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REVIEW PAPER

Value-based model of user interaction design for virtual museum

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Abstract
With the development of digital technology and the popularity of human-centered concepts in museum exhibition design, the user experience of VR (virtual reality)-based museum exhibition (VRME) is gradually being emphasized. There are still many problems that need to be solved in the integration of technology and interaction in today's VRME design. However, the existing museum exhibition design framework does not combine the characteristics of virtual reality technology to solve the problems unique to VRME in a targeted manner. Based on the traditional user experience framework, this paper summarizes the three levels of user experience (LoUX) in a museum exhibition and proposes the unique "creation level" experience of VRME, which constitutes the closed-loop of the VRME experience. Then, this paper analyzes the relevant researches in recent years through a literature review and summarizes the trends of technology application and the different interaction problems arising from each LoUX. Based on the results of literature analysis, this paper proposes a "rose model" of VRME. This model summarizes the relationship between exhibition technology, sensory types, LoUX, and human-exhibition interaction factors, which has certain guiding significance for VRME design. Finally, this paper discusses the results of the literature review and the interaction design insights brought by the model.

Keywords Virtual reality · Virtual exhibition · Museum · Interaction design · User experience

Abbreviations

VR	Virtual reality
AR	Augmented reality
MR	Mixed reality
VRME	VR-based museum exhibition(s)
LoUX	Level of user experience
HEIF	Human-exhibition interaction factor(s

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1 Introduction

1.1 The history of museum exhibition with virtual reality

The concept of "user interaction experience" in contemporary museum exhibition was not born with the concept of the museum, but has evolved and is always changing. The museum itself is a relatively new institution, and the basic principle of the contemporary museum was not defined until the second half of the twentieth century: it is a special tool for communication (Carrozzino and Bergamasco 2010). Since the birth of the "New museology" in 1984, human-exhibition interaction in exhibition design has been discussed (Miles and Alt 1988; Bitgood 1992); the focus of research on exhibitions has gradually shifted from a focus on the traditional exhibition to a more visitor-oriented spirit. (Ross 2004). Because of the popularity of human-centered concepts in museum exhibition design, and with the advances in digital technology, museums have been enriched as institutions that use technology to aid in cultural experiences (Carrozzino and Bergamasco 2010). In Ahmad et al. (2014) extended Lord, B. and Lord, G.'s study of the primary ways in which visitors understand the content of exhibitions in 2001, to different methods of communicating meaning in museum exhibitions. Since then, museums have been transformed from mere spaces for exhibiting man-made objects into sites for image-centered educational activities (Choi and Kim 2017). In 2019, Wang and Xia summarize a complete human-exhibition interaction (HEI) framework from three dimensions: exhibition design factors, audience experience factors, and behavior data of designers, museum organizers, and visitors (Wang and Xia 2019).

Museum exhibition technology has also evolved and is the driving force behind the development of interactive experiences in the museum exhibition. In the early days, the most widely used digital exhibition technology was the web page (Nentwig 1999), which allowed visitors to access information about the exhibits, such as pictures and descriptions, from the museum's web page. Technologies such as virtual reality (Carrozzino and Bergamasco 2010), augmented reality (Ho et al. 2011), and mixed reality (Schmidt et al. 2019) have become an important technological foundation for modern virtual reality museum exhibitions (VRME). These virtual reality technologies share some common characteristics: immersion, interaction, imagination (Burdea and Coiffet 1994), and also multi-perception, which open up many new possibilities for museum exhibition.

However, as a relatively new field, there are still some gaps in the integration of technology application and experience design in VRME: for example, visitors may not be able to quickly access an immersive museum exhibition experience using virtual reality (VR) and other technologies (Carrozzino and Bergamasco 2010), or they may not be able to empathize with the virtual image of an augmented reality (AR) guided tour (Schmidt et al. 2019). There are still many topics worth exploring in the field that require a guiding experience design framework as a foundation. However, the current methods or frameworks that apply to experience design for most exhibitions have not been expanded and widely applied to the field of human-exhibition interaction experience design because they do not incorporate the characteristics of virtual reality.

1.2 Paper structure

This paper provides a systematic literature review on the topic of VRME technology applications and experience design, excluding non-museum exhibition scenarios, such as temporary commercial exhibitions. First, this paper reviews the previous work to introduce the four important levels of user experience (LoUX) in VRME: artifact level, behavior level, spiritual level, and creation level. An overview of the research that has been conducted on the four levels of experience is summarized. In the second step, a detailed analysis of the relationship between each human-exhibition interaction factor (HEIF) and LoUX in VRME is conducted by focusing on 42 highly relevant pieces of research. Finally, a theoretical framework is adopted to conclude. The framework reflects the four LoUX, the HEIF, and their interrelationships that need to be considered in the design of a VRME, which expands the framework of VRME experience design, and elaborate the implications of this framework for future VRME design.

2 Four levels of user experience in VRME

In the process of the development of VRME experience design research, museum exhibition has gradually formed three important levels of user experience: artifact level, behavior level, and spiritual level. Thanks to the application of virtual reality technology in museum exhibition, a fourth level of user experience has gradually emerged in addition to these three levels: the creation level. At the same time, the three levels of artifact layer, behavior layer and spiritual layer have also been upgraded with the empowerment of virtual reality technology. These four experience levels are not only the audience's experience of viewing the exhibition but also the expression level of the museum exhibition information.

2.1 Artifact level

According to the user experience model summarized by Qing et al. (2018), the formation of the experience level relies mainly on the mental processing mechanism proposed by Norman (2004), and the experience at the artifact level relies mainly on the intuition level of the mental processing. The appearance of the artifacts in a museum exhibition is the main information that the viewer obtains at first glance, including the colors, shapes, patterns, textures, and decorative styles of the exhibits. The experience of artifact level is the main level of experience for the audience to identify and distinguish between different exhibits, often based on the audience's prior knowledge and evoking different aesthetic emotions through the heuristics (Kahneman et al. 1978).

2.2 Behavior level

The behavior level of experience refers to the perception of the exhibit by the audience through audio, visual, and movement, and relies primarily on the behavioral level of mental processing mechanisms (Norman 2004). The behavior level perceives the functionality of material exhibits or the operation of immaterial exhibits. In this level of experience, visitors often need to engage multiple senses, including visual and auditory. Virtual reality technology, with its multi-sensory characteristics, can add sensory experiences such as haptic and kinesthetic to the behavior level of experience that are difficult to achieve with traditional museum exhibition through sensing technology. Meanwhile, the collection of behavioral data such as gestures, movements, and eye movements become the norm, and it becomes easier for the audience to perceive the exhibits through behavior in VRME. To optimize the experience at the behavior level, the exhibition system has gradually changed from a simple paper-based presentation to a variety of digital virtual reality exhibition, and naturally, the complexity of the exhibition system has been greatly increased (Cole 2004). Therefore, the ease of use of the system in the behavior level experience is an important HEIF to be discussed.

2.3 Spiritual level

Spiritual level refers to the process by which the audience perceives the atmosphere of the exhibition and constructs the meaning of the exhibition, relying mainly on the reflection level of the mental processing mechanism (Norman 2004). After having a more comprehensive knowledge of the exhibit, the audience can be guided to reflect on the meaning of the exhibit, which in turn leads to personal values and attitudes. Thanks to the immersive characteristics of virtual reality technology, the spiritual level of VRME can bring a richer experience to the audience than the spiritual level of traditional museums. At the same time, because of the immersive characteristics of virtual reality technology, the coherence of the experience is even more important. Therefore, the spiritual level of experience in VRME relies heavily on the full artifact and behavioral levels of experience, but also moderates the behavioral level of experience to some extent, allowing the viewer to endure a certain degree of system usability problems (Luo and Ye 2020).

2.4 Creation level

The creation level of experience refers to the process by which the viewer associates with the exhibits and creates something using the exhibit or elements of it, relying on mental processing mechanisms at the levels of intuition, behavior, and reflection. This is a level unique to VRME. The purpose of creation is innovation, which relies on the imagination and association of the intuition level. Unlike the spiritual level of experience, the creation level often requires the involvement of audience behavior (Parker and Saker 2020), too. The emergence of the creation level is made possible by the interactive and conceptual characteristics of virtual reality technology. Unlike the behavior level, which mainly refers to the simulation of the characteristics of things that already exist, the conceptual feature of virtual reality technology enables it to broaden the viewer's cognitive scope and create things that do not exist or cannot exist in the objective world, which provides an important technical basis for the creation level. After generating personal values and attitudes through the spiritual level of experiences, the audience may be predisposed to aesthetics, cultural preservation knowledge, and consumption willingness, which have the potential to be transformed into actual behaviors such as aesthetic creation, cultural dissemination, souvenir purchase, etc. (He et al. 2018).

It has been found through previous studies that virtual reality can effectively influence individuals' imaginative abilities through contextual cues (Blascovich et al. 2002). He et al. also demonstrated through user studies that the introduction of a creation level in VRME is effective in enhancing users' imagination (He et al. 2018). Ch'ng et al. (2019) argue that stakeholder involvement in museum exhibition is important to sustain development, especially when participants and visitors are the core audience of museum activities.

In addition, the creation level has the following effects on museum exhibition:

1. Creation is the process of human conscious exploratory labor on the world, and in the museum exhibition, it can give new life to culture, increase cultural vitality, and promote cultural dissemination.
2. The creation level of experience simultaneously mobilizes the three mental processing mechanisms of intuition, behavior, and reflection, which can produce a very rich user experience.
3. Taking over the spiritual level of experience by transforming it into actual action, and feeding the reflection results back to the artifact level, forming a closed-loop of experience levels. By doing this, audience emotions and exhibition information can flow and circulate between the various experience levels, creating a more complete experience.

2.5 Summary

From the definition of the above four LoUX, their relationship is shown in Fig. 1. The artifact level experience, because it is processed by the intuition level which is the most basic of the mental processing mechanism, directly

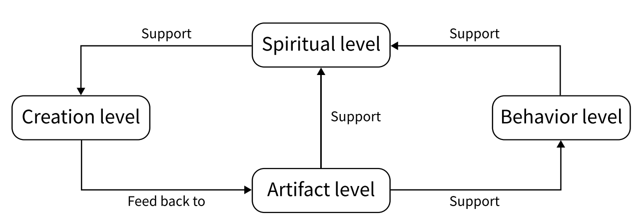

Fig. 1 The relationship between the artifact level, the behavior level, the spiritual level, and the creation level in the VRME

supports the behavior level and the spiritual level experience as the basis of the four LoUX, and the behavior level experience also supports the mental layer experience to a certain extent. The spiritual level of experience then supports the creation level of experience, which ultimately feeds back into the artifact level of experience.

3 Literature review

3.1 Study selection

The following section shows the process that how literature related to VRME be found and how the result is filtered. Then, the classification and the analysis of studies through three elements of museum virtual exhibition is conducted. The keywords “museum virtual exhibition” were searched in WoS, ScienceDirect and IEEE electronic databases, and most of the literature was filtered out according to the type of literature and access rights. Then the remaining literature was skimmed through to filter out some related literature that only involved web technology but not virtual reality technology, and the remaining literature was selected from research papers that involved specific design practice projects. Finally, a total of 42 studies were screened, and the literature screening process is shown in Fig. 2.

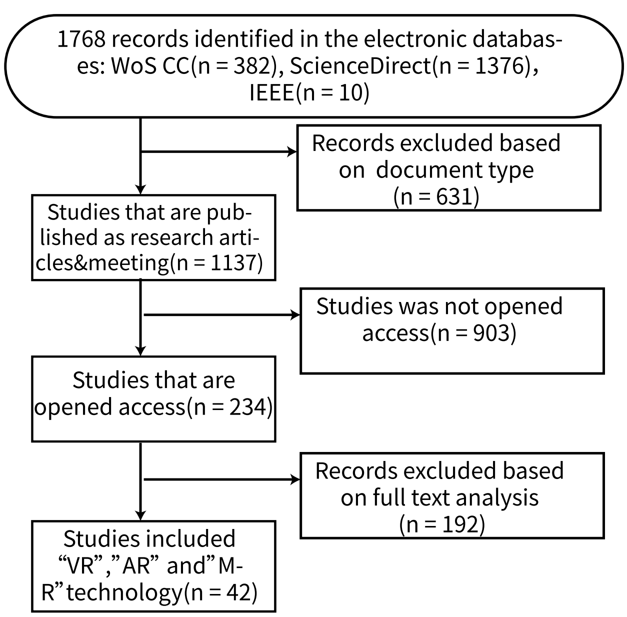

Fig. 2 Schematic diagram of the study selection process

3.2 Literature analysis standards

The literature obtained from the screening was reviewed and the cases of VRME mentioned in each literature were analyzed according to the following criteria.

1. LoUX: the experience levels involved in VRME, including the artifact level (cases mentioning exhibit appearance exhibition), the behavior level (cases mentioning exhibit function simulation or activity simulation), the spiritual level (cases mentioning atmosphere rendering and connotation construction) and the creation level (cases mentioning association and creation sharing).
2. HEIF: interaction factors common to VRME design.

a. Filter keywords: Combine the museum exhibition experience user test dimensions proposed by Lee et al. (2020) and the human exhibition interaction factors proposed by Wang and Xia (2019), with the types of learning behavior proposed by Ahmad et al. (2014), HEIFs are summarized:

- Learning: Learning is the most important function of museums. There are three main types of learning in museum exhibitions: cognitive learning, empathic learning, and social learning. Keywords like learning, perception, concentration, etc. are all considered as mentioning the factor of the learning.
- Emotion: refers to the immersion and aesthetic experience of the audience during the exhibition viewing process. Keywords like emotional, emotion, enjoyment, enjoyable, and satisfaction are all considered as mentioning the factor of emotion.
- Ease of use: refers to the usefulness, fault tolerance, robustness, etc. of the system. Keywords like the ease of use and usefulness are considered as mentioning the system’s ease of use.
- Behavior intention: refers to the user’s tendency to visit and consumer behavior, etc. during the exhibition viewing process. Keywords like intention, behavior intention, tendency, etc. are all considered as mentioning the factor of behavioral intention.

b. Review Standards: The above keywords should appear in the “research purpose”, “evaluation” or “Research Methods” section, but not in the “background”, “introduction”, “literature review” or “references” section. The context and meaning of the studies that meet the above standards will be further judged. At the same time, read and judge the studies that do not mention those keywords but are suspected to see if t any studies also meet the above standards.

3.3 Result

The classification results are shown in Table 1.

4 Results

4.1 Patterns of change in the study situation over time

The number of the studies related to three exhibition technologies changes with years as shown in Fig. 3. It can be seen that the number of applications of VR technology has always been higher than the number of applications of the other two technologies since 2011 and peaked in 2011, 2016, and 2019 respectively. After 2015, the number has always maintained a growing trend, indicating that the study heat of VR application in the virtual exhibition has continued to rise in recent years. The reason is inseparable from the rapid development of VR technology itself in recent years. Similar to the trend in the application of VR technology, the application of AR technology has also risen in popularity in recent years. It also reached a peak in 2019, but in recent years, the popularity has always been slightly lower compared to VR technology. Besides, the research on the application of mixed reality (MR) technology started relatively late due to the research of the MR technology itself. Although the current number is small, its appearance in 2019 marks a key node: MR technology has begun to be tried and applied in the virtual exhibition of museums.

As the museum exhibition scene has a feature, that is, physical and virtual exhibitions are equally important. Therefore, although the number of applications of VR technology is increasing, AR and MR technologies, which are better integrated with the real environment, will also maintain a certain degree of popularity. In particular, the MR technology, which integrates the real environment and the virtual environment better, will play a greater role in the virtual exhibition of the museum with the development of the technology itself.

The studies related to the four LoUX have a pattern of change over time as shown in Fig. 4. The figure shows that the number of cases related to all four levels basically tends to increase over time. Cases related to the creation level appearing almost only from 2018.

4.2 Relationship between the four LoUX

Figure 5 shows the number of cases involving the four LoUX in the reviewed literature. This result shows that the number of cases in the artifact level far exceeds that in the behavior and spiritual level, and most of the cases involving the behavior and spiritual level also have artifact level experience designs. For instance, Caarls et al. (2009)'s AR heritage restoration project in 2009, which involved not only the exhibition at the artifact level but also the simulation of heritage restoration in the behavior level and the spiritual level of heritage conservation connotation construction. Therefore, it can be assumed that the artifact level often serves as the basis for the behavior and spiritual level of experiences. The creation level has the least number of cases, with one case involving both the spiritual level (He et al. 2018) and the remaining three cases involving both the artifact level (Parker and Saker 2020; Ch'ng et al. 2019; Blanco-Pons et al. 2019).

4.3 The relationship between LoUX and sensory type

At present, the types of human senses involved in VRME mainly include visual sense, auditory sense, and kinesthetic sense (touch sense is a combination of kinesthetic sense and skin sense. For statistical convenience, this article classifies a small number of cases involving touch sense as kinesthetic sense, but It does not mean that this article believes that touch sense is equal to kinesthetic sense). Figure 6 shows the number of cases involving the different sensory types in the four LoUX. It can be seen from the figure that almost all cases involve visual senses, while the artifact level for scene reconstruction will involve relatively more auditory senses, while the behavior level and the spiritual level involve more kinesthetic senses in addition to visual sense and auditory sense.

4.4 The relationship between LoUX and learning types

As one of the HEIF, "learning" is divided into three types, namely cognitive learning, social learning, and empathic learning. From the study analysis results showed in Fig. 7, it can be found that the learning types involved in the experience of the artifact and behavior levels are mainly cognitive learning. The spiritual level of experience involves more empathic learning than the behavior and artifact levels. And the creation level involves a lot of social learning besides cognitive learning.

Cognitive learning is the most common learning type and is reflected in four LoUX. The reason is that the most common way of knowledge dissemination in museums is to explain an object through words or images. The process of acquiring knowledge through the explanatory information provided by the museum is biased towards the cognitive learning type. But in many studies, cognitive and social learning types play a role together. This is because the museum is a public space and a typical social scene. Visitors often get information through the exchange of information in

Table 1 Study classification results (This table is made by the author. "√" means that this HEIF is mentioned in the study. A blank means that this HEIF is not mentioned in the study. "*" means this study appears twice or more than twice in this table)

LoUX	Purpose of VRME	Content of VRME	Sensory type	HEIF				Studies
				Emotion	Learn	Ease of use	Behavior intention	
Creation level	Creation sharing	Tiltbrush signature	Visual, kinesthetic	Immersion	Social		√	Parker and Saker (2020)*
		Crowdsourcing reconstruction of 3D cultural relics, virtual scene placement	Visual		Social	√		Ch'ng et al. (2019)*
		Group photo of AR ancient buildings	Visual	Immersion	Social			Blanco-Pons et al. (2019)*
	Inspire association	Exhibits AR special effects	Visual	Immersion, Aesthetic	Cognitive		√	He et al. (2018)*
Spiritual level	Context rendering	Virtual astronaut commentator	Visual, auditory	Immersion	Empathic		√	Schmidt et al. (2019)*
		Virtual humanoid image gallery tour	Visual, auditory				√	Souza et al. (2010)
		Appreciate artworks in a virtual setting	Visual	Immersion	Empathic			Yoo and Gold (2019)*
		Exhibits AR special effects	Visual	Immersion, Aesthetic	Cognitive		√	He et al. (2018)*
		AR exhibition in real scenes	Visual	Immersion				Cirulis et al. (2015)*
	Connotation construction	AR fun test questions	Visual, kinesthetic	Immersion, Aesthetic	Cognitive		√	Sylaiou et al. (2010)*
		AR exhibition restoration artifacts	Visual	Immersion	Cognitive	√		Gherardini et al. (2019)*
		AR exhibition restoration artifacts	Visual, kinesthetic	Immersion				Caarls et al. (2009)*
		AR traditional culture card game	Visual, kinesthetic	Immersion	Empathic	√		Shih et al. (2015)
		Virtual exhibit pattern projection	Visual	Immersion				Lee et al. (2019)*
Behavior level	Functional simulation	Open box game	Visual, kinesthetic	Immersion	Cognitive			Galdieri et al. (2019)
		AR monument commentary	Visual, kinesthetic	Immersion	Social			Schaper et al. (2018)
		Virtual exhibit placement	Visual, kinesthetic	Immersion				Caarls et al. (2009)*
	Activity simulation	Escape Education VR Gam	Visual, auditory, kinesthetic	Immersion	Cognitive			Feng et al. (2018)*
		Ancient Roman building VR game	Visual, kinesthetic	Immersion, Aesthetic	Cognitive			Ferdani et al. (2020)*
		Traditional acrobatics VR teaching game	Visual, auditory, kinesthetic	Immersion	Cognitive			Kim et al. (2019)*

Table 1 (continued)

LoUX	Purpose of VRME	Content of VRME	Sensory type	HEIF				Studies
				Emotion	Learn	Ease of use	Behavior intention	
		Pirate ship building game	Visual		Social		√	Stuedahl and Smørdal (2011)
		Diving treasure hunt VR game	Visual, auditory, kinesthetic	Immersion		√		Secci et al. (2019)*
		Ancient British VR games	Visual, auditory	Immersion	Social			Schofield et al. (2018)*
		World War I tunnel VR experience	Visual, kinesthetic	Immersion	Cognitive			Duer et al. (2020)*
Artifact level	Scene reconstruction	Celebrity home VR reconstruction	Visual, auditory	Immersion, Aesthetic	Cognitive	√	√	Petrelli (2019)
		Virtual museum scene construction	Visual, kinesthetic		Cognitive			Kiourt et al. (2016)*
		Ancient building reconstruction	Visual, auditory	Immersion	Cognitive			Barreau et al. (2020)
		Traditional acrobatics scene restoration	Visual, auditory	Immersion	Cognitive			Kim et al. (2019)*
		Historical scene reconstruction	Visual, auditory	Immersion	Social		√	Parker and Saker (2020)*
		Ancient building reconstruction	Visual	Immersion	Social			Demetrescu et al. (2016)
		Disaster scene reconstruction	Visual, auditory	Immersion	Cognitive			Feng et al. (2018)*
		Ancient Roman architecture reconstruction	Visual	Immersion, Aesthetic	Cognitive			Ferdani et al. (2020)*
		Museum scene reconstruction	Visual	Immersion		√		Robles-Ortega et al. (2012)*
		Museum scene reconstruction	Visual	Immersion				Loaiza Carvajal et al. (2020)*
		Marine environmental reconstruction	Visual, auditory	Immersion		√		Secci et al. (2019)*
		Historical scene reconstruction	Visual, auditory	Immersion				Horáková and Mucha (2019)
		Historical scene reconstruction	Visual, auditory	Immersion	Social			Schofield et al. (2018)*
		Outdoor scene construction	Visual	Immersion	Empathic			Yoo and Gold (2019)*
		Historical scene reconstruction	Visual, auditory	Immersion	Cognitive			Duer et al. (2020)*
		Scene reconstruction	Visual, auditory	Immersion	Cognitive	√		Galdieri et al. (2017)
		Reconstruction	Visual, auditory	Immersion				Falconer et al. (2020)
		Ancient building reconstruction	Visual	Immersion	Cognitive			Blanco-Pons et al. (2019)*

Table 1 (continued)

LoUX	Purpose of VRME	Content of VRME	Sensory type	HEIF				Studies
				Emotion	Learn	Ease of use	Behavior intention	
	Exhibits exhibition	Landmark building VR exhibition	Visual, auditory	Immersion	Cognitive	√		Ho et al. (2011)
		Virtual cultural relic exhibition	Visual		Cognitive	√	√	Xiao et al. (2018)
		Virtual cultural relic exhibition	Kinesthetic, Visual		Cognitive			Choi and Kim (2017)
		Virtual rocket exhibition	Visual, auditory	Immersion	Empathic		√	Schmidt et al. (2019)*
		Virtual cultural relic exhibition	Visual		Cognitive			Kiourt et al. (2016)*
		Virtual cultural relic exhibition	Visual		Cognitive	√		Ch'ng et al. (2019)*
		Virtual cultural relic exhibition	Visual		Cognitive			Merino et al. (2018)
		Virtual tactile experience exhibits	Visual, kinesthetic	Immersion	Social	√		Comes (2016)
		Virtual cultural relic exhibition	Visual	Immersion		√		Robles-Ortega et al. (2012)*
		Virtual cultural relic exhibition	Visual	Immersion				Loaiza Carvajal et al. (2020)*
		VR avatar tour	Visual, auditory		Social	√		Li et al. (2019)
		Audio AR Navigation System	Auditory, kinesthetic	Immersion	Social	√	√	Kaghat et al. (2020)
		Virtual cultural relic exhibition	Visual	Immersion, Aesthetic	Cognitive			Sylaiou et al. (2010)*
		Virtual cultural relic exhibition	Visual	Immersion		√		Kyriakou and Hermon (2019)
		Virtual cultural relic exhibition	Visual	Immersion	Cognitive	√		Gherardini et al. (2019)*
		Virtual cultural relic exhibition	Visual	Immersion				Pierdicca et al. (2016)
		Virtual cultural relic exhibition	Visual	Immersion				Caarls et al. (2009)*
		Virtual cultural relic exhibition	Visual	Immersion				Cirulis et al. (2015)*
		Virtual cultural relic exhibition	Visual	Immersion	Cognitive			Skowronski et al. (2018)
		Virtual building exhibition	Visual	Immersion	Cognitive			Bekele (2019)
		Virtual cultural relic exhibition	Visual	Immersion				Lee et al. (2019)*

the museum scene. Cognitive and social learning type will play a role in this process.

Social learning is fully utilized in the VRME, not only at the creation level of experience but also at other LoUX. For example, an AR interpretation system developed by Schaper et al. (2018), interacts through interactive methods such as actions and gestures, creating a context of communication, suitable for group visits. Another example is, Parker and Saker et al., used tiltbrush to design a signature system in the virtual exhibition in 2020. This system allowed visitors to draw and sign virtually on the display screen, leaving traces of the visit. The traces are displayed on the

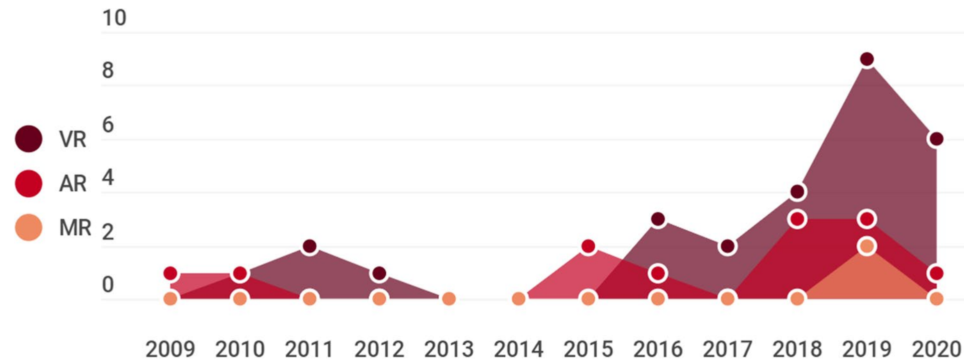

Fig. 3 The number of studies of three technologies changes over the years

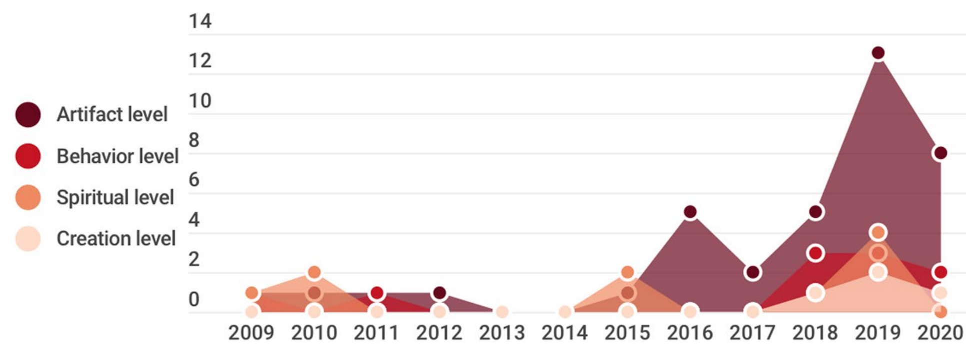

Fig. 4 The number of studies of four LoUX changes over the years

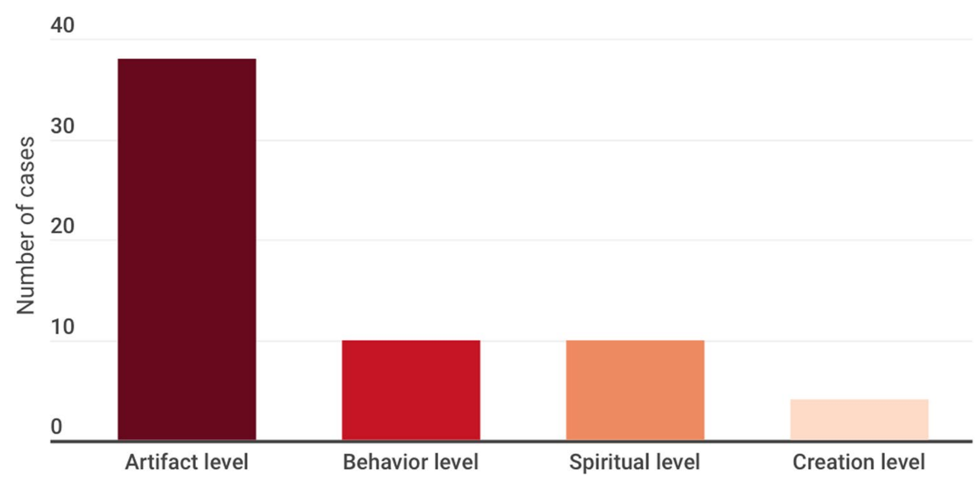

Fig. 5 The number of cases involving the four LoUX

large screen and can be shared on social networks (Parker and Saker 2020). In this case, what motivated the audience to carry out this activity is mainly social needs. Although the audience's social network is not on the exhibition site but through Internet sharing, the audience can discuss with more people, express their attitudes, and gain personal value. Through this, the audience can have a deeper impression of the exhibition content.

Empathic learning type is a special type, and it rarely appears in the virtual exhibition design of museums. However, empathic learning allows visitors to have a deeper understanding of the theme, making them feel substituting and inspiring visitors' emotional experience. With positive emotional feedback, visitors will learn more actively about the contents of the museum's exhibition. This is a type of learning that highly combines the two experiences of emotion and learning. For example, the virtual commentary system developed by Schmidt et al. (2019) simulating a virtual astronaut image that is highly related to the theme of the exhibition. By introducing exhibits in this virtual astronaut's tone, visitors empathize with the virtual commentator and enhancing the sense of immersion of the VR commentary system. It also increases tourists' intention to understand the subject. Virtual exhibition technology makes

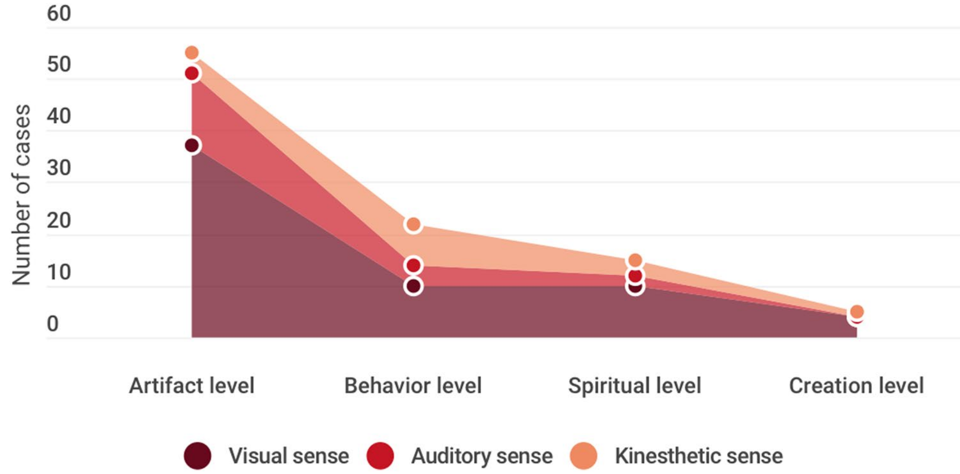

Fig. 6 The number of cases involving the different sensory types in the four LoUX

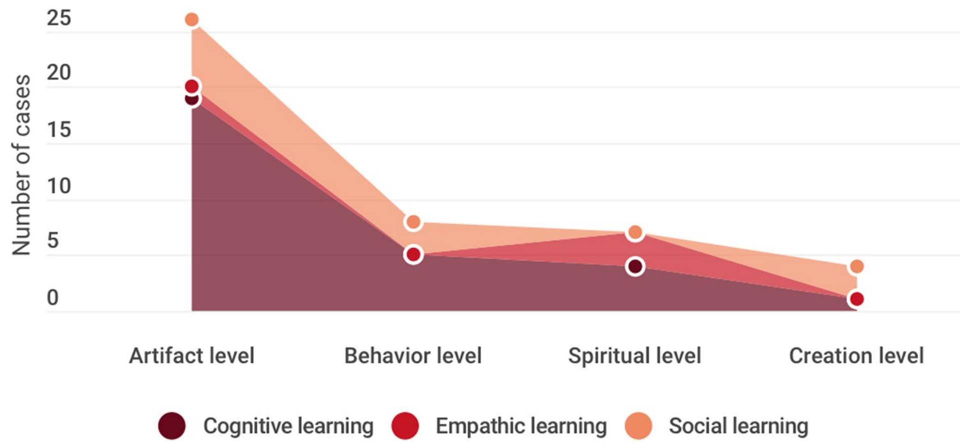

Fig. 7 The number of cases involving the different learning types in the four LoUX

empathic learning in museums easier to achieve through higher immersion. The emotional effect brought by empathic learning type can in turn increase the immersion brought by virtual exhibition technology, which is a very important factor to the spiritual level of experience.

4.5 The relationship between LoUX and other HEIF

In addition to learning factors, HEIF also includes emotion, ease of use, and behavior intention. These three factors are of secondary importance to VRME compared to learning. Most cases mention the emotion factor, but not all cases mention the ease of use and behavior intention at the same time.

4.5.1 The factor of emotion

According to Lee et al. (2020)'s study on museum immersive VR experience, the emotional experience of visitors indirectly affects the intention of visitors to visit museums through the two dimensions of being away from reality (Escapism) and aesthetic (Esthetic). Therefore, this article takes immersion and aesthetics as the two sub-dimensions of emotional experience.

Judging from the results of study analysis, most of the studies on virtual exhibitions in museums mention the experience of immersion. This shows that immersion is an important goal and evaluation metrics for the application of AR, MR, and VR technology. A high degree of immersion can bring a certain degree of pleasure, and a moderate degree of pleasure can also improve cognitive efficiency. The study of the correlation between the intensities of different emotions and the effects of cognition indicates that the appropriate intensity of happiness can maximize cognition effects (Sroufe 1979). Excessive immersion will affect the emotional experience of tourists to a certain extent. For example, in 2010, Carrozzino and Bergamasco (2010) researched the influencing factors of immersion in museum VR exhibitions and found through user interviews that excessive immersion will give users a lonely emotional experience. This will in turn affect users' cognition of exhibitions content. Interestingly, almost all exhibition involving AR technology or MR technology mentioned the immersion dimension, while some VR exhibition did not mention it. Because VR technology

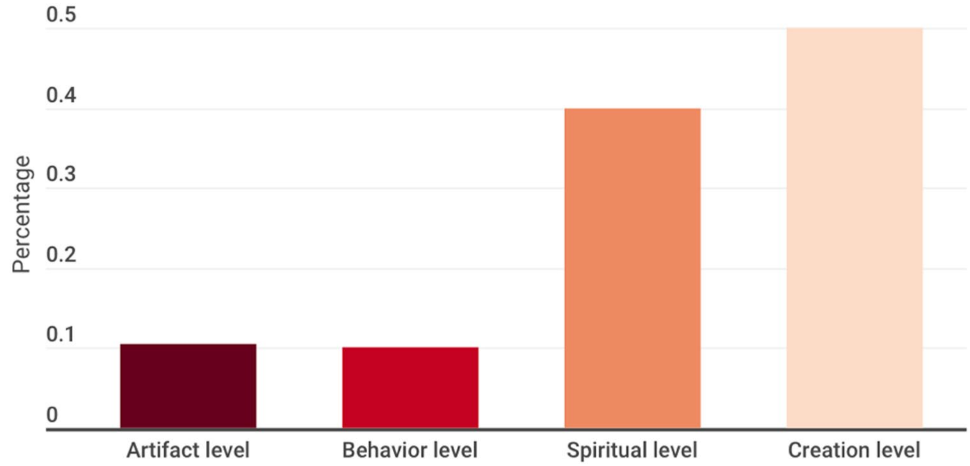

Fig. 8 The percentage of mentioned behavioral tendencies in the four LoUX

naturally has higher immersive attributes, so in some studies, this point is not specifically emphasized. However, AR technology or MR technology is weaker than VR technology in terms of immersive performance. Therefore, it is necessary to focus on immersion when designing the exhibition. Therefore, while the immersion that can be achieved by the exhibition technology is gradually improving, it is necessary to combine the characteristics of the technology and control the appropriate immersion level to bring the best emotional experience to visitors.

There are relatively few studies mentioning aesthetic emotional experience, only some special types of exhibitions will focus on it. The virtual exhibition of exhibits, mainly artworks, will pay more attention to the aesthetic experience of audiences. For example, in 2018, He et al. studied the impact of AR dynamic verbal information and AR dynamic visual information on tourists' aesthetic experience when they viewing art painting exhibits (He et al. 2018). Besides, the VR exhibition that reconstructs the scene will also pay attention to the aesthetic experience. On the one hand, the reconstruction of the scene needs to ensure the degree of restoration of the original scene. On the other hand, because this type of exhibition mainly relies on visual images, it is necessary to pay attention to whether the exhibition is pleasing to the eye. For example, when Ferdani and others developed VR games with ancient Roman architecture as the scene, they paid special attention to the aesthetic effect of the 3D reconstruction results (Ferdani et al. 2020). Therefore, when designing this type of exhibition, a better exhibition effect can be achieved by paying attention to the aesthetic experience of tourists.

From the results of the literature review, it can be found that the factor of emotion is mentioned in all four LoUX. Therefore, emotion runs through the closed-loop of the four LoUX as one of the HEIF.

4.5.2 The factor of ease of use

The necessity of testing for ease of use and testing methods are often determined by the technology. Some VR or AR technology applications have relatively high system complexity. For example, visitors are required to use unfamiliar HMD or control devices such as joysticks or remote controllers. Therefore, it is necessary to test the ease of use of the system. Some systems involve behavioral data acquisition, and usability testing is required to test the experience of the data acquisition process. On the one hand, a positive result can eliminate user learning or emotional experience problems caused by the ease of use, on the other hand, it can prove the rationality of the system's design.

4.5.3 The factor of behavior intention

Figure 8 shows a comparison of the percentage of mentioned behavioral tendencies in the four LoUX. In terms of this result, behavior intention is given more attention in the creation and spiritual levels of experience design. He et al. (2018) explored the tendency of the audience to consume after viewing an exhibition of an artist painting with special effects made by AR.

4.6 VRME design model

Through literature review, it is found that there are some connections between the four LoUX. Analyzing the relationship between LoUX, and HEIF, we can obtain the model in Fig. 9, which is called the "rose model" because of its rose-like shape. This model summarizes the connection between exhibition technology, sensory types, LoUX and HEIF in VRME.

As shown in Fig. 10, the model is broken down into four parts: (a), (b), (c), (d). (a) represents the virtual exhibition technology at the center, which will serve as the core and

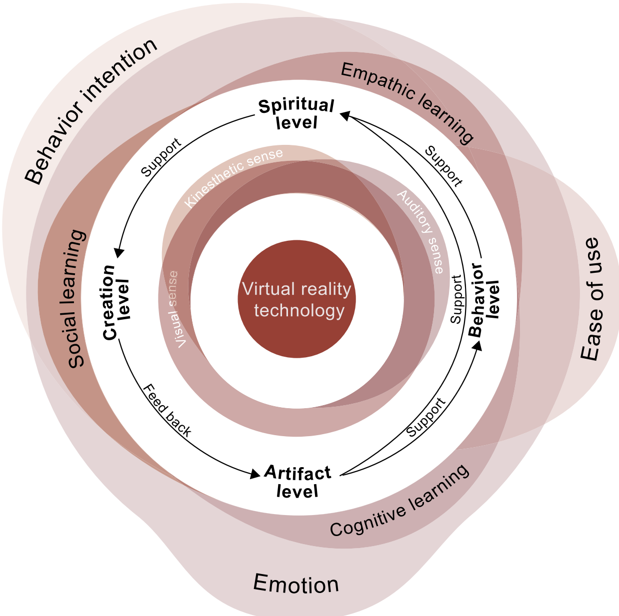

Fig. 9 The “rose model” of VRME interaction design

foundation of the whole system because of its immersion, multi-perception, interactivity and conceptualization features that traditional exhibition methods do not possess, creating a different sensory experience and interactive factors from traditional museum exhibition.

Part (b) shows the visual, auditory and kinesthetic sensory types and the relationship between them. According to the analysis above, visual experience is involved in all LoUX and dominates in all of them, so the graph representing visual is a complete circle evenly distributed on the four LoUX. However, auditory experience is mainly highlighted in the process of transformation from the behavior level to the spiritual level, and plays a weaker role in the creation level. The graph representing auditory is an irregular bump that gradually rises from the artifact level and falls back in the spiritual level adn the highest point is located in the middle of the behavior and spiritual level. The graph representing the kinesthetic experience is similar to the auditory one, but in a slightly different position, because according to the analysis results, the stronger role of kinesthesia is in the behavior, spiritual and creation levels, mainly in the

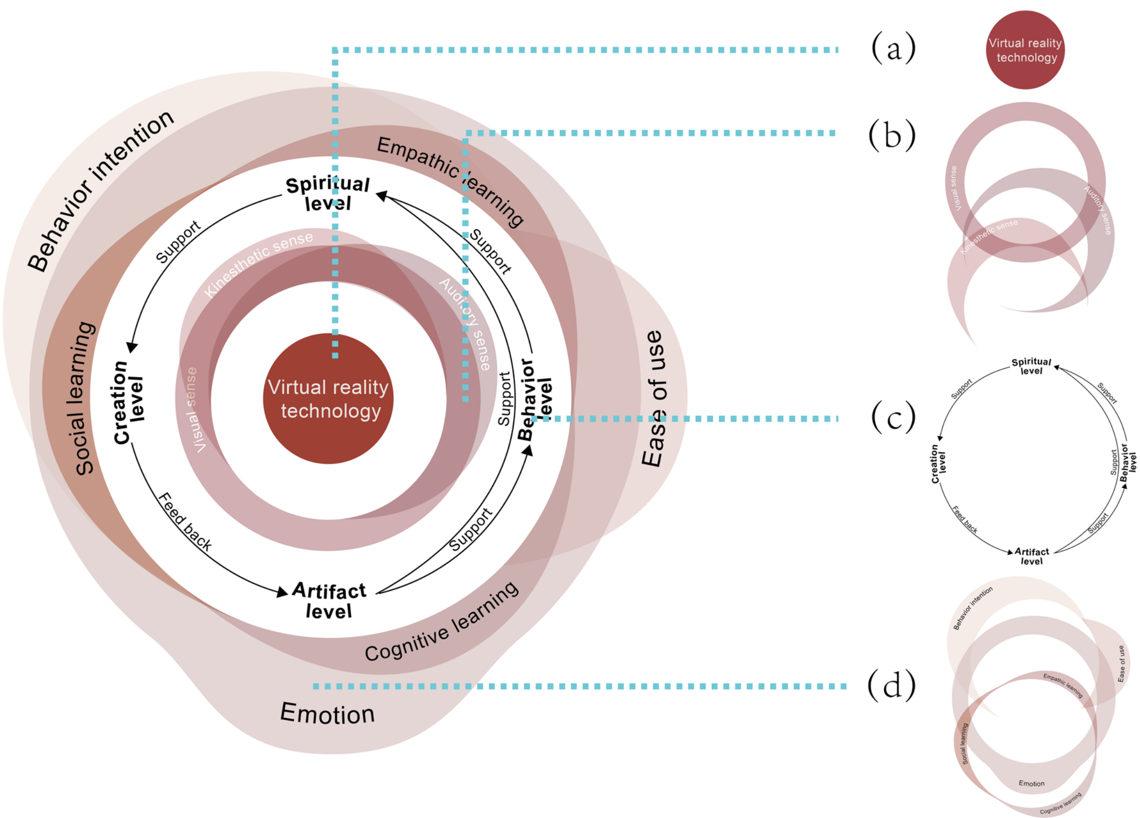

Fig. 10 The model is broken down into four parts: (a), (b), (c), (d)

process of transformation from the spiritual layer to the creation level.

Part (c) shows the relationship between the four LoUX. The relationship between the four LoUX is exactly the same as shown in Fig. 1 and has been explained above. Here they are rearranged on a circle for the sake of the appearance of the model.

Part (d) demonstrates a variety of the HEIF covered above, where cognitive, social, and empathic learning are different learning types. More cognitive learning occurs during the transformation of the artifact level to the behavior level, more empathic learning occurs during the transformation of the behavior level to the spiritual level, and social learning occurs mainly during the transformation of the spiritual level to the creation level and during the feedback from the creation level to the artifact level. The graphs of all three are therefore irregularly raised and have different distributions of the highest point positions. The graph for emotion is a complete circle with an irregular bump at the highest point corresponding to the artifact level, which indicates that emotion is evident in all four LoUX, but the artifact level tends to be the main LoUX that generates emotion. Behavior intention and ease of use factors are similar in graphical form, with more behavior intention such as user consumption and social sharing being evident in the process of transforming the spiritual level to the creation level, while the behavior level will generate more ease of use issues due to its own characteristics.

In summary, in this model, different sensory types and HEIF have spatial correspondence with the four LoUX. If the graph has a bump in the position of a certain experience level, it means that this sensory type plays a greater role in the transformation process between certain experience levels or certain experience levels itself, or the transformation process between certain experience levels or certain experience levels itself can produce a certain HEIF more obviously.

When using this model as a design reference, you can select the LoUX needed for the project and observe the corresponding sensory types and HEIF from the diagram. For example, if you need to design for the behavior level, you can intercept the behavior level and its corresponding elements as in Fig. 11 to obtain the following information: In the design of the behavior level, you need to try to ensure the three sensory types of visual, kinesthetic and auditory, and consider both cognitive and empathic learning types, and if appropriate, you need to conduct ease of use tests. More

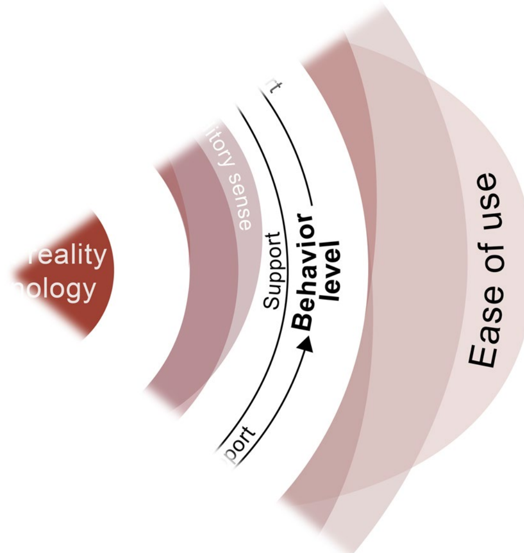

Fig. 11 Intercept the behavior level and its corresponding elements

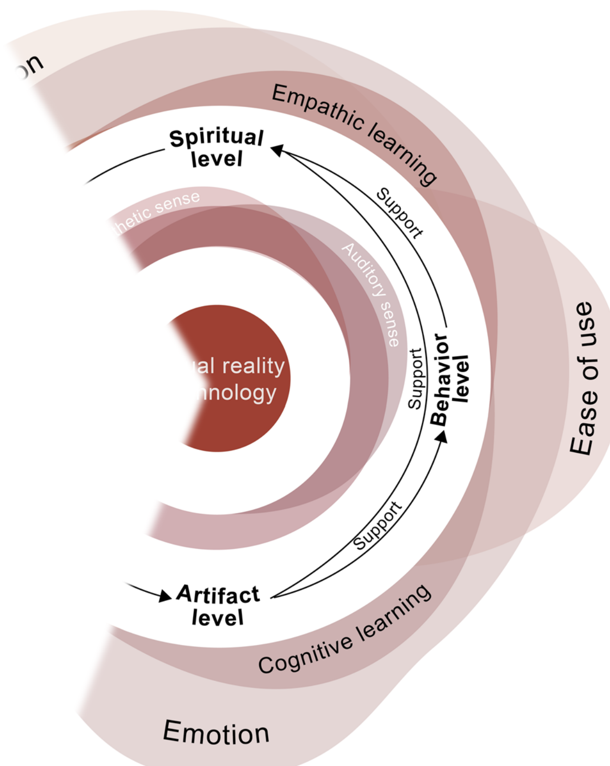

Fig. 12 The interception is expanded with the behavior level as the center

insight can be gained if the interception is expanded with the behavior level as the center (Fig. 12): the transformation process from the artifact level to the behavior level and the behavior level to the spiritual level is considered in the design solution. The artifact level can support the experience of the behavior level, and trying to transform toward the spiritual level can enrich the experience.

5 Discussion

From the perspective of museum virtual exhibition technology, this paper examines the studies on museum virtual exhibitions in recent years and discovers that the three main elements of museum virtual exhibitions are exhibition technology, EVMs, and IEs. In the process of literature review, it is found that the research hotspots on exhibition technology have gradually tended to more virtual technologies such as VR in the past few years. But the research heat of MR and other technologies have also risen rapidly in recent years, indicating that research in this field is gradually beginning to pay attention to how to integrate real exhibits or real environment with virtual technology, instead of just confining to absolute virtual museums. Since the birth of New Museology, no matter how the technology develops, attention to the exhibition experience of the audience has only increased. Focusing on a good exhibition experience is also one of the important differences between modern museums and traditional museums. Finally, this paper proposes a virtual exhibition design framework for museums. Through this framework, one can quickly grasp the composition of a museum's virtual exhibition system. This framework helps researchers to deeply understand the connotation of VRME.

According to this framework, we can also get some insights into the design of future VRME.

5.1 Facilitate the LoUX shift to the creation level

The creation level is an important experience level for future VRME, and the formation of the creation level experience relies on the step-by-step support of the artifact level, the behavior level, and the spiritual level.

In short, there are two main steps to improve the creation level of experience: the first is to improve the experience of the artifact level, the behavior level, and the spiritual level; the second is to facilitate the transformation of the artifact level experience to the behavior level, the spiritual level, and the creation level experience.

From the results of the literature review, we can find that most VRME cases at this stage focus on the research of the artifact level experience, and there are relatively few studies related to the behavior, spiritual, and creation level experiences. Future VRME research can deepen the behavior and spiritual level experiences more, and promote the transformation of the experience level to the creation level by enriching the sensory types and optimizing each HEIF.

5.2 Enriching the types of senses involved in VRME

According to different theories, there are many human senses such as visual, auditory, olfactory, gustatory, kinesthetic, tactile, etc. At present, only visual, auditory, kinesthetic, and tactile senses are widely used in VRME, among which visual and auditory senses still occupy the main position.

Future VRME research needs to optimize the kinesthetic and kinesthetic-based haptic senses in addition to the visual and auditory experience. Besides, increasing the experience of other sensory types such as smell, heat, and cold will also be a major innovation for VRME interaction. When the sensory types are enriched, the concept of "synesthesia" can be used to create a richer multimodal sensory experience.

5.3 Inspiring audience's social and empathic learning

The audience's learning type in the museum virtual exhibition is mainly cognitive learning, supplemented by social and affective learning. The museum is a public and thematic scene, which is an ideal place for social and affective learning. This distinguishes the museum from classrooms or other educational scenes. Therefore, how to use exhibition technology to stimulate the audience's social and affective learning types will be a topic worthy of research in the future.

Virtual reality technologies will hinder the interaction between people to a certain extent, so in order to promote social learning, when applying VR technology applications, we can use device networking to try multi-person collaboration. When using AR or MR technology, we can create a communication context between people through projection or other ways to share the screen. In the development of exhibition content, it is possible to increase two-person or multi-person cooperation games or give the audience the chance to share through social platforms. The principle is encouraging the audience to put themselves in a social environment when viewing the exhibition.

In a museum exhibition with strong themes, affective learning can be used to deepen the audience's impression of the exhibition theme. The key to realizing empathic learning lies in the presentation of content, which needs to strengthen the rendering of the theme. On the one hand, use narrative methods to tell the story. On the other hand, create the atmosphere through high-immersion exhibition technology like VR technology.

5.4 Keep moderate immersion and focus on aesthetic experience

Immersion is an important emotional experience that needs to be paid attention to when applying virtual reality technologies in museum virtual exhibitions. Especially when AR and MR technologies are limited by technical characteristics, which caused the immersion created is often inferior to VR technology, more attention needs to be paid to the immersive experience. At the same time, it is necessary to keep the immersion to an appropriate level to avoid excessively high immersion, which causes users to have negative emotions. In the future museum virtual exhibition design, no matter what technology is used, immersion is required as an important design goal. The audience's immersive experience needs to be verified in the user test phase.

Besides, if the exhibition content involves works of art or the exhibition content will occupy most of the audience's visual channels, attention needs to be paid to the audience's aesthetic experience. The artwork itself has extremely high viewing value and will bring a good aesthetic experience. When use virtual exhibition technology to explain the art exhibits, it is necessary to ensure that the original aesthetic experience is not damaged as much as possible and try to optimize the aesthetic experience. A visual image-based exhibition such as scene simulation also needs to pay attention to whether the image is beautiful and whether it can bring good visual enjoyment to the audience. If an image-centric virtual exhibition cannot bring the audience a good visual experience, it will greatly destroy the overall viewing experience.

Immersion and aesthetic experience together affect the emotional experience of the audience when viewing the exhibition, and the emotional experience will affect the audience's visit and consumption behavior tendency together with the learning method. Therefore, in the future museum virtual exhibition design, it is necessary to avoid focusing on improving technical functions while ignoring the emotional experience at the interactive level. We should use technology but should not be limited by technology.

5.5 Future works

This paper summarizes a model for VRME design based on the literature review, but the design insights from this model are not only applicable to museum exhibition scenarios from a certain perspective, but also have some possibilities to be useful in other virtual reality applications, such as virtual reality stores, virtual reality art creation, and virtual reality games. Of course, this model is mainly based on the literature review and is still highly subjective, so in our future research, we will conduct some quantitative user studies to further improve the model and extend it to more virtual reality applications.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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