fabric texture mapping, and colorway design. A virtual store scene containing functional areas such as window displays, racks, fitting rooms, and a service counter was then constructed using 3Ds Max and Unity. On this basis, an immersive interaction system was developed on the Unity and SteamVR platforms with HTC VIVE devices, enabling first-person roaming, garment information browsing, and real-time color switching. Finally, a questionnaire survey and regression analysis based on the Technology Acceptance Model (TAM) were conducted. The results suggest that the proposed system can support user experience and purchase intention.

Keywords: VR Technology; Virtual Clothing; 3D Modeling; Visual Merchandising; User Experience; Purchase Intention
https://doi.org/10.64509/jdi.13.104

1 Introduction

At present, online apparel shopping is still primarily web-based. Consumers mainly rely on product images, textual descriptions, and user reviews to evaluate products. As a result, online apparel shopping still has weak interactivity, limited immersion, and difficulty in conveying fabric texture and wearing effects, which can affect purchase decisions and increase the risk of returns and exchanges. By contrast, although physical stores provide intuitive try-on experiences and scenario-based consumption, they are constrained by high costs such as rent, labor, store decoration, and geographic limitations. Virtual reality technology, characterized by immersion, interactivity, and multisensory perception, offers a new technological pathway for reconstructing the apparel retail experience. Introducing VR into virtual clothing stores can enhance consumers' perception of apparel products and sense of participation, while also helping merchants reduce operational costs and improve brand presentation. Therefore, research on the construction of virtual clothing store systems and immersive interaction design is of clear theoretical and practical significance.

Existing studies have explored virtual garment modeling, virtual scene construction, and interactive system design [1, 2]. In garment modeling, Shin *et al.* [3] realized virtual garment visualization by combining image rendering with 3D human models, which strengthened the representation of garment details but relied heavily on training data and involved relatively high application costs. Lu *et al.* [4] increased the reusability of 3D garment models by fitting them to human bodies with different body shapes and poses, but their work mainly focused on the garment model itself rather than on retail scenarios. Ma Fenfen [5] reconstructed Tibetan costumes with CLO3D and refined garment simulation effects, yet the study mainly targeted single-garment restoration and lacked expansion to retail space design. In virtual scene research, Deeksha Shravani *et al.* [6] proposed a VR supermarket platform enhanced by intelligent recommendation, but their study focused on general retail scenarios. Chen Wen [7] developed

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a virtual apparel e-commerce platform with 360° virtual try-on and styling functions, but the emphasis remained on try-on and functional display rather than on integrated store-space construction. Lu Wenli [8] and Xu Ling [9] developed virtual costume exhibition and virtual fashion show systems, respectively, expanding the application of VR in fashion display, but these systems mainly emphasized cultural or dynamic presentation and lacked interaction mechanisms oriented toward consumer purchase decisions. In interaction design, Cordier *et al.* [10] proposed an interactive web-based virtual clothing store, but the interaction remained webpage-dependent and lacked immersion. Lv Xinyi [11] constructed a VR-based virtual store, but it was still primarily intended for online viewing. Wang Qi [12] achieved apparel styling display and scene optimization, yet insufficient attention was given to the spatial organization and multi-level interaction of a complete virtual clothing store. More recent studies have extended this field to metaverse fashion retail [13] and AI-driven virtual try-on. Hu *et al.* [14] examined how luxury fashion firms use metaverse retail strategies to enhance brand experience, while Mu *et al.* [15] discussed the prospects of fashion intelligence in the metaverse. Islam *et al.* [16] reviewed deep learning-based virtual try-on methods, showing that AI try-on research mainly focuses on garment transfer, personalized fitting, and image-based visualization.

Despite recent advances in metaverse fashion retail and AI-driven virtual try-on, current research still shows three limitations. First, the overall space, functional zoning, merchandise display, and lighting atmosphere of virtual clothing stores are not yet fully integrated. Second, most existing systems still rely on PC-based operation, resulting in limited immersion and natural interaction. Third, garment models, scene construction, and interactive systems are often developed separately, lacking an integrated implementation path. To address these gaps, this study proposes a VR-based design and implementation method for a virtual clothing store. Through garment modeling with texture and wrinkle refinement, virtual store scene construction, and immersive interaction system development, it establishes an implementation workflow from offline store investigation to VR system deployment, forming an integrated ”garment space merchandising interaction” framework. Unlike existing studies that focus on a single aspect such as garment modeling, virtual scene construction, or interaction design, this work brings these three dimensions together and further examines their influence on consumer purchase intention through the TAM model. This study provides a practical implementation pathway for the digital transformation of apparel retail.

2 Design Framework

2.1 Overall Framework Design

Based on field investigations of physical stores and a comparative analysis of online virtual platforms, this study identified a virtual clothing store for young consumers as the research target and divided the implementation process into three interconnected levels: garment content construction, store scene construction, and VR system integration [17], as shown in Figure 1.

Figure 1 illustrates the overall framework of the virtual clothing store. At the garment construction level, the required garment categories were determined and digitally modeled using Style 3D. At the store scene construction level, 3Ds Max and Unity were used to build the store space, display devices, and decorative environment, while texture mapping and lighting design were applied to improve scene realism. At the VR system integration and testing level, Unity and SteamVR were used to integrate system functions, enabling users to enter the virtual store through HTC VIVE devices and perform immersive roaming, garment information browsing, and color switching. In this way, a complete implementation path from content production to spatial construction and system operation was established.

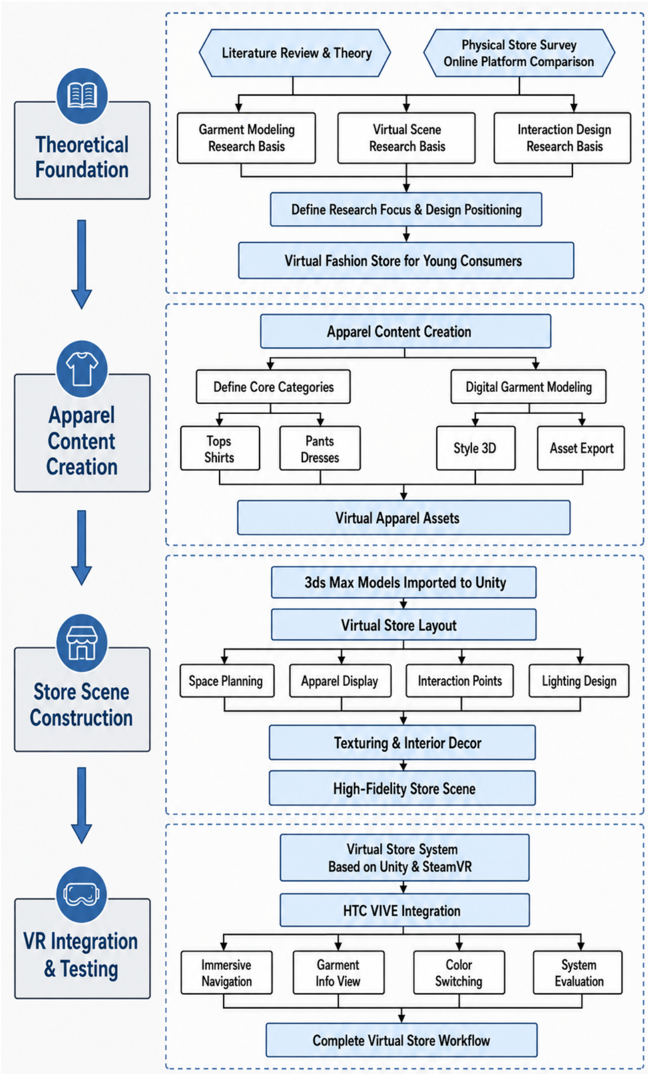

Figure 1: Overall framework

2.2 Garment Content Construction

Garment content construction was carried out first. According to the display requirements of a fashionable womenswear store, T-shirts, shirts, trousers, and dresses were selected as the core garment categories. More than 40 digital garment models were ultimately created, forming a structured merchandise library. Style 3D was used for pattern import, avatar matching, virtual sewing, and fabric and wrinkle processing. The front and back panels, sleeves, and other structural parts of each garment were sewn together, after which key details such as necklines, cuffs, waists, and bust wrinkles were adjusted to refine the integrity and visual quality of the garment silhouettes, as shown in Figure 2.

Figure 2: Virtual sewing

Further refinement was then performed to optimize wrinkles and drape effects by adjusting internal lines, folding arrangements, and particle spacing. Garment craftsmanship details were also strengthened by adding buttons, topstitching, and local thickness treatments. To improve visual expressiveness, Adobe Photoshop was used to create graphic patterns and fabric textures, making the garments more comparable to real retail products in terms of pattern continuity, color performance, and material appearance, as shown in Figure 3.

(a) White shirt model (b) Textured shirt model

Figure 3: Shirt design

Finally, to support the display of multiple colorways of the same style and the subsequent color-switching interaction, selected core styles were developed into multiple color schemes. This improved the diversity of product display and the feasibility of system interaction, as shown in Figure 4.

Figure 4: Colorway design

2.3 Store Scene Construction

For store construction, the store was first positioned as a fashionable womenswear shop for young female consumers based on field investigations of physical stores, with particular attention paid to store decoration style, clothing type, and customer circulation patterns. These observations were used to determine the overall design direction of the virtual store.

Second, in terms of spatial organization, the virtual store was divided into a window display area, merchandise display area, fitting room, and service counter, and the overall spatial framework was built in Unity. The store was constructed at a near 1:1 scale [18], with an approximate spatial size of 10 m × 8 m × 4 m and an entrance width of about 2 m, while the remaining frontage was designed as the window display area. This arrangement ensured that users could follow a clear browsing path when entering the system, as shown in Figure 5.

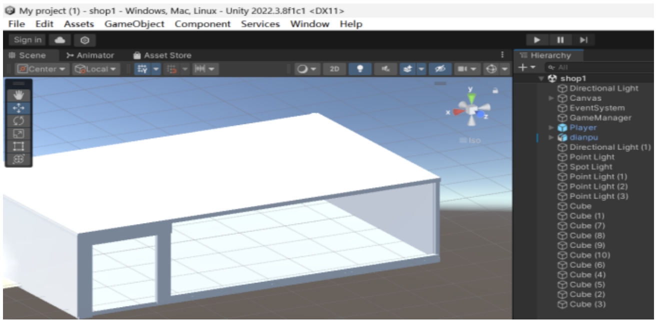

Figure 5: Storefront model design

For local display modules, 3Ds Max was used to build mannequins, display shelves, hangers, window installations, and part of the interior decoration, which were then imported into Unity [19]. The window area was designed as the main visual focus through the combination of mannequins, garments, and decorative elements. Garment racks and shelves displayed clothing through hanging, folding, and grouped arrangements, while the service counter, sofas, and green plants were used to improve the spatial structure and visual hierarchy of the store, as shown in Figure 6.

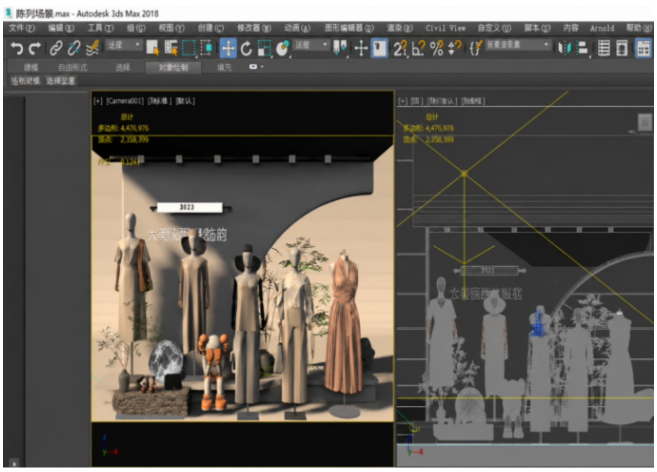

Figure 6: Window display modeling

After scene construction, texture mapping and visual optimization were further applied to both garments and the store. Garment surface detail was represented through fabric textures, pattern mapping, and color expansion. The store environment was refined through unified material treatment of walls, floors, shelves, and decorative objects. Featured items, coordinating items, and garments of different color series were also displayed in an organized manner according to merchandising principles. Lighting combined general lighting, accent lighting, and auxiliary lighting. Spotlights were placed in the window area to highlight key display items, while point lights and natural lighting were used inside the store to simulate indoor illumination. The resulting virtual clothing store employed 2048×2048 texture maps, physically based rendering (PBR) materials, and a three-layer lighting scheme (ambient, accent, and spot), as shown in Figure 7.

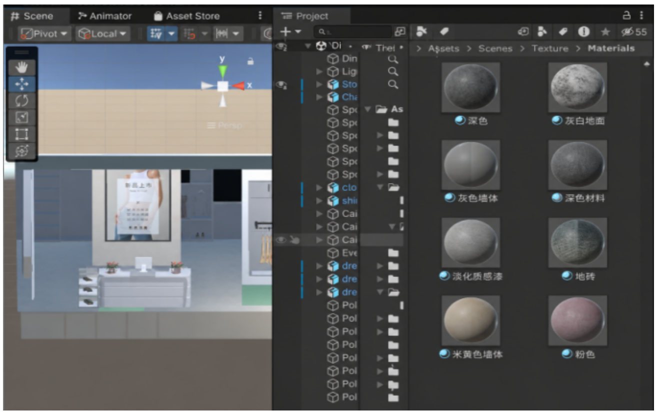

Figure 7: Store texture mapping

2.4 VR System Integration and Interaction Embedding

For VR system integration and interaction development [20], Unity was used as the core development platform, SteamVR served as the virtual reality runtime interface, and HTC VIVE head-mounted displays and controllers were used to establish the interactive environment. First, the Steam environment and VR plug-ins were configured to connect the headset, controllers, and computer. Second, the garment models, character models, and store scene assets created in Style 3D and 3Ds Max were imported into Unity, where file format conversion, material transfer, skeleton matching, and hierarchy organization were completed. Subsequently, scene layout and script mounting were carried out in Unity to develop first-person roaming, garment information display, and garment color switching. The roaming function supported user movement and observation inside the virtual store; the information display function retrieved the garment's price, fabric, and style; and the color-switching function called different colorways of the same garment. Dynamic digital characters and background music were also added to enrich the interactive content and atmosphere of the virtual store.

The development environment was configured with Unity 2022.3.8f1c1, SteamVR 2.8.0, and VRTK 4.0, deployed on an HTC VIVE Pro Professional Edition headset connected to a computer equipped with an AMD Ryzen 7 processor, 16 GB RAM, and an NVIDIA GeForce RTX 4060 GPU (GDDR6) running Windows 11. Garment textures were rendered at 2048×2048 resolution and scene assets at 1024×1024 resolution. The system was configured according to the 90 Hz refresh requirement of the HTC VIVE Pro, with motion-to-photon latency controlled toward the commonly accepted VR comfort threshold of below 20 ms. Each garment model contained approximately 5,000–15,000 triangles, and the total scene complexity was kept under 500,000 triangles to support smooth real-time performance on the target hardware.

3 Implementation and Evaluation

Based on the construction workflow described above, this section evaluates the implemented garment display, store scene, and interaction performance from the perspectives of visual presentation, system operation, and scalability.

3.1 Visual Evaluation of Garment Display

In the visual evaluation of garment display, the completed digital garments were examined in terms of silhouette, fabric texture, wrinkle layers, color differences, and real-time rendering suitability. The shirt model, for example, displayed details such as the neckline, cuffs, and front pleats, while after texture mapping, the pattern and fabric texture became clearer, as shown in Figure 8.

(a) Before wrinkle processing (b) After wrinkle processing

Figure 8: Wrinkle processing

The skirt model further showed the waist structure and fabric drape after styling, supporting a coordinated outfit display, as shown in Figure 9.

(a) White skirt model (b) Textured skirt model

Figure 9: Skirt design

Colorway design enabled the same garment style to be displayed in multiple color schemes, which increased the richness and consistency of merchandise presentation. All color variants shared the same topology and UV layout, so texture memory overhead remained constant regardless of the number of colorways, making the approach suitable for real-time VR rendering. Taken together, the constructed virtual garments showed clear retail-display attributes and could support subsequent store merchandising and color-switching functions.

3.2 Visual Evaluation of Store Scene

In the visual evaluation of the store scene, the implemented virtual clothing store was examined as an integrated retail space. The near 1:1 scene presented the spatial boundaries, internal structure, and browsing circulation of a physical apparel store.

In the final effect, the window area served as the primary visual anchor of the store. The combination of mannequins, garments, and decorative elements gave the storefront a clear display identity with high visual contrast against the surrounding scene. Inside the store, a layered arrangement was created through shelves, hangers, and mannequins, allowing different garment types to be placed by area and reflecting the merchandising logic of featured items, coordinated items, and garments of different color series. Meanwhile, the addition of the counter, sofas, and green plants improved the functional and decorative completeness of the store, making the overall atmosphere closer to that of a real retail store.

The store's exterior and interior presentation was refined through texture mapping, merchandising, and lighting optimization. Window spotlights strengthened the emphasis of the entrance display, while indoor point lights and natural light made garment contours, material relationships, and spatial layers clearer. Together, these elements formed a virtual clothing store scene with spatially consistent visual quality, as shown in Figure 10. The entire store scene comprised approximately 200K visible triangles per frame. Under the target hardware configuration (ASUS TUF A4, RTX 4060, 16 GB RAM), the system was designed around the 90 FPS display requirement of the HTC VIVE Pro and the VR comfort threshold of motion-to-photon latency below 20 ms, providing a basis for real-time immersive browsing.

(a) Storefront (b) Interior display

Figure 10: Overall design of the virtual clothing store

3.3 System Performance Evaluation

In the system performance evaluation, the implemented interaction functions were examined in the VR environment. After wearing the HTC VIVE headset, users could browse the virtual store in a first-person perspective and use the controller to move forward, turn, and observe the window area, display racks, and key garments along the designed path. Unlike the "flat browsing" mode of conventional web-based shopping, the system transformed garment presentation from page switching into immersive roaming in real space, allowing users to perceive the store scale, display relationships, and product distribution while gaining a sense of spatial presence that is difficult to achieve in 2D browsing interfaces, as shown in Figure 11. In terms of system responsiveness, color switching was implemented as a lightweight material or texture replacement operation, and the UI panel was designed to respond immediately to controller input. These design choices helped provide a fluid interactive experience during normal roaming and browsing.

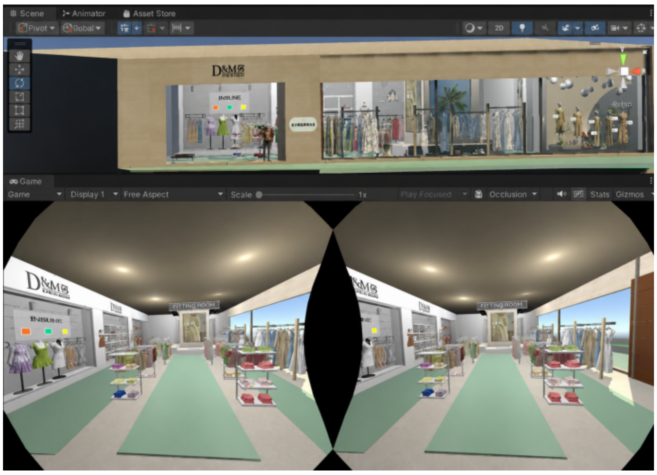

Figure 11: Roaming effect

For merchandise information interaction, the system enabled users to retrieve garment detail interfaces. When approaching a target garment, users could click the corresponding button with the controller to open a UI panel and view information such as the garment's style, fabric, color, and price. After viewing, the interface could be closed and the user could continue exploring the scene. This function allowed the system not only to display garment appearance but also to present merchandise information synchronously, which strengthened the retail attributes of the virtual store, as shown in Figure 12.

Figure 12: Window-detail interface

Regarding garment color interaction, the system realized real-time color switching for the same garment style. Multiple color options were provided in the interface, and users could switch colors through controller raycasting and drag operations. After switching, the garment model immediately displayed the new color state, enabling users to intuitively compare the same style under different color conditions. This function supported the online shopping process of browsing multiple colorways of the same product while enhancing user engagement and interactivity, as shown in Figure 13.

Figure 13: Garment color switching

Dynamic characters and background music were incorporated into the system. The animated store-assistant figure increased scene liveliness, while the background music further reinforced the atmosphere of a fashionable womenswear store. In this way, the system completed the basic interaction flow of "entering the store – roaming and browsing – viewing garment information – switching garment colors."

For scalability, the current prototype was designed for a 40-plus-garment demonstration rather than a large commercial inventory. The main rendering load would increase when many high-polygon garments, fabric textures, and display props enter the camera view at the same time. In this system, wrinkle effects were mainly completed during Style 3D modeling and imported into Unity as preprocessed geometry and texture information, so the roaming stage did not require real-time cloth simulation. Color switching was implemented by replacing material or texture variants on the same garment structure, keeping the interaction lightweight. During normal roaming along the aisle and display route, the scene remained visually smooth in observation, while occasional frame drops could occur when dense garment areas were viewed simultaneously or when the viewpoint was rotated rapidly. For larger inventories, LOD (Level of Detail), frustum culling, occlusion culling, texture compression, batching, and on-demand loading should be adopted to reduce the number of rendered polygons and texture memory use.

4 Purchase Intention Analysis

The theoretical pathways through which multidimensional VR experiences—sensory, interactive, emotional, and thinking—influence consumer purchase intention via perceived usefulness (PU) and perceived ease of use (PEOU) have been established in prior research [21, 22]. Building on this framework, the present study introduces the Technology Acceptance Model (TAM) [23] to empirically validate the application value of the VR clothing store. In the research model, sensory experience, interactive experience, emotional experience, and thinking experience were treated as antecedent variables; PU and PEOU were treated as mediating variables; and purchase intention (PI) was treated as the outcome variable [24], as illustrated in Figure 14. In this study, sensory experience (SE) refers to consumers' visual and auditory perception of the virtual store environment; interactive experience (IE) refers to real-time controller-based interaction with the virtual scene; emotional experience (EE) refers to affective responses evoked by the shopping atmosphere; and thinking experience (TE) refers to cognitive engagement and curiosity stimulated by the virtual store.

$$
\begin{aligned}
PU &= \beta_1 SE + \beta_2 IE + \beta_3 EE + \beta_4 TE + \varepsilon_1 \\
PEOU &= \beta_5 SE + \beta_6 IE + \beta_7 EE + \beta_8 TE + \varepsilon_2 \\
PI &= \beta_9 SE + \beta_{10} IE + \beta_{11} EE + \beta_{12} TE \\
&\quad + \beta_{13} PU + \beta_{14} PEOU + \varepsilon_3
\end{aligned} \tag{1}
$$

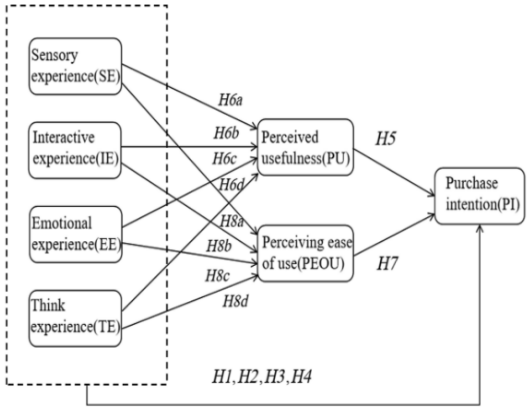

Figure 14: Purchase intention analysis model

Questionnaires were distributed to young consumers aged 18–35, yielding 202 valid responses. The measurement scales were adapted from established studies, and the data analysis procedures followed the established methodology in prior research [21]. Based on statistical results from 202 valid samples [25], the measurement scale met the acceptable thresholds for reliability and validity and was suitable for subsequent analysis. Direct-effect testing showed that both perceived usefulness and perceived ease of use had positive effects on purchase intention. The path coefficient for PU $\rightarrow$ PI was $\beta = 0.454$, $t = 7.214$, $p < 0.001$, while that for PEOU $\rightarrow$ PI was $\beta = 0.544$, $t = 9.160$, $p < 0.001$ [26]. These results suggest that the more users believe that the VR clothing store helps them understand product information efficiently, improves their shopping judgment, and provides a clear interface and convenient interaction, the higher their reported purchase intention. Among the four experience dimensions, sensory experience ($\beta = 0.414$) and thinking experience ($\beta = 0.400$) showed stronger direct effects than interactive experience ($\beta = 0.210$) and emotional experience ($\beta = 0.183$), indicating that visual perception, product information clarity, and cognitive engagement were more influential in this VR shopping context. Compared with PU, PEOU exerted a greater influence, suggesting that interaction smoothness and interface comprehensibility are especially important for user acceptance of virtual clothing stores [27], as shown in Figure 15 and Table 1.

Further mediation analysis showed that both PU and PEOU played mediating roles between multidimensional experience and purchase intention [28]. Sensory experience, interactive experience, emotional experience, and thinking experience could promote purchase intention both directly and indirectly by strengthening users' perceptions [29] that the system was "useful" and "easy to use." Among them, the positive effects of sensory experience and thinking experience on purchase intention through PEOU and PU [30] were more pronounced, indicating that immersive visual and auditory perception, clear information presentation, and the stimulation of users' attention and curiosity can strengthen their acceptance of the VR clothing store. In particular, the largest mediation coefficient was observed for SE → PEOU → PI ($\beta = 0.401$), followed by TE → PU → PI ($\beta = 0.346$) and IE → PU → PI ($\beta = 0.298$), suggesting that sensory presentation and thinking-based product evaluation were the most important indirect pathways, as shown in Table 2.

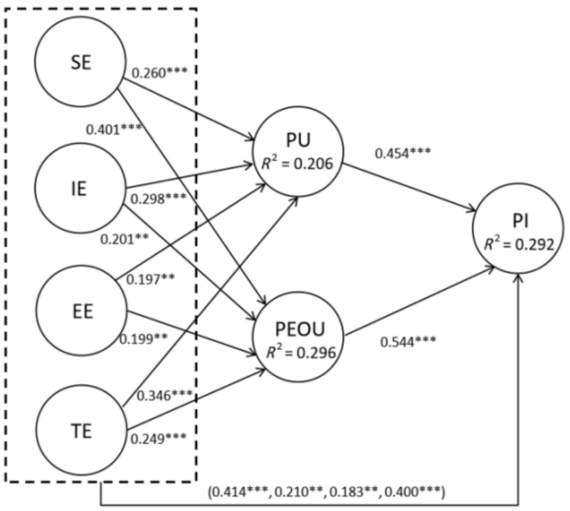

Figure 15: Path coefficient diagram

Overall, the virtual clothing store constructed in this study showed positive perceived usefulness and perceived ease of use at the empirical level [21]. On the one hand, the system helped users acquire intuitive information about garment style [25], fabric, color, and price, supporting the perceived usefulness of the system. On the other hand, first-person roaming, information retrieval, and color-switching functions allowed users to browse and interact smoothly, confirming the perceived ease of use of the system. Together, these two factors promoted purchase intention, indicating that virtual clothing stores have potential for further application development and commercial promotion [31].

5 Conclusion and Future Outlook

This study proposed an integrated design and implementation method for a VR-based virtual clothing store, covering garment modeling, store scene construction, and immersive interaction system development. Over 40 digital garment models were created using Style 3D, a complete virtual store was constructed with 3Ds Max and Unity, and interactive functions including first-person roaming, garment information browsing, and real-time color switching were implemented on the HTC VIVE platform. The TAM-based empirical analysis with 202 valid responses showed that all four experience dimensions—sensory, interactive, emotional, and thinking—positively influenced purchase intention, with perceived ease of use showing the strongest effect.

However, this study has limitations. The current prototype was designed for a limited garment inventory rather than a commercial-scale catalog, and the sample consisted mainly of young consumers. Tactile feedback and real-time cloth simulation were not included. Future work could expand the garment database, incorporate AI-driven personalized recommendation, and conduct longitudinal studies on repurchase behavior and brand loyalty in VR retail environments.

Table 1: Direct effect results

Hypothesis	Path	β-values	t-values	p-values	Result
H1	SE → PI	0.414	6.438	< 0.001	Supported
H2	IE → PI	0.210	3.037	0.003	Supported
H3	EE → PI	0.183	2.638	0.009	Supported
H4	TE → PI	0.400	6.168	< 0.001	Supported
H5	PU → PI	0.454	7.214	< 0.001	Supported
H7	PEOU → PI	0.544	9.160	< 0.001	Supported

Note: All p-values are two-tailed. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

Table 2: Mediation effect results

Hypothesis	Path	β-values	t-values	p-values	Result
H6a	SE → PU → PI	0.260	3.812	< 0.001	Supported
H6b	IE → PU → PI	0.298	4.416	< 0.001	Supported
H6c	EE → PU → PI	0.197	2.841	0.005	Supported
H6d	TE → PU → PI	0.346	5.220	< 0.001	Supported
H8a	SE → PEOU → PI	0.401	6.182	< 0.001	Supported
H8b	IE → PEOU → PI	0.201	2.897	0.004	Supported
H8c	EE → PEOU → PI	0.199	2.868	0.005	Supported
H8d	TE → PEOU → PI	0.249	3.629	< 0.001	Supported

Note: All p-values are two-tailed. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

Funding

This research received no external funding.

Author Contributions

Conceptualization, Z.X. and Y.C.; methodology, Z.X.; software, Z.X.; validation, R.C.; formal analysis, R.C.; investigation, R.C.; resources, Y.C.; data curation, R.C.; writing—original draft preparation, Z.X.; writing—review and editing, Z.X.; visualization, Z.X. and R.C.; supervision, Y.C.; project administration, Z.X. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

All the authors declare that they have no conflict of interest.

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