

A Mixed Reality-Based Personalization System for Recreational Vehicle Interior Customization

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Abstract: Traditional RV customization relies heavily on designer-led communication and static visualization, often resulting in vague user requirements, low efficiency, and high modification costs. This study presents a Mixed Reality (MR)-based personalization framework for RV interior customization using Microsoft HoloLens 2. The proposed system enables users to visualize and modify interior layouts, materials, and components through real-scale, gesture-controlled interaction in a physical environment. A complete MR workflow was designed-including system architecture, user interface, and feedback mechanisms - to enhance immersion and collaboration. Usability testing with 10 participants achieved a 100% task completion rate, an average test time of 161.4 ± 15.70 seconds, a mean System Usability Scale (SUS) score of 80.39 ± 3.60 (Good grade), and a mean Compared System Usability Scale (C-SUS) score of 85.70 ± 12.78 (Excellent grade), indicating high effectiveness and user satisfaction. Compared with traditional design methods, the MR approach improved interaction efficiency and reduced communication delays between users and designers. The research demonstrates the feasibility of MR as an immersive, user-centered solution for personalized vehicle customization and provides practical insights for future intelligent manufacturing applications.

Keywords: customization; Microsoft HoloLens2; mixed reality; personalization; RV interior

1 INTRODUCTION

Since the late 1980s, consumers' demand for customized products and services has gradually increased. Although this kind of personalized service is possible, there are still many challenges in realizing personalization for some industries that use the traditional model of producing before selling [1], and the model as one-to-one customization, inevitably inefficient and costly [2]. Manufacturing is transitioning from traditional mass production to Mass Customization (MC), to cater to customers with diverse and personalized needs [3], including product styling, functionality, structure and other aspects [4]. Recreational vehicle (RV), particularly its interior spaces, represents a typical product category with pronounced personalized requirements. Generally, its customization process is primarily designer-driven and relies heavily on offline interactions. The typical workflow involves consumers' communicating their needs to sales personnel, who then relay these requirements to designers for customization, as shown in Fig. 1. Key challenges in this process lie in acquisition, transformation, and communication of user requirements: The user's demand expression often is vague, which leads to product design relying more on the designer's experience rather than the actual consumer demand, and cognition difference between designers and consumers can frequently lead to repeated design modifications [5]. Inaccurate demand transformation reduces the success rate of product design and further increases operating costs [6]. From a design standpoint, MC is mainly manifested in two dimensions: one lies in expanding the design modules of the product itself, and the other centers on uncovering latent user experience needs [7].

The rapid development of technology has facilitated the realization of personalization [4]. The Internet has become an effective tool for enabling product customization [8], playing a significant role in the fields of product design, manufacturing, and supply chain management. A variety of visual tools and applications have been developed, including interactive design software

and digital technology platforms [9-11]. In 1996, Dell Inc. added e-commerce functionality to its portal, via an online platform, allowing consumers to select product configurations. The company then assembled and produced computers based on consumer preferences, thereby offering customized products with minimal price variation [12]. With the development of the Internet, similar applications have become increasingly common, as shown in Fig. 2. Nervous System represents a more advanced personalized customization (<https://n-e-r-v-o-u-s.com/>). On this website, consumers can adjust parameters such as the size, elements, and density of jewelry to change the overall shape of the jewelry. Through 3D printing, they obtain personalized items and gain a deeply engaging experience. This fully customized approach is particularly effective for small accessories like jewelry. Similarly, users can configure features such as body color, lighting, wheel hub design, interior materials and colors for Tesla electric vehicles. They can observe the effects in 720° panoramic views to finalize their purchase style. Customization applications in industries such as automobiles, computers, and electronics have received positive feedback from both consumers and enterprises [13, 14]. These approaches not only accurately address individualized consumer needs but also foster deeper brand trust and emotional resonance [15].

RVs are high-value products with large size and complex structure, suffer from inefficient communication between designers and consumers when relying on traditional media such as design drawings, photographs, and videos. Due to the limitations of personal computers in terms of presentation and interaction, there are also significant differences between the three-dimensional spatial sense, realism and customization effect of Internet-based customization methods. Zafiroglu and Chang revealed the significant advantages of digital technologies in RV design - noting their potential to offer greater spatial flexibility for consumers and enhance the personalized customization experience [16], their work lacked practical validation regarding design efficiency improvement and the enhancement of consumer immersion and engagement.

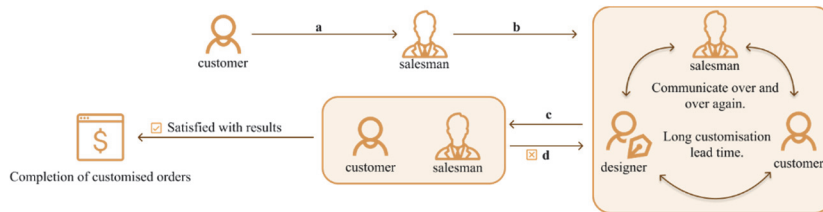


Figure 1 Traditional RV customization process (a) Contact sales with customization requirements; b) Salesman organizes a group chat; c) View customized results; d) If unsatisfied with results, return to factory for modification.)

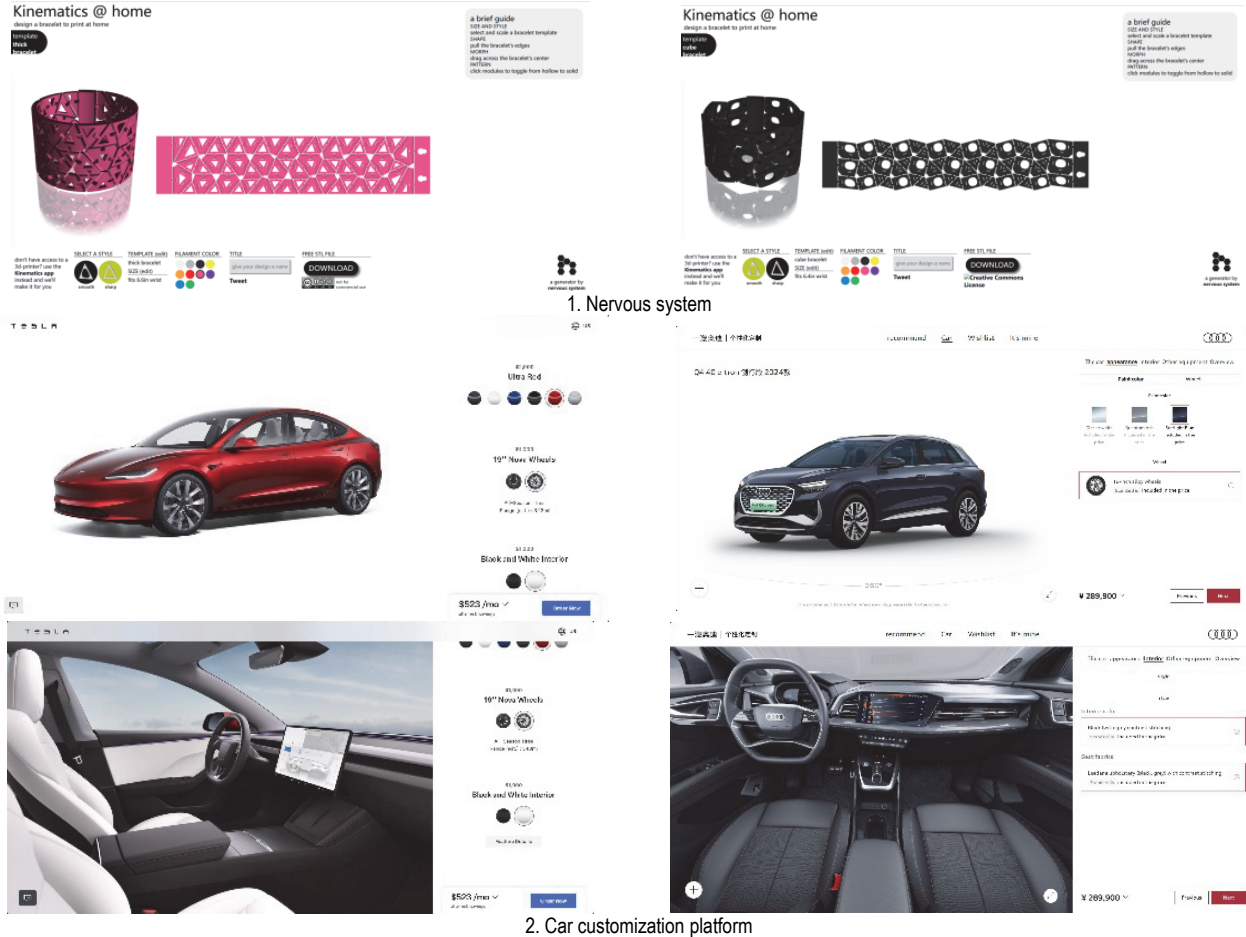


Figure 2 Example of customization systems

This study proposes a MR-based framework for RV interior customization. This framework integrates spatial visualization and gesture-based interaction to elevate the consumer experience. The usability and efficiency of the system, along with subjective user satisfaction, are rigorously evaluated through controlled testing.

2 REVIEW

2.1 Mass Customization

2.1.1 Mass Customization Framework

The MC framework is a systematic approach to transforming consumer needs into final products, encompassing five areas, as illustrated in Fig. 3.

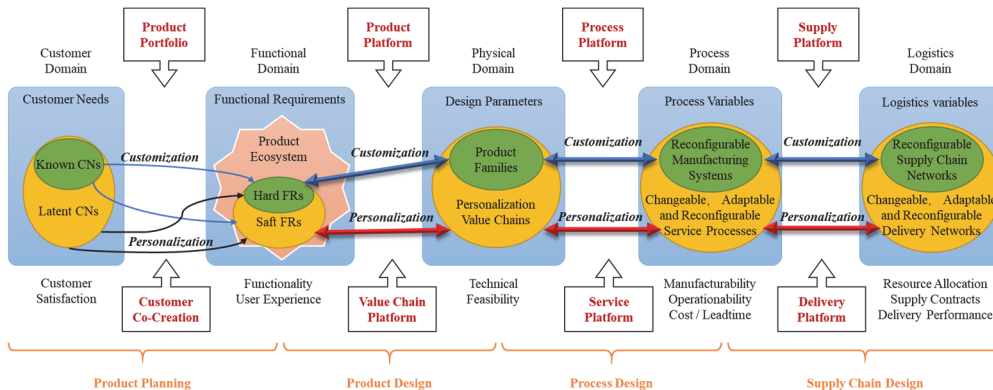


Figure 3 A framework for MC [4-5]

The customer domain, the functional domain, the physical domain, the process domain, and the logistics domain [4, 5]. The framework aims to address specific functional requirements, which are usually clearly defined and directly related to the physical characteristics of the product. Basic functions and performance are usually achieved through physical components. For example, in computer design, hardware elements like CPU, memory, and storage are directly related to system performance. Custom solutions are usually provided by adjusting the arrangement and combination of such components to individual needs.

However, in addition to these explicit functional requirements, there are other implicit functional requirements, such as software, services, processes and other intangible elements. Variations of these functional requirements are relatively easy to design and have low implementation costs [4, 5].

2.1.2 Requirements of RV Interior Customization System

According to the preliminary research and analysis of RV-related personnel, it is found that the consumers' needs are relatively extensive, of which the explicit functional needs are mainly materials, color, style, layout, etc.; the invisible functional needs mainly contain the requirements of technology, man-machine, safety, and other software, as well as the service experience of the atmosphere, journey, use of feelings, brand, and other needs.

Therefore, to achieve the design of an effective customization platform, the following five functions should be incorporated:

(1) Provision of diverse options and configurations: Enable consumers to make selections based on their individual preferences and needs. This includes providing customizable options for aspects such as color, material, dimensions, and functionality [17].

(2) Design references and case studies: Offer a rich repository of design references and case studies. This assists consumers in understanding the characteristics of different styles and design solutions, facilitating a more accurate expression of their needs and preferences [18].

(3) Real-time feedback and adjustment: Provide immediate feedback to consumers during the design

process. This allows them to visualize the impact of their choices and adjustments on the final design, fostering more active and engaged participation [19].

(4) Consumer research and feedback mechanism: Implement a structured approach for conducting regular consumer surveys and gathering feedback. This mechanism is crucial for gaining deeper insights into consumer needs and opinions, enabling the timely optimization of both the customization system and design proposals, ultimately enhancing consumer satisfaction and engagement.

(5) Personalized recommendations and suggestions: Leverage data on consumers' historical choices and preferences to offer personalized design recommendations and advice. This guides consumers towards more informed decisions and strengthens their sense of involvement [20].

2.2 Mixed Reality

Mixed reality (MR) is a technology that integrates the real world with the virtual world, enabling natural and intuitive interaction between humans, machines and the real environment to the greatest extent possible [21]. Milgram and Jr define MR as a combination of Augmented Reality (AR) and Virtual Reality (VR), in which virtual objects are superimposed on real space [22]. MR technologies, including AR and VR, have developed rapidly and have achieved a variety of application scenarios, helping stakeholders to participate in the design process [23], improving consumer engagement and user experience [24], and having significant advantages in evaluating the design of highly interactive products.

2.2.1 Characteristics of MR

The technical principles of MR technology mainly include visual perception, positional tracking, computer vision, 3D modeling, spatial awareness and mapping, physics and collision detection. The combination of these technologies makes MR technology more effective in terms of interaction, the combination of reality and illusion, and sense of immersion and spatial positioning has obvious advantages. It is reflected in the following four aspects, as shown in Fig. 4.

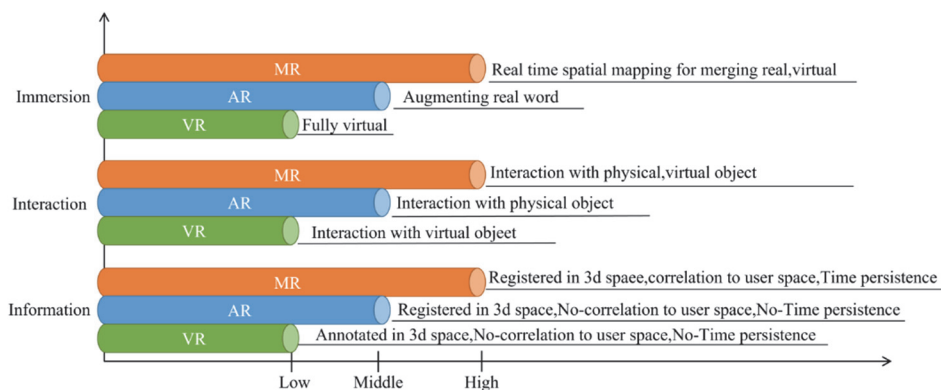


Figure 4 A comparison of three features about VR, AR, and MR [27]

(1) In terms of interaction [25], MR technology can be used to control and manipulate virtual objects through a variety of interaction methods, such as visual recognition, gesture recognition, voice recognition, and so on, thus

improving the user's interactive experience and sense of participation.

(2) In terms of the integration of virtual and reality [26], MR technology can combine virtual and real environments

through visual perception, 3D modeling, and other technologies, enabling consumers to experience real and virtual content at the same time, thereby enhancing their perception of the scene.

(3) In terms of spatial positioning, MR technology can accurately locate the user's position and posture of users in the real environment through technologies such as position

tracking and computer vision, so that virtual objects can be accurately positioned in the real scene.

(4) In terms of immersion, MR technology presents more realistic and vivid scenes through visual perception and computer graphics, thereby enhancing consumers' immersion and participation, and significantly improving experience.

Table 1 Comparison among VR, AR, and MR technologies in the context of RV interior customization

Feature	Traditional method	VR	AR	MR (used in this study)
Device Used	Language, sketching, and more	HMD (Oculus Rift, HTC Vive...)	Mobile phone/tablet, smart glasses	HoloLens 2
Environmental Immersion	/	Full, complete virtual simulation	Partial - overlays virtual on real	Hybrid - integrates virtual into real space
User Interaction with Physical Space	/	/	Limited (no occlusion or physical understanding)	High (spatial mapping, gesture input)
Physical space constraints	/	high	low	low
Suitability for Real-time Customization	/	Medium - immersive but not context-aware	Low - limited tracking and model interaction	High-real-time interaction within physical RV
Spatial Awareness	/	Not applicable	Basic (no depth sensing)	Advanced (depth mapping, SLAM)
User Experience Feedback	/	Fully simulated, may be disorienting	Static overlays	Dynamic, context-aware, intuitive feedback
Cognitive Load	/	Moderate to high (learning curve)	Low to moderate	Moderate, balanced with real-world anchors
Application to RV Interior Customization	Suitable	Suitable but lacks integration with a real RV	Limited - lacks scale & depth perception	Optimal - blends digital customization into RV

2.2.2 Comparison about VR, AR, MR for Customization

VR [28], AR [29] and MR technologies exhibit different characteristics in the customization process, as shown in Tab. 1.

(1) VR Customization

a) VR technology can provide a fully immersive experience, allowing consumers to fully integrate into the virtual environment. This experience allows consumers to deeply feel the appearance and texture of the product, thus enabling more precise personalization [30]. This immersion surpasses the other two technologies, providing consumers with a more intuitive and concrete experience, but may lead to disorientation.

b) The technology completely isolates consumers from the real world, allowing them to focus on the product customization process without external interference. This focus helps consumers to understand and experience the personalization process more deeply, thereby improving the quality and satisfaction of customization. However, a significant limitation of this approach is its substantial reliance on a dedicated physical space, which restricts its portability and flexible deployment across different environments.

(2) AR Customization

a) AR technology superimposes virtual objects into the real-world, enabling users to experience product effects directly in the actual environment. This integration with the actual environment can help users assess the adaptability and usefulness of the product better [23], leading to more effective personalization. However, for large-scale objects, visual incompleteness or occlusion may occur.

b) The technology allows users to adjust the attributes of virtual objects in real time and view their effects immediately. This real-time adjustment and feedback can help users customize products more flexibly to meet their individual needs, but the interaction means are relatively simple.

(3) MR Customization

a) MR technology adeptly integrates the advantages of VR and AR [25], enabling seamless integration of virtual objects into the real environment. This allows consumers to interact with virtual content while remaining grounded in their physical surroundings. The fusion preserves the authenticity of the real world while delivering a highly immersive experience.

b) MR allows users to interact with both physical and virtual objects through multi-modal channels, adjust virtual properties in real-time, and observe changes instantly while maintaining awareness of their actual environment. This flexibility enables more accurate evaluation of a product's effectiveness and supports more dynamic parameter adjustments [31].

c) MR systems support multi-user collaboration and shared experiences by allowing several consumers to connect simultaneously to the same mixed-reality environment. Participants can collectively view and modify product designs. This collaborative functionality enhances cooperation between consumers and designers, accelerates the customization process, and helps ensure the final product aligns with consumer expectations [32].

3 METHODOLOGY

3.1 System Development

3.1.1 System Development Platform

In the field of MR devices, HoloLens 2 incorporates spatial modeling, object recognition and tracking, coordinate registration and mapping, visualization, and information transmission rendering algorithms. Combined with its perception of the real environment and capture of consumer gestures and movements, it can achieve intelligent interaction through voice recognition, haptic feedback, and sound interaction. This allows consumers to interact with full-size virtual models in physical space, adjust key design elements such as color, material, and

style in real time, and receive instant visual feedback, intuitively showcasing functional customization features that are difficult to convey quickly using traditional methods. These factors provide ample justification for using HoloLens 2 as the development platform in this study.

3.1.2 System Requirements for Physical Space

This system will be used in various environments such as offline stores and exhibition halls. To ensure that the system is suitable for actual scenarios, specific performance indicators must be met. Based on the technical characteristics, HoloLens 2 devices have certain requirements for the spatial size and lighting conditions of the usage scenarios.

(1) Spatial requirements

Using mixed reality technology, consumers can view virtual objects at their actual scale within a physical space. The equivalent dimensions of a typical RV generally range from 5m to 9m in length and approximately 3m in height. To achieve accurate alignment between virtual objects and the physical environment, the space must be sufficiently open and free of complex structural elements that could interfere with device positioning [33].

(2) Lighting Requirements

The HoloLens 2 relies on its depth-sensing cameras and optical sensors to capture and track objects in the surrounding environment [34]. Therefore, illumination intensity is critical to the performance and functionality of the device. For effective environmental recognition and tracking, the HoloLens 2 requires lighting conditions adequate for normal visual perception. Unstable ambient lighting may lead to tracking inaccuracies or failures, negatively impacting the user experience [35].

3.1.3 System Development Environment and Tools

(1) Hardware configuration

A laptop (ROG Phantom 16), equipped with an Intel i7 processor, 16 GB of RAM, a 1 TB solid-state drive, and an NVIDIA GTX 3060 graphics card, provided the necessary computational performance to support real-time MR

rendering and interaction. A HoloLens 2 head-mounted display was used as the deployment device. It was connected to the laptop via a 5 GHz Wi-Fi network using holographic remoting technology, enabling real-time streaming and synchronization between Unity and the headset.

(2) Software development

Rhinoceros 6 was employed to construct 3D models of the RV structure and its interior components. Figma was used to design the interactive interface for the customization prototype. Unity 2020 served as the primary development platform, with C# as the scripting language for implementing system logic and user interaction. Prior to development, the Mixed Reality Toolkit 2 (MRTK2) was integrated into Unity to configure the MR development environment and ensure compatibility with the HoloLens 2.

3.1.4 Consumer Demands for Customized RV Interiors

Based on the analysis of RV interior customization requirements and applying the Interaction Network Relationship Map (INRM) method proposed by Si et al. [36], a structured consumer demand system was constructed.

(1) An 11-expert valid scoring questionnaire was collected using a five-point Likert scale. The normalized direct influence matrix *N*, as shown in Tab. 2, was obtained after normalization processing.

(2) Using the matrix, the centrality and causality degrees were calculated, and demand elements were mapped onto a two-dimensional plane to form the INRM quadrant diagram, as shown in Fig. 5, with causality on the horizontal axis and centrality on the vertical axis. This visual framework helps identify core, dependent, linkage, and independent elements. The results show the following order of descending centrality importance: perception, constraint, value-added, product, and storage elements, which were assigned weights of 5, 4, 3, 2, and 1, respectively. These findings provide a quantitative basis for prioritizing customization strategies in RV interior design.

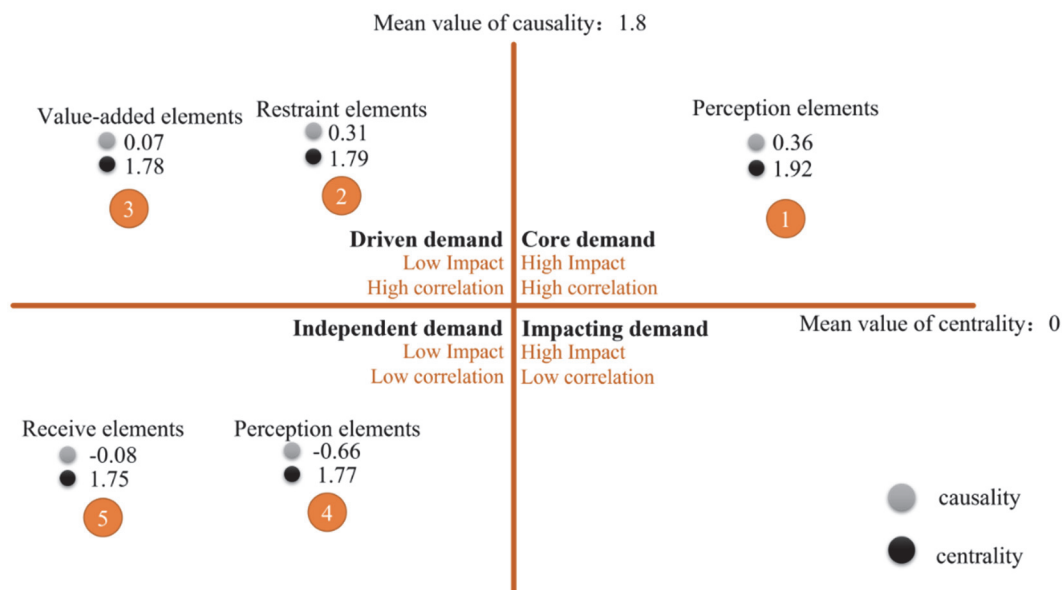


Figure 5 System requirements for RV interiors customized

(3) Ten senior RV modification designers from a partner company were invited to assess the customization demand level for each component using a 3-point scale (2 for high customization potential, 1 for medium, and 0 for none). Expert scoring revealed that seats, storage cabinets, and stoves received the highest scores, indicating these

three components have the highest customizability and customization priority, thus requiring more diversified solutions, as shown in Tab. 3. Consequently, the customization system can prioritize component customization content based on these scores.

Table 2 Stander impact matrix

<i>N</i> 5*5	Perception element	Restraint element	Value-added element	Product element	Storage element
Perception element	0	0.26	0.29	0.15	0.30
restraint element	0.24	0	0.28	0.19	0.25
value-added element	0.18	0.26	0	0.23	0.29
product element	0.15	0.20	0.17	0	0.26
storage element	0.25	0.21	0.25	0.17	0

Table 3 Scoring table for Customization requirements for interior components

Interior Components	Score	Interior Components	Score	Interior Components	Score	Interior Components	Score
F4 Seats	16.45	F7 Lighting	10.95	F11 Dishwasher	8.3	F14 Microwave	7.9
F1 Storage cabinet	15.15	F17 Refrigerator	10.7	F18 Washing machine	8.3	F21 Bath heater	7.85
F19 Cooking Stove	15.05	F9 Frontal bed	10.3	F15 range hood	8.25	F6 Office supplies	7.85
F8 Fixed bed	12.5	F22 Toilet	9.25	F12 sterilizer cabinet	8.1	F16 Sink	7.8
F3 Storage table	11.55	F10 Integrated Cooking Stove	8.7	F20 Shower	8.1	F24 Washbasin	7.6
F2 Dressing table	11.4	F5 Audio-visual facilities	8.45	F13 Induction cooker	8.05	F23 Exhaust fan	7.5

3.1.5 Interaction Design

(1) Interface and Interaction

The interface design primarily focuses on three key aspects: interface layout, auxiliary information, and visual style, as illustrated in Fig. 6.

a) Interface layout: Consumers prefer a combined interface layout, that is, a combination of text and images. This layout helps to present customized content and its detailed information simultaneously [37].

b) Auxiliary information: Unlike PC-based interaction, users often lack familiarity with MR interaction paradigms. It is therefore essential to provide contextual guidance to inform users of available actions on each interface. Furthermore, as the RV interior customization process involves dynamic changes in interface information, clear procedural guidance should be provided. Users prefer interactive guidance that combines text and graphics to remind them of the current operation location and clearly show the entire customization process [38].

c) Visual style: Covering icon style, font, interface style, and brand identity. Consumers prefer icon designs

that integrate lines and planar elements, with sans-serif fonts being the mainstream choice [39].

(2) Interaction Methods

The HoloLens 2 supports multiple human-computer interaction modalities, such as gesture, voice, and eye movement interaction. A survey showed that 58% of consumers prefer to use a combination of gestures and voice interaction. In HoloLens 2, the user's fingers will be recognized as a skeletal model, so as to capture gesture movements more accurately. The interaction between the user and the virtual object is basically the same as daily gestures. By guiding the operation mode through vision and hearing, a perfect gesture interaction experience can be constructed. Compared with eye movement interaction, the combination of gesture interaction and voice not only has a lower learning load, but also allows consumers to interact directly with virtual objects and is more in line with the user's operating habits [40]. Therefore, the RV interior customization prototype mainly adopts gesture interaction operations such as click, swipe, rotate and zoom, as shown in Fig. 7.

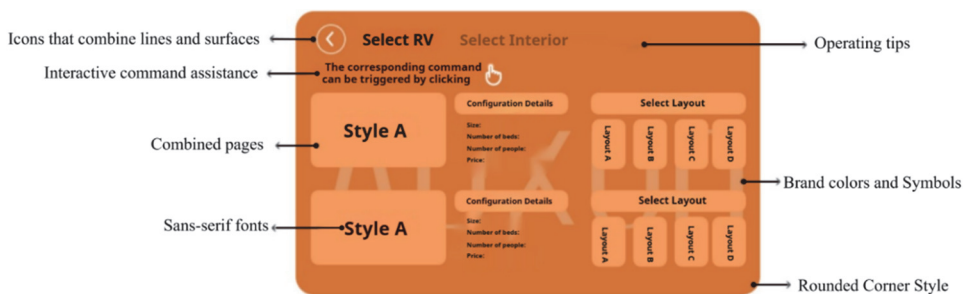


Figure 6 Interactive interface conceptual diagram

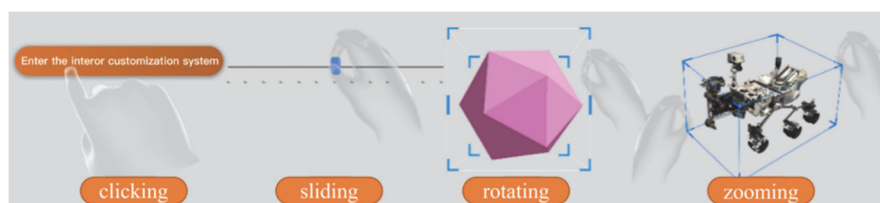


Figure 7 Interaction preferences

(3) Feedback mechanisms

In system design, the product needs to provide clear feedback for each operation. This feedback may be confirmation or negation of the user's behavior, and its purpose is to let the user clearly understand the result of their operation [41]. In order to ensure that the user can interact effectively with the product, it is necessary to ensure that each operation is accompanied by appropriate feedback, whether it is visual, auditory or tactile feedback. This feedback mechanism can not only enhance the user's

understanding of the product, but also improve the overall consumer experience [42]. This system adopts two interactive feedback methods - visual prompts and auditory feedback, as shown in Fig. 8. When the user touches an object, the system will trigger the bounding box of the object to remind the consumer that the corresponding interactive object has been successfully touched. After users complete the operation instruction, the system will issue a prompt sound effect to confirm that the operation is completed.

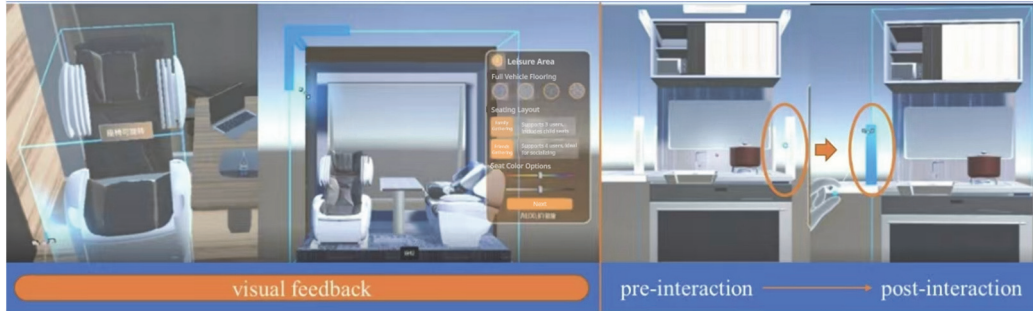


Figure 8 Interactive feedback

3.1.6 RV Interior Customization System Framework

Based on consumer customization preferences, the framework of the prototype customization system is structured into five distinct stages, as shown in Fig. 9. System introduction, Model recommendation, Layout customization, Component customization, and Order confirmation. Building upon this structure, the system architecture was constructed, and corresponding interactive interface models were designed, as outlined in Tab. 4.

(1) System introduction: Before the customization is launched, the system will demonstrate the prototype system and the customization process to consumers to help them master the basic operation methods.

(2) Model recommendation: At the start of customization, the system suggests a base vehicle model tailored to the consumer's intended use for the RV. Users can then view detailed exterior styling, functional parameters, and other configuration information for the recommended model.

(3) Layout customization: Consumers can review different layout diagrams and select their preferred interior arrangement. Each layout is annotated with key information, such as recommended occupancy capacity and interior style, displayed at the bottom of its representation.

(4) Component Customization: After a layout is selected, users enter a view of the RV's interior space. From this interface, they can interact with various components - for instance, inspecting part functionalities and customizing interior colors and materials. Furthermore, consumers can select specific interior components for personalized modification, adjusting parameters such as dimensions, stylistic features, materials and finishes, and accessory models.

(5) Order confirmation: Orders can be viewed in the system to understand the customization results in real time. Once the consumer has completed all customizations, they can submit their order.

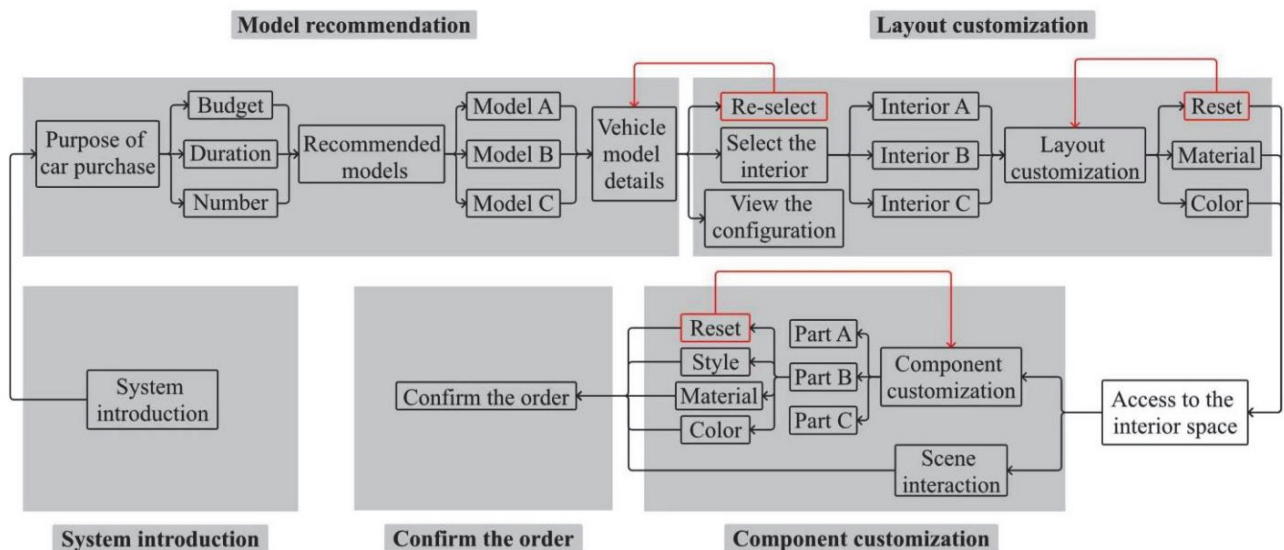
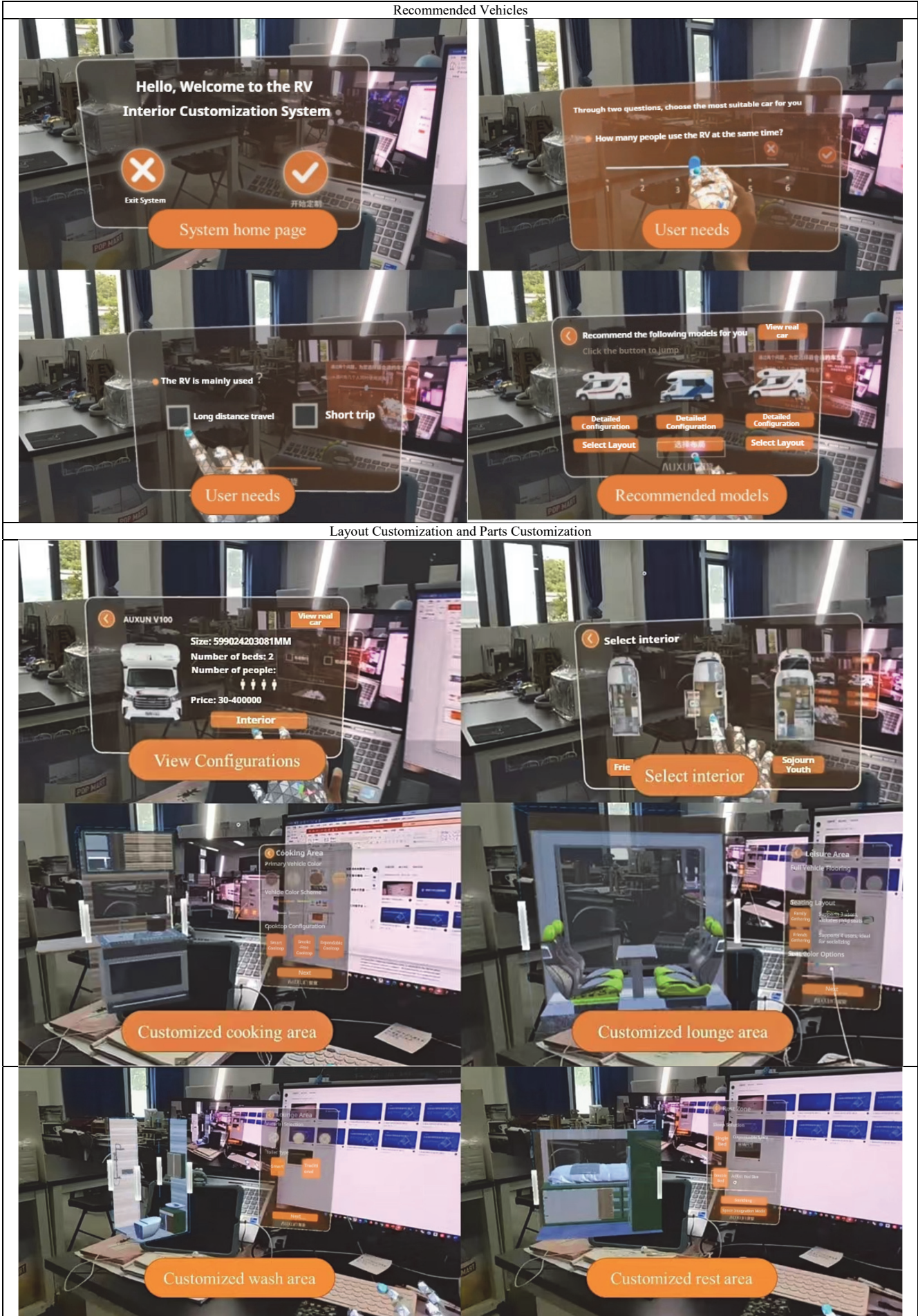


Figure 9 System framework

Table 4 Interactive real-time demo Recommended Vehicles





3.2 System Usability Testing

After completing the development without any errors, export the development files to HoloLens 2 through Visual Studio (VS) and conduct usability testing. The test includes three items of effectiveness indicators, efficiency indicators, and subjective satisfaction.

3.2.1 Participants

According to Nielsen's suggestion, a sample size of 10 people is sufficient to identify most interface problems in usability issues [43]. This study successfully recruited 20 adult volunteers (10 male, 10 female; mean age 36 ± 0.4 years, range 25-50). All participants had prior experience with offline RV customization consultations and expressed purchase intent. Among them: 10 participants were from the 2023 Shenzhen International RV Exhibition and

Cuishan RV Campground (representing an environment with external interference), and 10 from 4S dealerships (environment controlled without interference). Furthermore, 10 participants had prior experience with VR head-mounted displays (e.g., for gaming), while the other 10 had no prior experience with any immersive technology and were completely new to MR. Before the experiment, all participants received training on MR concepts and the operation of the HoloLens 2, followed by a hands-on practice session with the device to familiarize themselves with basic interactions.

3.2.2 Experiment Tasks

Following the best practices of usability testing, especially the principle of representative task coverage [43], seven tasks were selected to reflect the key operational stages commonly encountered in the process of

RV customization. The entire process was confirmed by email whether the user had successfully completed the experiment. The specific task list is as follows:

Task 1. System Entry: Open the system and enter the customization page.

Task 2. Model selection: Select a motorhome model suitable for three people to travel long distances.

Task 3. Select RV model: Select a model that supports dual expansion function.

Task 4. Specification Review: Review the detailed configuration of RV and verify it.

Task 5. Layout Customization: Select a specific layout named "Travelling Youth".

Task 6. Component editing: Change the seat style to leisure and adjust the color to blue.

Task 7. Order Submission: Confirm and submit the order; the system will automatically send an email.

3.2.3 Experiment Implementation

The experiment was conducted by two testers: one was responsible for introducing the task process and experimental tasks to the participants; the other observed the participants' operations in real time through the projection screen, made records, and provided immediate assistance when the participants encountered operational difficulties. Due to the communication delay of the screen projection synchronized with the consumer's perspective, the time accuracy of the test was only at the second level. When the participants were wearing the equipment and

ready, the test program could be started and the timer started. During the test, if the participants could not complete the task for a long time, a reminder would be issued in a timely manner. There was no fixed time limit for the entire test process, and the participants could stop operating at any time according to their own situation. Some experiment scenarios are shown in Fig. 10.

3.2.4 Satisfaction Evaluation

After the experiment, the participants were asked to evaluate their subjective satisfaction. First, the system satisfaction evaluation was conducted. This paper uses the SUS standard scale designed by Bangor et al. to evaluate subjective satisfaction. It can produce consistent rating results from a relatively small sample, and its reliability is as high as $(\text{Alpha}) = 0.91$ [44]. Second, Compared System Usability Scale evaluation was conducted. The participants were asked to use the Semantic Differential Method to compare the traditional communication method with the method proposed in this paper, and to use a seven-level scale (-3, -2, -1, 0, 1, 2, 3) to rate the method. Scores closer to the left end of the scale indicate a preference for the traditional method, whereas scores closer to the right end indicate a preference for the method proposed in this study. The data were converted into a percentage for further analysis. In addition to the scale, the participants' experience information was also collected through interviews.



Figure 10 Some experiment scenarios

4 RESULTS AND DISCUSSION

4.1 Data Statistics

Participants were grouped by gender (male, female), test environment (no interference, interference), and prior virtual device experience (not experienced, experienced) for statistical analysis, and corresponding one-way ANOVA tests were performed. As shown in Tab. 5 results, these three attributes did not significantly affect the time required to use the system or the satisfaction scores generated. Cognitive, perceptual, and behavioral differences across different user groups were minimal. Interview feedback indicated that the device and system

were novel, leading to high concentration levels among participants. The pre-test training was also effective in providing necessary guidance, resulting in generally smooth task completion.

4.2 Task Completion Rate

As shown in Fig. 11, all participants successfully completed all operational tasks, yielding a 100% completion rate. However, 3 participants failed Task 3, 1 failed Task 4, and 1 failed Task 5 in terms of correct object selection. Notably, one participant did not identify the incorrect selection from Task 3 during Task 4. The average

task correctness rate was 96.4%. Task 3 had the lowest correctness rate (85%), while all other tasks maintained correctness rates above 90%. Post-experiment interviews revealed that the dual expansion function in Task 3 was a

new RV model unfamiliar to three participants, leading to their errors, suggesting this was not primarily a system-related issue.

Table 5 Data statistics and one-way ANOVA

	Gender			Environment			Experience		
	male	female	<i>p</i>	Interference	interference-free	<i>p</i>	Experienced	not experienced	<i>p</i>
Task1	6.90 ± 1.66	7.60 ± 2.63	0.486	6.60 ± 1.51	7.90 ± 2.60	0.188	6.60 ± 1.58	8.11 ± 2.62	0.111
Task2	18.20 ± 4.39	13.00 ± 4.22	0.051	16.80 ± 5.73	14.40 ± 4.01	0.292	14.70 ± 5.38	16.11 ± 4.73	0.289
Task3	27.10 ± 6.01	19.80 ± 6.16	0.720	24.30 ± 8.64	22.60 ± 5.23	0.601	21.50 ± 8.20	24.78 ± 5.21	0.458
Task4	20.70 ± 6.50	27.30 ± 8.07	0.059	25.00 ± 9.71	23.00 ± 5.93	0.585	26.00 ± 9.84	22.56 ± 5.79	0.474
Task5	24.40 ± 4.74	21.30 ± 8.26	0.317	23.80 ± 4.10	21.90 ± 8.79	0.543	24.00 ± 6.70	21.89 ± 7.34	0.578
Task6	51.40 ± 3.13	60.40 ± 9.90	0.130	53.20 ± 6.66	58.60 ± 9.61	0.161	55.50 ± 10.09	57.00 ± 7.18	0.614
Task7	11.90 ± 3.57	12.80 ± 6.20	0.695	13.50 ± 4.86	11.20 ± 5.01	0.311	13.80 ± 5.18	11.11 ± 4.70	0.324
Sus	81.28 ± 3.40	79.50 ± 3.92	0.293	80.13 ± 4.12	80.64 ± 3.41	0.765	79.36 ± 4.04	81.23 ± 3.53	0.370
C-sus	87.14 ± 12.51	84.29 ± 14.21	0.934	90.00 ± 11.76	81.43 ± 13.55	0.148	84.29 ± 15.72	85.71 ± 10.10	0.998

Note: *p* is the test level, and the threshold is set to 0.05

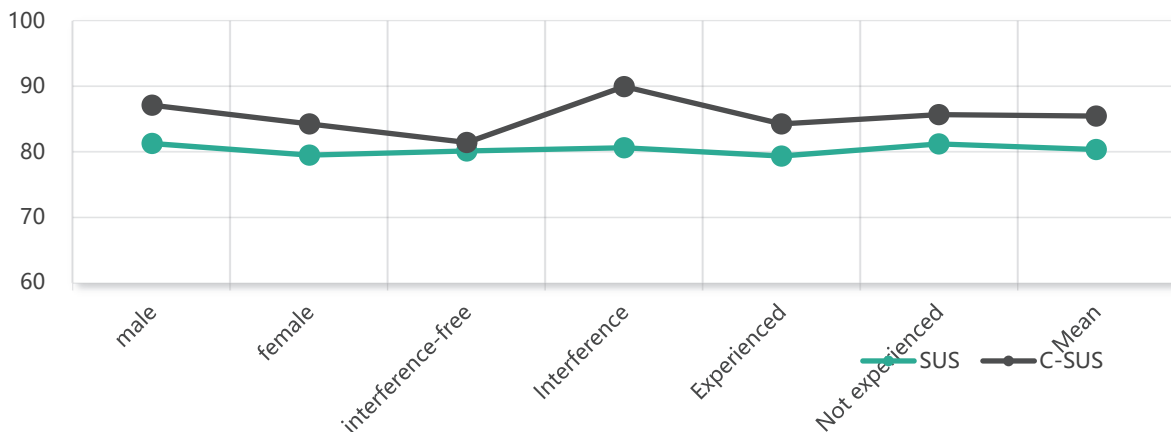
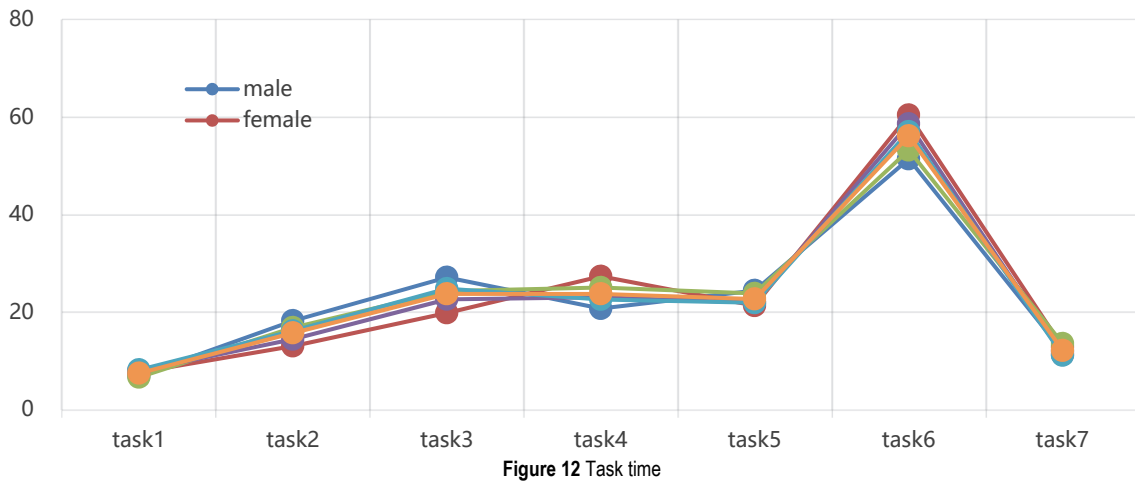
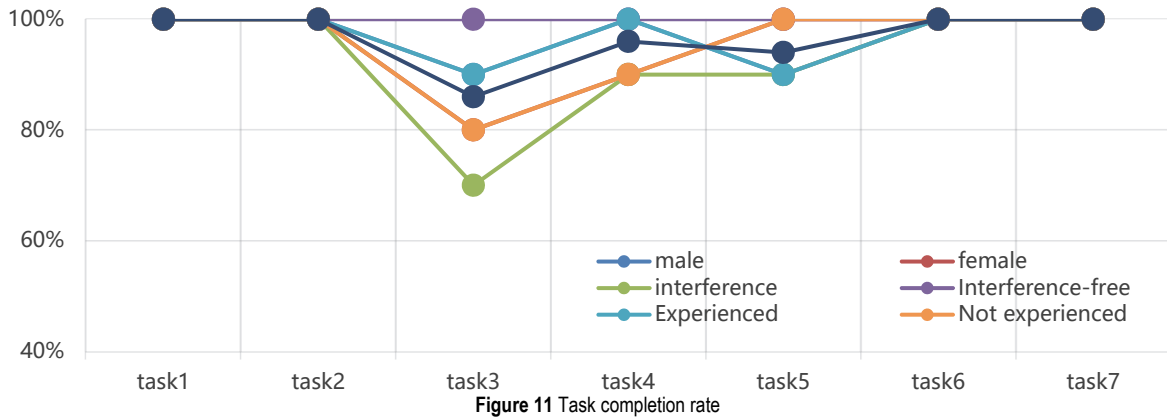


Figure 13 SUS and C-SUS scores

4.3 Task Completion Time

The average time to complete all tasks was 161.4 ± 15.70 seconds. As can be seen from Fig. 12, the time required for each task was different: Task 6 was more complex and required the longest time; Task 1 was to start the system and required the shortest time. Intuitively, for each task, the completion times for various groups were roughly the same, showing no significant differences. In particular, the time required for Task 1 and Task 7 was very close, and the differences between each group were not significant, which is consistent with the results of the one-way ANOVA in Tab. 5.

4.4 Satisfaction Evaluation Analysis

The SUS reflects participants' overall subjective evaluation of the system. As shown in Fig. 13 and Tab. 5, the mean SUS score was 80.39 ± 3.60 . According to the adjective rating scale provided by Bangor et al. [44], this falls into the Good grade, indicating the system was generally well-received. Participants gave positive evaluations in terms of willingness to use, ease of use or not, ease of learning or not, etc.

As shown in Fig. 13, C-SUS reflects participants' preferences between the traditional method and the one proposed system, derived from converted SD ratings, yielded a mean score of 85.70 ± 12.78 . Referencing the standards by Bangor et al. [44], this corresponds to an Excellent grade. Although the relatively large standard deviation suggests dispersed score distributions, it still clearly indicates a stronger preference for the proposed method over the traditional one. These results demonstrate that the system achieves excellent usability and a high level of user satisfaction, which aligns with previous findings that MR technology enhances interactive experiences and improves task efficiency [45].

Interview data corroborated this, with participants highlighting the system's unique advantages in visualization, autonomy, immersive interaction, and timeliness. They noted it addressed the time-consuming and labor-intensive drawbacks of traditional RV customization method, thereby improving both the efficiency and experience of interior customization. The MR-based tool allows consumers to preview modification effects in real-time, eliminating the need to purely imagine the final outcome. This clarity not only enhances the efficiency of design communication but also ensures that design intent is conveyed with greater precision and transparency [46]. The interactive experience fosters a greater sense of control and co-creation-fulfilling the desire for "I designed it myself" [47]. This transforms the user's role from a passive acceptance to an active participant in the creative process, consequently significantly enhancing satisfaction with the final product.

5 CONCLUSIONS

This study developed and evaluated a MR - Based personalization system for RV interior customization, leveraging immersive interactions to enhance consumer experiences. The system integrates real-scale spatial visualization, gesture-based control, and real-time

feedback mechanisms. Its key advantages include heightened user engagement, more accurate capture of user intent, and reduced reliance on physical space and product.

Usability testing demonstrated excellent system performance and high user satisfaction: the tasks were 100% completed, with a correct rate of 96.4%. The mean score of SUS was 80.39, corresponding to Good grade, and the mean score of C-SUS is 85.70, equivalent to an Excellent grade. The system effectively facilitated deep user involvement, shortened iteration cycles, and improved decision-making precision, validating the broader conclusion that immersive technologies can fundamentally enhance customer experiences in design-driven industries [48].

However, hardware limitations of the HoloLens 2, such as processing latency and a constrained field of view, currently restrict the user experience. Future research will explore more capable development platforms and investigate directions such as multi-user collaboration, integration with AI-driven recommendation systems, and cross-platform deployment to achieve intelligent personalized solutions.

Acknowledgements

The paper was funded by Social Science Foundation Research Project of Jiangsu Province of China (NO. 25YSD006), General Project of Art Science of National Social Science Fund of China (25BG149), the Project of Industrial Design Research Center of Humanities and Social Sciences Research Base of Education Department of Sichuan (NO. GYSJ2022-02).

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