Research on the Design System of Bamboo-Woven Products Based on Traditional Bamboo-Weaving Craft VR Experience

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Abstract

Virtual reality (VR) is a simulated experience capable of replicating or creating an entirely new environment. Through VR experience, designers can learn bamboo-weaving techniques at a low cost and showcase their design models of bamboo-woven products virtually, allowing these products to be put into production after experience and evaluation. This study introduces novel techniques to transform and innovate traditional bamboo-woven products to establish a comprehensive VR-based product experience design system. This system follows a pioneering pathway, including the following steps: VR weaving skill experience, generative artificial intelligence design (AIGC)–driven bamboo design creativity, 3D modeling technology support, and VR product evaluation. Moreover, the framework conducts user experience research from three dimensions: visual design, system function design, and human–computer interaction design. Usability assessments and statistical analysis were employed before and after the VR experience to assess the system's reliability. The findings indicate that designers and users can remarkably use and evaluate the new system, offering a practical technical pathway for the modern design exploration of traditional bamboo products.

Bamboo is a renewable and biodegradable, ecofriendly material (Cheng et al. 2024) and a crucial forest plant in the Asia–Pacific region, offering diverse benefits to meet social and environmental needs (Cheng et al. 2024). Promoting the "bamboo instead of plastic" industry initiative fully leverages bamboo forest resources to enhance bamboo cultivation and its growth in the market. This approach also encourages the adoption of green lifestyles. Vogtländer et al. (2010) investigated the sustainability of bamboo products in local and Western European applications, and results indicated that bamboo offers outstandingly low ecological costs. Traditional bamboo-woven utensils from China are skillfully and carefully crafted from bamboo using specialized techniques. With a rich history, these techniques are classified as intangible cultural heritage. In recent years, bamboo products such as bamboo baskets, food packaging, and home goods have become part of daily lives worldwide. These products retain the characteristics of traditional bamboo weaving and incorporate modern elements, making them more aligned with contemporary aesthetic demands.

Virtual reality (VR) technology simulates experience and provides new techniques for preserving traditional cultural heritage (Yang and Kang 2018). With this advanced technology, intangible cultural heritage methods have shifted from a passive, object-centered presentation to an interactive model involving people and artifacts. Furthermore, a VR experience system integrated with the sale of cultural creative products has made these items interactive. This approach boosts consumers' willingness to purchase and enhances cultural dissemination. Beyond online shopping, VR has been significantly applied in game design (Martel and Muldner 2017), and art education (Qiu et al. 2020). While VR has been used substantially in product design and developing bamboo-weaving materials, research in this domain remains limited.

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This study investigated the traditional bamboo-weaving techniques of the She ethnic group in China. She is a Chinese ethnic minority dispersed across mountainous areas in more than 80 counties within seven provinces, including Fujian, Zhejiang, Jiangxi, Guangdong, and Anhui. As shown in Figure 1, the She homeland is renowned for its lush bamboo, and its landmass is rich in bamboo-weaving cultural heritage resources. To effectively preserve traditional bamboo weaving, integration of VR technology offers more authentic, three-dimensional (3D), and comprehensive documentation of the bamboo-weaving culture of the She people. From the user experience standpoint, VR technology offers immersive, multi-angle observation, significantly promoting understanding and transmission of the She bamboo-weaving culture. However, the application of VR in disseminating bamboo-weaving culture and designing bamboo products is insufficient. Based on VR technology, this research utilized the Unity 3D engine to construct a VR experience system for bamboo product design. This system offers immersive learning of bamboo-weaving culture, allowing users to acquire hands-on experience in working with fundamental bamboo-weaving techniques. It also includes user evaluations of new bamboo products, emphasizing immersion and interactivity in the VR experience content and functionality.

Moreover, we constructed a usability evaluation method using bamboo products to maintain the functionality of the VR experience design and assess satisfaction levels among designers and users. This technology strives to minimize the development costs of bamboo material products, improve product design quality, and shorten the product design and development process. We aimed to explore the innovative application of traditional bamboo material product design based on VR technology by simulating and displaying bamboo product models in a virtual environment. This technology enhances user experience and evaluation before production, offering significant benefits for the applications of innovative traditional bamboo materials.

Literature Review

Interactive experience research on intangible cultural heritage based on VR

It is feasible to use VR technology (Du 2022) to protect and bequeath intangible cultural heritage. Bozzelli et al. (2019) introduced a virtual exhibition platform to improve the semantics and perception of art crafts, allowing users to understand them through immersive and participatory interactions. Disseminating intangible cultural heritage through VR technology can overcome the singularity and limitations of traditional methods. For example, Li (2020) applied VR technologies in the Mid-Autumn Festival in Xiangxi, China, to explore digital protection solutions for intangible cultural heritage. Du (2022) used VR technology to explore a visualization platform for jade-carving techniques. Currently, the application of VR in intangible cultural heritage domains is limited to display design, with less consideration given to user experience factors. Notably, research on VR-based interactive design and usability evaluation is relatively scarce. Moreover, existing literature on VR-based studies of the intangible cultural heritage of the She ethnic group in China frequently emphasizes elements such as clothing. Zhang and Liang (2020) developed a diversified protection system for She traditional clothing culture using a virtual museum as a platform. In this case, our research focuses on the cultural inheritance and product innovation of bamboo weaving. As a result, development of bamboo-woven products that align with modern aesthetics and lifestyles holds practical and significant value for cultural inheritance and education.

Digital technology for bamboo product development

Optimizing the digital platform of the bamboo and wood industry can offer precise market analysis of bamboo products and provide development services for bamboo enterprises and farmers (Wu et al. 2025). While the design and development of bamboo-woven products are moving toward digital transformation, research on traditional bamboo weaving using digital technology is still limited. Existing findings are categorized into three areas:

First, several studies have emphasize leveraging digital technology to promote bamboo-weaving culture preservation and perpetuation. Meng et al. (2022) introduced strategies for digital preservation, stressing the feasibility of digital preservation for bamboo weaving. Zhang and Cheng (2003) reported on bamboo's classification and material properties, categorizing different bamboo-weaving styles and compiling a list of commonly used techniques and 40 typical weaving structures. Jiang and Fu (2021) conducted

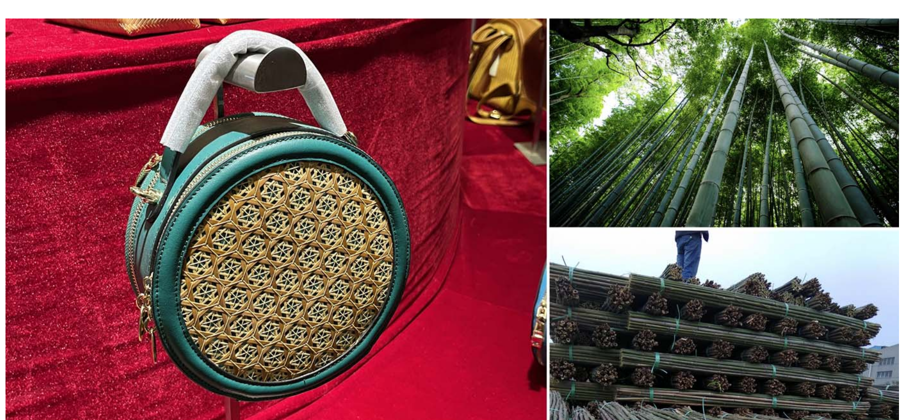

Figure 1.—Bamboo forest resources and bamboo-woven product production in the She ethnic group's habitat.

parametric simulations and developed research on bamboo-weaving structures. You et al. (2021) explored the application of digital technology in bamboo-weaving techniques. Li and He (2024) integrated modern digital technology with conventional primary weaving techniques to develop 3D weaving technology.

Second, existing studies have also explored the practical applications of digital platforms. Wu and Kang (2021) collected comprehensive data to develop a digital design platform for women's bamboo handbags. Zhang and Zou (2018) created an online communication platform for bamboo product design based on VR digital technologies and Unity 3D. Zhang and Wu (2023) championed the inheritance and innovation of conventional bamboo-weaving crafts through an "art design + digital platform."

Third, researchers have also emphasized digital interactive design systems for bamboo products. Wu and Zhang (2017) developed parametric modeling technology for 3D printing bamboo baskets. Li et al. (2023) utilized computer-aided design technology to build bamboo-weaving pattern tools, assisting designers in developing innovative bamboo products. Sun and Liu (2022) built software to facilitate free weaving and interactive design for rapidly creating new 3D bamboo models. This interactive approach allows users to refine their designs gradually through real-time visualization.

While these studies provide specific digital methods and application practices, their research direction is mainly based on digital design for bamboo culture. Moreover, their discussions on collaborative innovation across different technological fields for the collaborative development of bamboo products are still limited, requiring further exploration.

Application of VR technology in bamboo product development research

The integration of VR into the interactive bamboo-weaving experience is beginning to take shape. VR technology supports innovation in bamboo products, with existing research primarily focusing on the following aspects: First, VR provides users with a unique bamboo-weaving experience, attracting more people to learn and promote bamboo culture. For example, Feng and Li (2024) utilized virtual display technology to digitally showcase the weaving techniques and production scenes of collected bamboo patterns. Meng et al. (2022) established a digital exhibition hall for bamboo weaving.

Second, the bamboo-weaving VR experience system offers captivating advantages that help designers master bamboo-weaving techniques and develop new products. However, traditional bamboo-weaving skills are technically demanding and challenging for beginners to grasp quickly. Designers often struggle with handling bamboo strips during the weaving experience, leading to issues such as misalignment and distortion in the finished products and causing frustration for designers. Moreover, limited bamboo-weaving experience can severely constrain creative output. Even if designers exhibit exquisite design ideas and appealing shapes, a lack of solid bamboo weaving skills can lead to loose structures and low feasibility in weaving. As a result, VR technology can quickly enhance designers' understanding and cognitive levels of bamboo-weaving techniques, laying a foundation for innovating bamboo products and optimizing bamboo-weaving skills. Some scholars have explored the learning and application of bamboo-weaving techniques in VR environments. Chen and Fu (2023) employed VR technology to teach bamboo product manufacturing processes. Through the traditional processing of bamboo products using VR technology, learners can more intuitively grasp the traditional crafts' production processes and skills, thereby effectively improving teaching efficiency. Wu et al. (2021) built VR technology and Unity 3D applications on bamboo-weaving inheritance to showcase the weaving steps of bamboo patterns to learners in a virtual environment. This technique helps designers to understand bamboo culture and techniques more vividly and intuitively, aiding in bamboo product design.

Third, VR technology is crucial in developing products inspired by traditional bamboo arts. Using this VR technology, Shen et al. (2023) developed a virtual purchasing system for bamboo-woven products. Zhang and Zou (2018) built an online communication platform based on Unity 3D to address communication barriers encountered during the bamboo design. Therefore, applying VR technology in bamboo arts primarily leverages virtual display and experience. Despite extensively reviewing the relevant literature, few studies, such as that by Xie and Wang (2024), have explored the interactive design of bamboo-weaving techniques in VR environments. Hence, existing research has not explored interactive design and its specific applications in the development of new bamboo products. As a result, we aimed to improve and optimize the bamboo-weaving system through user experience by emphasizing innovative VR interface and interaction design practices. This technique provides innovative methods for applying VR technology in the preservation and dissemination of bamboo arts.

In summary, interactive design is critical in realizing the experience of bamboo culture and product development using VR technology. As digital design showcases a cross-disciplinary trend in bamboo product development, a singular VR technology approach still cannot meet the demands. By integrating artificial intelligence for generative content (AIGC) with VR technology, a technical pathway based on VR experience can be constructed. This research pursued innovative bamboo products using a pathway consisting of VR weaving skill experience, AIGC-driven bamboo design creativity, 3D modeling technology support, and VR product evaluation. By providing creative ideas for the digital preservation and innovation of bamboo-weaving crafts, we contribute theoretically and practically to the research on interactive design and usability evaluation of VR systems.

Development of the Bamboo-Weaving VR Experience System

Material collection

The VR experience system allows users to gain an in-depth understanding of the She ethnic group's bamboo-weaving culture. Materials were collected in She's residential areas, museums, and cultural heritage preservation centers. First, exhibits related to the history, culture, and customs of She bamboo weaving included photos, images, and textual and cultural artifacts. Second, bamboo-weaving patterns that reflect traditional She weaving techniques were gathered, assisting participants in the bamboo-weaving skill experience segment to access the necessary bamboo patterns for designing unique bamboo creations, as shown in Figure 2.

Creation of the 3D scene

By conducting on-site investigations at the She Museum, performing online research, and referencing the dimensions and quantities of certain collection items in 3D models, we initiated the design of the bamboo-weaving experience system's scene and exhibit models. The 3D models were created using 3ds Max software and several strategies. First, the spatial framework of the exhibition hall was drafted, outlining walls, floors, ceilings, and columns, marking the locations of important exhibits. Next, individual booth designs were created based on the design requirements of the exhibition hall floor plan and the creation of display table models and shapes. Afterward, 3D models of the exhibits were integrated into the respective booth locations, and lighting was carefully designed within the exhibition hall model to ensure optimal brightness and visual impact for the displays. Moreover, we employed textures that reflected the materials and characteristics of the exhibits. After several adjustments and optimizations, we enhanced the model's realism and authenticity, ultimately exporting it in a suitable 3D file format.

Building the system using the utility 3D engine as the development tool

Once the 3D scene was completed, the VR experience system was constructed following these specific steps:

1. After completing the scene and prop modeling in 3ds Max software, all fbx model files are imported into the Unity 3D system development platform.
2. Afterward, we set up various types of lighting in the virtual scene. In Unity 3D, different types of lighting were configured within the virtual environment, and the models were simplified during the scene optimization process to improve the scene loading speed.
3. Interactive functions were implemented, including the user interaction interface and VR interaction functions.
4. Scene navigation: Based on user needs, two navigation methods were implemented: manual and teleportation point navigation. Manual navigation allows users to explore interesting areas of the exhibition hall independently by clicking the manual navigation button. During teleportation point navigation, the user is instantly transported to the corresponding location when a ray in the scene contacts a teleportation point.
5. System output: The VR experience system was output as EXE files for mobile and personal computer platforms to enhance the overall experience and cater to different user groups.

During the implementation step, as shown in Figure 3, for example, based on the Unity 3D platform, TextMeshPro in Unity graphical user interface was used to build a question-answering system; when users interact with bamboo-weaving exhibits, they can use a Virtual Reality Toolkit combined with SteamVR to achieve handle interaction, and the integration of the physics engine supports the grasping and rotation of bamboo-weaving exhibit models, allowing users to perform interactive operations such as zooming, moving, and rotating the exhibits 360 degrees. As shown in Figure 3, in the bamboo-weaving skill experience area, users are guided through step-by-step tasks, and the animator and particle system are used

Figure 2.—Traditional bamboo-weaving patterns of the She ethnic group.

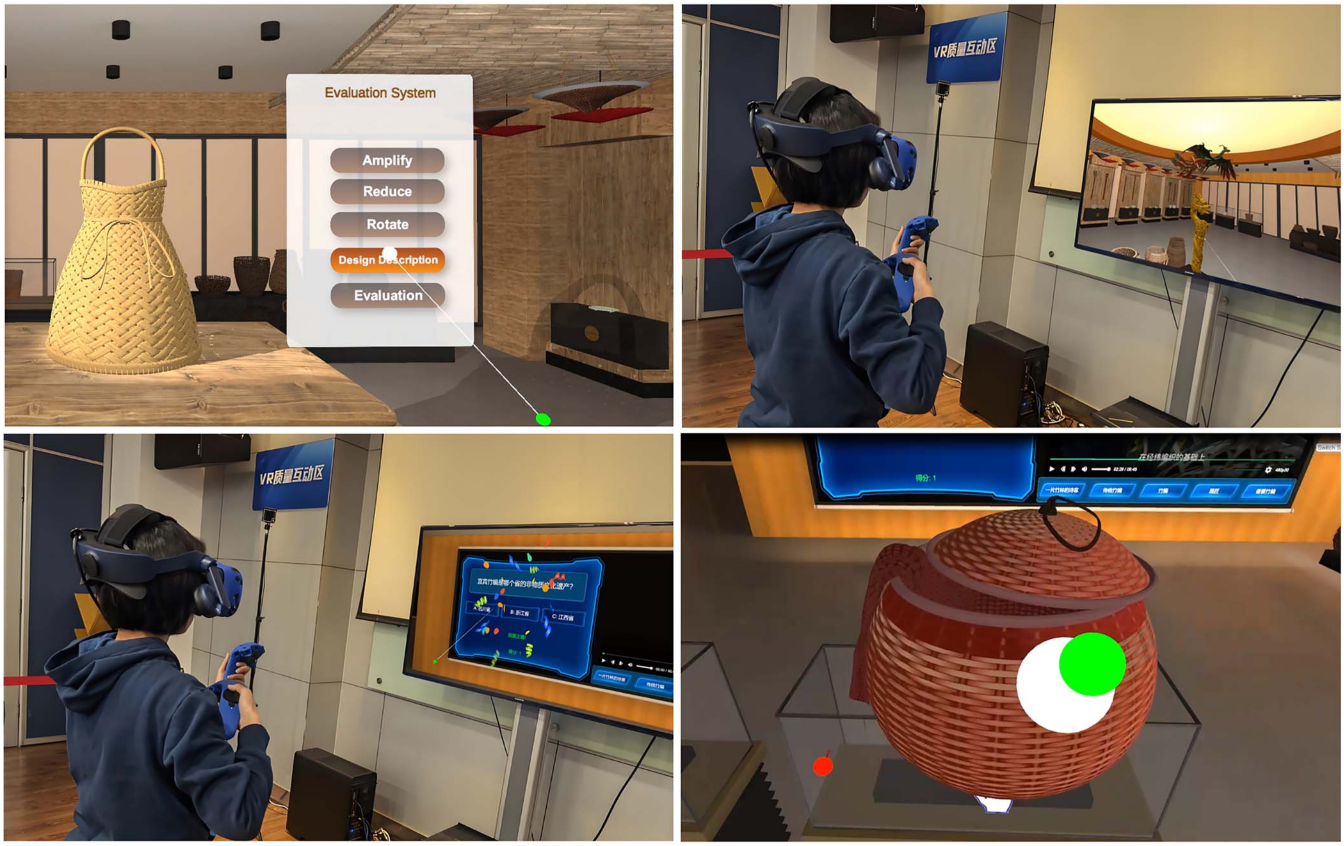

Figure 3.—Virtual reality (VR) interaction features of the She ethnic group include bamboo weaving and a VR experience system.

to create settlement animations, enhancing the sense of accomplishment.

Evaluation experiment

Purpose and method.—Once the system development was completed and the project was published in Unity, all the designed functionalities were fully demonstrated as intended during system operation. The HTC VIVE device was connected, and a model from a specific exhibition area was randomly selected in the virtual exhibition hall scene to conduct an initial test to confirm the system ran smoothly. Following optimization, the goal was to guarantee a satisfactory experience for users (respondents). Subsequently, users were tested based on pre-established typical tasks, and an experiment was performed to assess differences in the VR experience between designers and users and evaluate the effectiveness of the virtual exhibition experience system. Subsequently, respondents were asked to complete a survey, and findings from user evaluation results were used to identify the system's strengths and weaknesses, providing a basis for modifications to the VR experience design system.

Respondents and equipment.—Developing and implementing the She ethnic group's intangible cultural heritage VR experience system required the following equipment platforms: HTC VIVE, which includes a high-resolution display screen, sensors, and controllers, enabling users to immerse themselves in the virtual reality environment and move freely while interacting. Moreover, VR headsets and head-mounted devices create VR environments, engrossing users in virtual reality. Following this, developers can use Unity, which is widely used in VR, to create interactive virtual and augmented reality applications. This technology offers a powerful visual editor and supports programming languages such as C# and JavaScript. Owing to the complex VR device-wearing process and the high cognitive load of human–computer interaction operations, we selected 86 respondents to ensure adaptability in user experience and enhance the data collection effectiveness. Figure 4 shows a user group of $n = 54$ and a designer group of $n = 32$, which were established for comparative testing.

Experimental process.—The VR experience system consists of three functional areas: immersive learning of bamboo-weaving culture, experience of basic weaving techniques, and user evaluation of newly developed bamboo-woven products. The immersive learning section introduces users to bamboo-weaving culture, historical background, and cultural information, assisting in forming a preliminary impression of bamboo weaving. The basic weaving technique experience section provides users with fundamental weaving methods, allowing them to immerse themselves in bamboo weaving and cultivate their interest in the associated culture. User evaluation of bamboo-woven products involves scoring based on specified evaluation criteria to assess the product design effects. The three components of the bamboo-weaving VR experience system were broken into eight tasks, allowing respondents to complete them sequentially based on the evaluation criteria. Here are the eight tasks outlined more clearly:

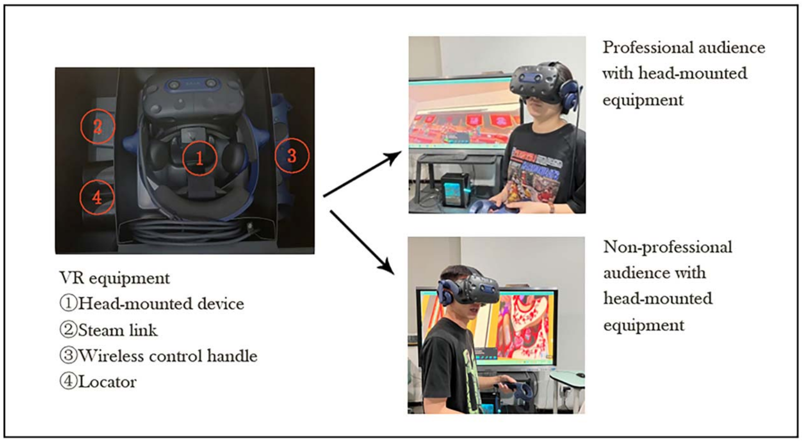

Figure 4.—Equipment and participants wearing equipment.

1. The surroundings are assessed to determine one's position and whether the imagery is coherent and fluid.
2. A video is watched to learn the bamboo-weaving history and culture.
3. The next step is participating in a knowledge quiz on bamboo weaving.
4. Afterward, bamboo artifacts in display cases are browsed to examine the details of these artifacts.
5. The bamboo-weaving experience system is entered, and a weaving method is selected.
6. Then, the size and color of the bamboo strips are adjusted.
7. Next, the bamboo weaving process is completed.
8. Finally, the newly developed bamboo-woven products are evaluated.

After browsing, users were evaluated using the questionnaire shown in Table 1. Throughout experiments involving designers and users, respondents were asked to fill out a questionnaire that assessed their feelings toward each statement, effectively capturing their experiences during the experiment. The questionnaire utilized a Likert scale, with scores ranging from 1 to 5, to understand the perceptions of the two approaches. The questionnaire consisted of 17 items, each offering a response-point scale with options: "very good," "good," "average," "poor," and "very poor." The scoring assigned points were as follows: "very good" received 5 points; "good" received 4 points; "average" received 3 points; "poor" received 2 points; and "very poor" received 1 point. These items measured three dimensions:

1. Visual design included the interface's aesthetics, layout, style, and color coordination.
2. System functionality primarily encompassed the learning experience of bamboo-weaving culture, the weaving technique experience, and the evaluation of new bamboo product designs.
3. Human–computer interaction assessed the interactive fun of bamboo exhibits, the clarity of the interaction logic framework, and the smoothness of the interaction process.

Table 1.—User satisfaction survey questionnaire for the virtual reality She ethnic minority museum.

Dimensions	Questions	Very poor	Poor	Ordinary	Good	Very good
Visual design	A1. What is the aesthetic appeal of the interface?					
	A2. How is the text style of the interface?					
	A3. Is the layout of the interface reasonable?					
	A4. Is the information hierarchy of the interface clear?					
	A5. Is the overall style consistent?					
	A6. Are the sizes, proportions, and arrangement of various functional buttons appropriate?					
	A7. What is the color scheme of the interface?					
	A8. How effectively does the interface reflect bamboo-weaving culture?					
System function	B1. What is the learning experience of the historical and cultural aspects of bamboo weaving?					
	B2. What is the experience of the bamboo-weaving craftsmanship?					
	B3. How effective is the navigation system for evaluating new product designs?					
Human–computer Interaction	C1. Are the icon indications in the interface easy to understand?					
	C2. Is the complexity of the interface satisfactory?					
	C3. How is the readability of the text?					
	C4. Is the logical framework of the interaction clear?					
	C5. How engaging is the display and interaction with bamboo-weaving objects?					
	C6. Is the interaction process smooth?					

Results and Discussions

Pre-improvement and postimprovement assessments were conducted to evaluate the VR experience system's effectiveness. The first assessment established the design strategy, allowing for a comprehensive system enhancement. After the improvements, a subsequent evaluation was conducted to evaluate whether the established improvement guidelines led to significant differences in design.

Reliability and validity analysis of the test questionnaire

Reliability analysis of the questionnaire.—This study used the alpha coefficient (α) to determine the scale's internal consistency reliability. A higher α value indicates that the item findings within the questionnaire are more consistent, reflecting better scale reliability. An α coefficient below 0.6 indicates low reliability, suggesting consideration for the questionnaire's reconstruction or filtering out controversial indicators. Conversely, an α coefficient above 0.9 suggests that the questionnaire data are very stable, while values between 0.7 and 0.8 indicate reasonable stability. Table 2 shows the reliability of the questionnaire variables, visual design, system functionality, and human–computer interaction, which were calculated using the aforementioned method. The corrected item-total correlation values for the 17 items ranged from 0.514 to 0.832, exceeding 0.4. The removal of items did not result in a significant increase in Cronbach's alpha values. Specifically, Cronbach's alpha for visual design, system functionality, and human–computer interaction were 0.911, 0.790, and 0.847, respectively. These results demonstrate high stability and a substantial degree of credibility.

Table 3 displays the reliability results for the questionnaire variables, comprising visual design, system functionality, and human–computer interaction, calculated using the aforementioned method. The corrected item-total correlation values for the 17 items ranged from 0.412 to 0.860, exceeding 0.4. However, removing items did not lead to a significant increase in Cronbach's alpha values. As a result, Cronbach's alpha for visual design, system functionality, and human–computer interaction were 0.903, 0.926, and 0.797, respectively. These results indicate high stability and a notable level of credibility.

Table 2.—Reliability analysis (pretest).

Variables	Questions	Correlation of revised items with total	Cronbach's alpha after item deletion	Cronbach's alpha
Visual design	A1	0.610	0.909	0.911
	A2	0.810	0.891	
	A3	0.661	0.904	
	A4	0.832	0.889	
	A5	0.678	0.903	
	A6	0.721	0.900	
	A7	0.645	0.905	
	A8	0.757	0.896	
System function	B1	0.632	0.719	0.790
	B2	0.642	0.701	
	B3	0.630	0.722	
Human–computer interaction	C1	0.514	0.847	0.847
	C2	0.718	0.803	
	C3	0.694	0.809	
	C4	0.582	0.830	
	C5	0.634	0.821	
	C6	0.658	0.818	

Table 3.—Reliability analysis (posttest).

Variables	Questions	Correlation of revised items with total	Cronbach's alpha after item deletion	Cronbach's alpha
Visual design	A1	0.592	0.900	0.903
	A2	0.590	0.901	
	A3	0.808	0.880	
	A4	0.735	0.887	
	A5	0.707	0.890	
	A6	0.704	0.891	
	A7	0.699	0.891	
	A8	0.735	0.887	
System function	B1	0.860	0.888	0.926
	B2	0.841	0.903	
	B3	0.856	0.887	
Human–computer Interaction	C1	0.592	0.756	0.797
	C2	0.527	0.775	
	C3	0.566	0.762	
	C4	0.622	0.751	
	C5	0.620	0.753	
	C6	0.412	0.794	

Validity analysis of the questionnaire.—the Kaiser-Meyer-Olkin (KMO) test, proposed by Kaiser, Meyer, and Olkin, is a Measure of Sampling Adequacy. It serves as a statistical method to evaluate whether data is suitable for factor analysis.The scale's validity indicators were assessed through exploratory factor analysis using the KMO test, indicating validity when KMO > 0.6 and Bartlett's sphericity test shows a significance level of $p < 0.05$. The findings exhibit the suitability of the questionnaire for principal component analysis (factor analysis). Specifically, an analysis questionnaire with $0.8 <$ KMO < 0.9 is considered very suitable. Moreover, the factor analysis of $0.7 <$ KMO < 0.8 for a questionnaire is appropriate. However, $0.6 <$ KMO < 0.7 is deemed acceptable, and if the KMO value is <0.6, then the questionnaire is unsuitable.

Table 4 indicates that the KMO value for visual design is 0.866, with Bartlett's test of sphericity yielding an approximate chi-square of 441.707 and $p < 0.001$. The KMO value for system functionality is 0.709, with Bartlett's test yielding an approximate chi-square of 74.365 and $p < 0.001$. Lastly, the KMO value for human–computer interaction is 0.785, with Bartlett's test yielding an approximate chi-square of 250.728 and $p < 0.001$. These results exhibit excellent scale validity.

Table 4.—Kaiser-Meyer-Olkin (KMO) and Bartlett's test for variables.

Variables	KMO measure of sampling adequacy	Bartlett's test of sphericity		
		Approximate chi-square	Degree of freedom	Significance
Visual design	0.866	441.707	28	<0.001
System function	0.709	74.365	3	<0.001
Human–computer interaction	0.785	250.728	15	<0.001

Comparative analysis of pre-improvement and postimprovement testing

In pre-improvement tests, the average visual design, system functionality, and human–computer interaction scores ranged from 3.13 to 3.51, as shown in Table 5, indicating that the overall average rising from 3 to 4. This finding suggests that the overall satisfaction level was moderate, highlighting that further enhancement is required in these three areas. In postimprovement tests, the average scores in visual design, system functionality, and human–computer interaction ranged from 4.09 to 4.62, with the average value decreasing from 4 to 5. This outcome reflects an increased level of satisfaction. Our findings demonstrate that the improvements significantly improved the visual design, system functionality, and human–computer interaction.

In response to user feedback highlighting various pain points, we enhanced the bamboo-weaving technique experience system. This improvement enabled users to experience and learn the fundamental weaving techniques better. As shown in Figure 5, the dynamic weaving process allows users to adjust the size and color of bamboo strips and design unique weaving creations. In this process, each step is designed following the principles of bamboo weaving, gradually guiding observers in understanding the weaving process. Upon completion, users receive a thoughtfully designed feedback mechanism as a reward, transforming the intricate weaving process into an engaging and immersive experience. This approach facilitates enjoyable learning of bamboo-weaving culture for users and helps designers deepen their understanding of bamboo-weaving techniques. Consequently, the technique reduces the time required to learn bamboo weaving, promoting the integration of traditional bamboo weaving with modern design.

After using the bamboo-weaving technique, designers developed a profound understanding of bamboo weaving, significantly enhancing their creative conceptualization. During the initial design stage, the designers produced hand-drawn sketches that showcased the integration of structural integrity and innovation within bamboo products. Subsequently, various possible forms of bamboo products were generated using image-to-image AIGC design technology based on the hand-drawn sketches of bamboo baskets. As depicted in Figure 6, designers utilized AIGC technology to accelerate the design creation and product generation. By selecting the most promising design drafts from the eight forms provided by AIGC technology and applying 3D modeling skills, users could effectively complete the 3D modeling for the products. Upon importing the selected design drafts into the Unity 3D virtual environment, the innovation and feasibility of the bamboo products were further validated. Ultimately, the designers incorporated the completed 3D models of the bamboo products into the VR system, allowing real-time simulation and display of the product's appearance and weaving patterns.

In the bamboo product design evaluation area, VR technology allows designers to showcase details of bamboo products, which include styles, colors, and textures, within a virtual environment. This immersive experience enables users to understand and appreciate bamboo products better. After improving the design, the enhanced visualization effects improve designers' creative efficiency and attract a broader user base, providing a unique interactive experience for expanding the market for bamboo products. As illustrated in Figure 7, users can utilize VR headsets and handheld controllers to magnify, move, and rotate the bamboo products. The interface employs image scaling and other sensory stimuli to enhance user interaction. Then, users score the bamboo products based on the evaluation criteria indicated on the interface, allowing them to assess the design effectiveness. Consequently, users can identify any defects in the bamboo products before production, allowing them to address these issues promptly. This proactive approach reduces production and development costs,

Table 5.—Descriptive statistics before and after improvement.

Items	Evaluation items	Before improvement		After improvement	
		Mean	Standard deviation	Mean	Standard deviation
Visual design	What is the aesthetic appeal of the interface?	3.26	1.15	4.38	0.843
	How is the text style of the interface?	3.23	1.234	4.40	0.885
	Is the layout of the interface reasonable?	3.44	1.001	4.33	0.846
	Is the information hierarchy of the interface clear?	3.48	1.253	4.52	0.808
	Is the overall style consistent?	3.30	1.138	4.37	0.895
	Are the sizes, proportions, and arrangement of various functional buttons appropriate?	3.50	0.93	4.42	0.727
	What is the color scheme of the interface?	3.40	1.098	4.30	0.753
	How effectively does the interface reflect bamboo-weaving culture?	3.38	1.042	4.27	0.86
System function	What is the learning experience of the historical and cultural aspects of bamboo weaving?	3.43	1.385	4.47	0.836
	What is the experience of the bamboo-weaving craftsmanship?	3.33	1.287	4.62	0.722
	How effective is the navigation system for evaluating new product designs?	3.41	1.141	4.42	0.789
Human–computer interaction	Are the icon indications in the interface easy to understand?	3.31	1.055	4.09	1.025
	Is the complexity of the interface satisfactory?	3.13	1.015	4.21	1.064
	How is the readability of the text?	3.17	0.948	4.20	0.931
	Is the logical framework of the interaction clear?	3.38	0.883	4.21	0.842
	How engaging is the display and interaction with bamboo-weaving objects?	3.44	0.902	4.35	0.794
	Is the interaction process smooth?	3.51	0.808	4.26	0.754

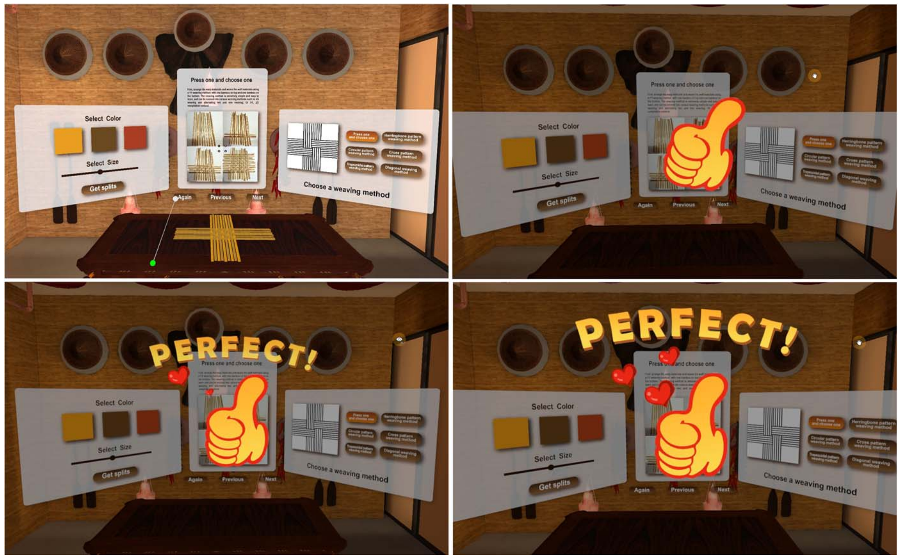

Figure 5.—Virtual reality experience design of improved bamboo-weaving techniques.

enhances design outcomes, and shortens the bamboo product design and development process.

Visual design.—A paired sample t test was conducted to analyze the differences in visual design before and after the improvements. As shown in Table 6, the average score reported by respondents was 3.374, with a standard deviation of 0.872 before the enhancements. However, the average score increased to 4.374, with a standard deviation reducing to 0.640, at postimprovement testing. As a result, the paired sample statistics indicate a significant difference in visual design between the pre-improvement and postimprovement phases ($t = 10.323$, $p < 0.001$). The postimprovement mean of 4.374 compared to the pre-improvement mean of 3.374 demonstrates a notable enhancement in visual design. As exhibited in Figure 5, the improved interface visual design achieved consistency in style after standardizing fonts, colors, and graphic elements. The overall color scheme primarily reflects the natural hues of bamboo materials, thereby reinforcing the association between color and product, facilitating users' understanding of the cultural significance of bamboo weaving. A clean and stable page layout also constructed a transparent and efficient page structure, ensuring users could quickly and accurately access the necessary information.

System function.—A paired sample t test was employed to investigate system functionality variations before and after the enhancements. Table 7 shows that respondents reported an average score of 3.388 with a standard deviation of 1.070 before the upgrades. The average score increased to 4.500 with a standard deviation of 0.732 following the enhancements. System functionality differed significantly between the pre- and postimprovement periods, based on

Figure 6.—AIGC-assisted bamboo-weaving product design.

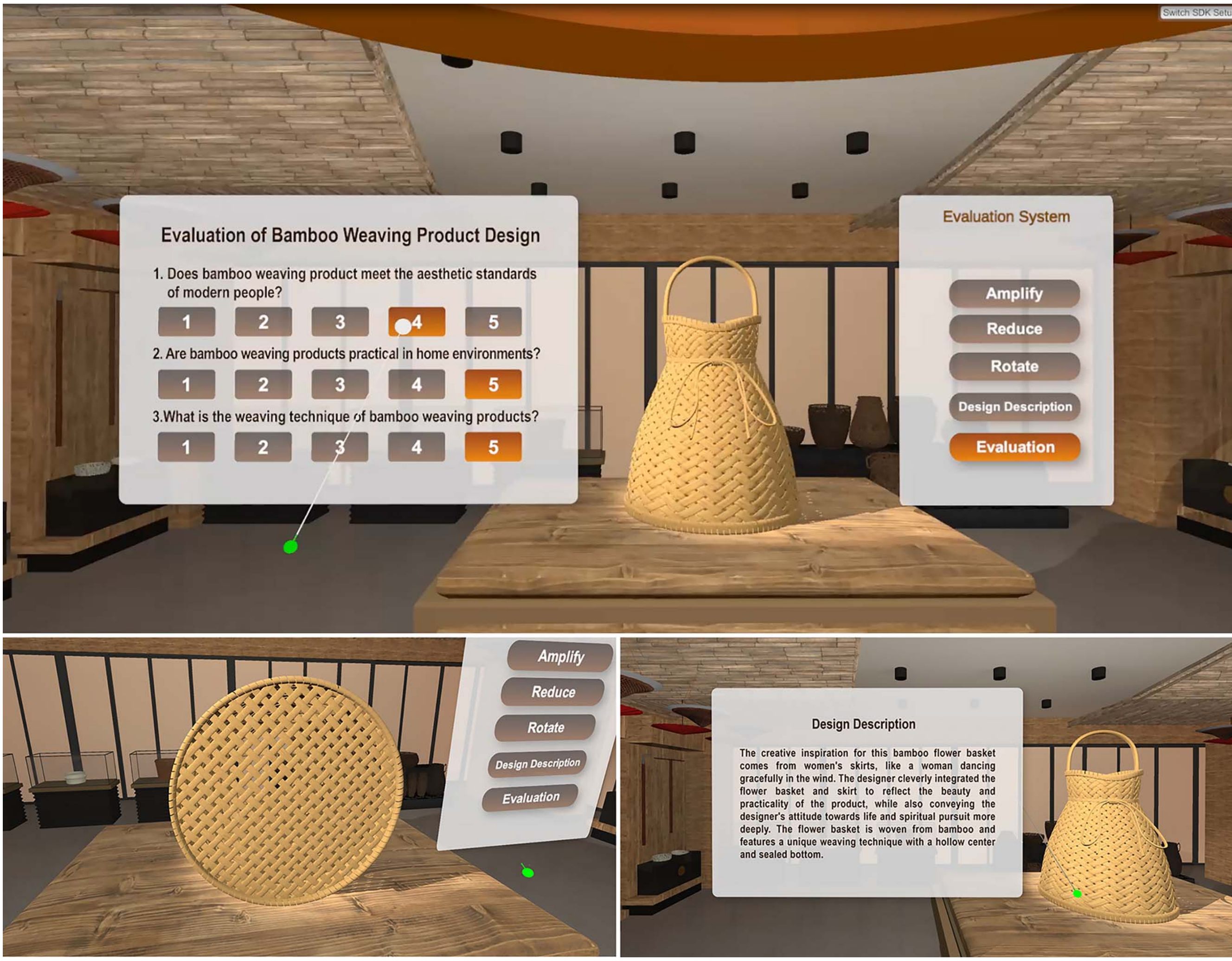

Figure 7.—Evaluation of bamboo-woven product design based on virtual reality.

the paired sample statistics with $t = 8.388$ and $p < 0.001$. The significant improvement in system functionality is shown by an average score of 4.500 compared to the pre-improvement average of 3.388. The system functionality improvements streamlined operational processes, eliminated unnecessary distractions, and reduced the cognitive load for users.

Human–computer interaction.—A paired sample t test was conducted to analyze the differences in human–computer interaction before and after the improvements. As shown in Table 8, respondents reported an average score of 3.326 before the enhancements, with a standard deviation of 0.707. After the improvements, the average score increased to 4.219, with a standard deviation 0.640. The paired sample statistics indicate a significant difference in human–computer interaction between the pre- and post-improvement stages ($t = 9.516$, $p < 0.001$). Therefore, compared to the pre-improvement mean of 3.326, the postimprovement mean of 4.219 signifies a substantial enhancement in human–computer interaction. As depicted in Figure 7, the optimized human–computer interaction effectively directs users' attention to the most important aspects of the content, thereby improving information retrieval and interaction. For example, when users view the details of the exhibits, the interface provides real-time feedback signals for zooming or rotating the exhibits upon touch activation. This dynamic interaction mechanism visually presents the characteristics of bamboo-weaving patterns and

Table 6.—Paired sample statistics comparing assessments of visual design before and after improvement.

	Number of cases	Mean	Standard deviation	t	P^a
After improvement	86	4.374	0.640	10.323	<0.001*
Before improvement	86	3.374	0.872		

[a] $* = p < 0.001$.

Table 7.—Paired sample statistics comparing assessments of system functionality before and after improvement.

	Number of cases	Mean	Standard deviation	t	P^a
After improvement	86	4.500	0.732	8.388	<0.001*
Before improvement	86	3.388	1.070		

[a] $* = p < 0.001$.

Table 8.—Paired sample statistics comparing assessments of human–computer interaction before and after improvement.

	Number of cases	Mean	Standard deviation	t	P^{a}
After improvement	86	4.219	0.640	9.516	<0.001*
Before improvement	86	3.326	0.707		

[a] $* = p < 0.001$.

encourages users to engage in deeper exploration and information extraction.

Figure 5 also shows that the optimized human–computer interaction for the bamboo-weaving experience utilized an engaging and straightforward interactive approach. This approach encourages users to participate in learning and practicing bamboo-weaving techniques. Moreover, the framework significantly enhanced users' learning experience of bamboo-weaving skills and sparked their enthusiasm for engaging with bamboo culture.

Comparison analysis of designer and user satisfaction

We emphasized designers and users as assessment subjects to deepen the relationship between users' backgrounds and their perceptions of the redesigned system's operation to align more closely with user-centered design. The relevant data are compiled in Table 9. The statistical results show notable differences in the evaluations of visual design, system functionality, and human–computer interaction between designers and users. The following analysis will address these three aspects individually.

Visual design: This aspect includes elements such as the aesthetic appeal of the interface, the style of text, the rationality of the layout, the clarity of information hierarchy, the consistency of overall style, the appropriateness of the size, proportion, and arrangement of functional buttons, the color combinations, and how the bamboo-weaving culture is reflected. The average scores for the designer group ranged from 3.97 to 4.34, while the user group scored between 4.41 and 4.63. Overall, the user group scored higher than the designer group.

System functionality: This aspect encompasses the learning experience about the historical and cultural aspects of bamboo weaving, the experience of the weaving technique, and the effectiveness of the product design evaluation guide system. The average scores for the designer group ranged from 4.19 to 4.28, compared to the user group's scores of 4.52 to 4.81. The user group outperformed the designer group.

Human–computer interaction: Key elements in this process include the understandability of icon indicators, satisfaction with the interface, readability of text complexity, clarity of the interactive logic framework, the engaging nature of the bamboo products displayed, and the smoothness of the interaction process. The average scores for the designer group fell between 3.88 and 4.13, while the user group scored from 4.17 to 4.50. Consistently, the user group scored higher than the designer group.

Visual design.—An independent samples t test was conducted to analyze whether there were significant differences in visual design scores between the designer and user groups. Table 10 presents the average score of 4.125 for the designer group, with a standard deviation of 0.929. After the improvements, the average score for the user group increased to 4.521, with a standard deviation reducing to 0.305. The results indicate a significant difference between the designer and user groups ($t = 2.337$, $p = 0.025 < 0.05$). The mean score for the user group was 4.521, while the designer group had a mean score of 4.125, indicating that the user group scored significantly higher than the designer group.

System function.—An independent samples t test was conducted to determine whether there were significant

Table 9.—Comparison of user group testing of subjective satisfaction.

		User group		Designer group	
Items	Evaluation items	Mean	Standard deviation	Mean	Standard deviation
Visual design	What is the aesthetic appeal of the interface?	4.63	0.560	3.97	1.062
	How is the text style of the interface?	4.48	0.771	4.25	1.047
	Is the layout of the interface reasonable?	4.50	0.505	4.03	1.177
	Is the information hierarchy of the interface clear?	4.63	0.708	4.34	0.937
	Is the overall style consistent?	4.48	0.720	4.19	1.12
	Are the sizes, proportions, and arrangement of various functional buttons appropriate?	4.59	0.496	4.13	0.942
	What is the color scheme of the interface?	4.44	0.572	4.06	0.948
	How effectively does the interface reflect bamboo-weaving culture?	4.41	0.630	4.03	1.121
System function	What is the learning experience of the historical and cultural aspects of bamboo weaving?	4.63	0.623	4.19	1.061
	How is the experience of the bamboo-weaving craftsmanship?	4.81	0.392	4.28	0.991
	How effective is the navigation system for evaluating new product designs?	4.52	0.574	4.25	1.047
Human–computer interaction	Are the icon indications in the interface easy to understand?	4.17	0.841	3.97	1.282
	Is the complexity of the interface satisfactory?	4.26	0.994	4.13	1.185
	How is the readability of the text?	4.26	0.757	4.09	1.174
	Is the logical framework of the interaction clear?	4.41	0.533	3.88	1.129
	How engaging is the display and interaction with bamboo-weaving objects?	4.50	0.505	4.09	1.088
	Is the interaction process smooth?	4.48	0.540	3.88	0.907

Table 10.—Independent sample statistics of visual design for two groups.

Group	Number of cases	Mean	Standard deviation	t	P[a]
User group	54	4.521	0.305	2.337	0.025*
Designer group	32	4.125	0.929		

[a] * = $p < 0.05$.

Table 12.—Independent sample statistics of human–computer interaction for two groups.

Group	Number of cases	Mean	Standard deviation	t	P[a]
User group	54	4.346	0.390	2.054	0.047*
Designer group	32	4.005	0.888		

[a] * = $p < 0.05$.

differences in system functionality scores between the designer and user groups. As shown in Table 11, the average score for the designer group was 4.240, with a standard deviation of 0.999. In comparison, the average score for the user group was 4.654, with a standard deviation of 0.458. The results in Table 11 show a significant difference between the designer and user groups ($t = 2.215$, $p = 0.033 < 0.05$). The mean score for the user group was 4.654, while the designer group's score was 4.240, indicating that the user group scored significantly higher than the designer group.

Human–computer interactions.—An independent samples t test was conducted to analyze whether significant differences were noted in human–computer interaction scores between the designer and user groups. As shown in Table 12, the average score for the designer group was 4.005, with a standard deviation of 0.888. In contrast, the average score for the user group was 4.346, and the standard deviation was 0.390. The results indicate a significant difference between the designer and user groups ($t = 2.054$, $p = 0.047 < 0.05$). The mean score for the user group was 4.346, while the designer group's mean score was 4.005, indicating that the user group scored significantly higher than the designer group.

The paired sample t-test analysis exhibited a significant improvement in visual design, system functionality, and human–computer interaction before and after the enhancements, suggesting the effectiveness of our targeted improvement measures. Furthermore, the independent samples t test revealed significant differences between the designer and user groups across visual design, system functionality, and human–computer interaction. The user group expressed greater satisfaction with the current results, whereas the designer group tended to have higher expectations. The users rated the experience higher than the designers owing to several factors. First, users approached the evaluation from the exhibition visitors' perspective, focusing on the smoothness and intuitiveness of the entire virtual exhibition. Moreover, they prioritized aspects such as ease of operation, clarity of information conveyed, and overall enjoyment of the experience. In contrast, designers' evaluation was based on the design standpoint, emphasizing aesthetic appeal and functional details. Their higher expectations may have led them to concentrate excessively on technical details or aesthetic evaluations, resulting in scoring biases during the testing phase.

Table 11.—Independent sample statistics of system function for two groups.

Group	Number of cases	Mean	Standard deviation	t	P[a]
User group	54	4.654	0.458	2.215	0.033*
Designer group	32	4.240	0.999		

[a] * = $p < 0.05$.

Conclusions

Designers can leverage the unique characteristics of bamboo materials to develop innovative bamboo-based products and gain a deeper understanding of bamboo craftsmanship to meet public demand (Chen and Fu 2023). The immersive experience of bamboo-weaving culture based on VR systems provides technical support for designers in developing bamboo products (Wu and Kang 2021). This study constructed a VR experience and product development system for traditional bamboo-weaving techniques, and the findings indicate that the system demonstrates good usability, reduces the cognitive load during user interaction, and enhances users' exploration, understanding, and learning of bamboo culture information, thereby improving the efficiency of new product development. The research also validates the feasibility of combining VR technology with the experience of bamboo-weaving craftsmanship. Future studies could explore the VR systems' applicability in the context of traditional bamboo weaving or intangible cultural heritage across different regions and ethnicities, thereby expanding its application prospects. Moreover, this study created a novel bamboo design pathway that included VR weaving technique experience, AIGC-driven bamboo design creativity, 3D modeling technology support, and VR product evaluation. This innovative approach significantly shortens the time required for designers to learn traditional bamboo-weaving techniques and provides adequate technical support for the modern design of traditional bamboo products. Using VR experience in design, this research examined bamboo VR experiences and product design evaluations from three dimensions: visual interface design, system functionality, and human–computer interaction, while comparing the differences in experiences between designers and users. The results show that designers and users highly evaluated the improved system. Bamboo products developed based on this system, after user experience evaluations, can be put into actual production. This system can enhance user satisfaction with bamboo products, shorten the product design and development process, and establish a practical pathway for the modern design of traditional bamboo products.

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