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Exploring how the metaverse of cultural heritage (MCH) influences users' intentions to experience offline: a two-stage SEM-ANN analysis

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Abstract

The metaverse for cultural heritage (MCH) serves as a digital platform that enables users to access and engage with cultural heritage resources online. With the rapid expansion of cultural digitisation, many organizations have adopted the MCH to increase their impact and reach. However, empirical research is essential to substantiate the role and significance of MCH. This study examines users' intentions to engage with MCH and their offline experiences. Using the SEM-ANN method, 989 respondents participated in an analysis framed by the NVM approach through questionnaires. The results show a dependence of users' offline experience intentions on their intentions to engage with MCH ($\beta = 0.216$, $T = 7.915$, $P < 0.001$), along with perceived benefits ($\beta = 0.199$, $T = 6.576$, $P < 0.001$) and perceived risks ($\beta = -0.051$, $T = -2.008$, $P = 0.045$). Results suggest that MCH has the potential to enhance offline experiences; factors such as creativity, entertainment and narrative significantly influence users' positive evaluations of MCH, while privacy data, performance ethic and negative psychology influences may reduce users' positive evaluations. These findings have important implications for cultural heritage managers, developers and designers, suggesting that the use of the metaverse can enrich the cultural heritage experience, attract a broader user base beyond offline methods, and promote the appreciation and dissemination of traditional culture.

Keywords Metaverse of cultural heritage (MCH), Perceived benefits, Perceived risk, Experience intention, Structural equation modeling (SEM), Artificial neural network (ANN)

Introduction

Cyberspace has emerged as the quintessential medium for individuals worldwide to search for, acquire and disseminate information in the digital age. The rapid evolution of digital technology has revolutionised this domain, ushering in a new epoch of communication, interaction, learning and knowledge sharing that transcends geographical and temporal boundaries [1]. Immersive technologies such as virtual and augmented reality have given rise to the metaverse, an innovative and sophisticated cyberspace [2]. Coined in Neal Stephenson's "Snow Crash", the metaverse is presented as a complex realm where individuals create digital avatars to inhabit a parallel virtual world through VR devices [3]. This concept suggests a comprehensive integration of the physical and digital worlds, providing an immersive, expansive and self-sustaining virtual shared space. Within the metaverse, shared virtual environments and interoperable networks facilitate synchronous interactions between users and digital entities through avatars [4, 5]. This pioneering virtual space, characterised by its immersive, intuitive and interactive nature, represents a paradigm

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shift from conventional modalities of communication and information exchange and is at the forefront of technological innovation [6].

The role of the metaverse in cultural heritage (CH) has gained prominence, driven by the burgeoning appeal of metaverse applications [7, 8]. CH, a cornerstone of collective human civilisation, encompasses a range of cultural expressions, traditions, skills and knowledge. Its complexity, diversity, dynamism and narrative richness inherently limit its communication [9]. Nevertheless, the metaverse provides a platform for creating immersive and interactive virtual CH experiences that offer new ways of discovering and sharing information [10, 11]. Various disciplines have ventured into the metaverse for cultural heritage (MCH), exploring historical figures [12], cave paintings [13], ethnographic methods [14], agricultural traditions and museums [15, 16], among others. In general, MCH initiatives use the metaverse to attract attention, generate user interest in CH, and encourage participation in offline experiences. Despite this, most MCH initiatives are still at an early stage, with developers seeking clarity on strategies to achieve their goals. Consequently, determining the effective use of MCH to engage a wider audience in both online and offline CH experiences is a compelling research question.

At present, the technological, content and market maturity of MCH is not sufficient for individuals to avoid real-world experiences in favour of complete immersion in virtual environments. There is a symbiotic relationship between MCH and real-world experiences. Based on the premise that the metaverse can augment offline experiences, this research examines the impact of MCH on users' intentions to understand and participate in offline CH. To elucidate these complex dynamics, we developed a hypothetical model based on the Net Valence Model (NVM) to facilitate the design of questionnaires and the interviewing of MCH users. Subsequent analysis of the user data using structural equation modelling (SEM) and artificial neural network (ANN) techniques confirmed the hypotheses and model, and shed light on key influencing factors. The findings of the study are of potential value to cultural heritage practitioners, digital platform developers, communicators and researchers, providing insights into how to enhance the MCH experience through the metaverse, increase user engagement and promote the appreciation and preservation of traditional culture.

Literature review and hypotheses development

Metaverse of cultural heritage (MCH)

The metaverse, a transformative and intuitive medium that reflects human civilisation and cultural values, has materialised with the rapid advancement of augmented and virtual reality technologies [17]. It encompasses a spectrum of technologies, including networking, computing, the Internet of Things, blockchain, human–computer interaction, artificial intelligence, and visualization [18]. Metaverse platforms allow digitised cultural heritage (CH) to transcend physical and temporal boundaries and present global cultures in a virtual format. Digital tools such as holography, 3D modelling, data visualisation and AI interactive systems are central to CH, enabling the recreation of intricate cultural performances, rituals, ceremonies and historical knowledge systems [12]. Users can digitally engage with traditional dance forms through motion capture or practice craft techniques in virtual studios [19].

CH, which includes both tangible and intangible elements, benefits from the metaverse's ability to protect, preserve, display and promote this heritage beyond the capabilities of the material world [20, 21]. The metaverse recontextualises CH by facilitating the exchange of social, cultural and educational knowledge, transforming learning into an experiential journey. It also democratises CH, allowing it to flourish across borders in an all-encompassing virtual space [12]. In this way, immersive metaverse environments enable wider access to, understanding of and participation in CH, and promote its preservation and dissemination.

MCH is a digital space that transforms CH from the physical to the virtual world, encouraging creative transformation and immersive experiences [17, 22]. Through techniques such as modelling and rendering, abstract concepts become tangible and users can interact with the digital environment, enhancing their in-depth understanding of CH [23]. This approach represents a departure from traditional CH communication, with users in the metaverse actively engaged in cultural activities, unrestricted by geography [17]. They become contributors to the preservation, development and transmission of CH, with the ability to explore the metaverse at will, engage with chatbots, appreciate art and participate in global information exchange [24, 25]. MCH disseminates both tangible and intangible data, supporting the collection, storage, display, sharing, preservation, restoration, monitoring, protection, research and transmission of CH [17].

Net valence model (NVM)

The Net Valence Model (NVM) provides a nuanced and comprehensive perspective based on established behavioural theories. It synthesises various theoretical frameworks, including the Theory of Reasoned Action (TRA), the Theory of Planned Behaviour (TPB) and the Technology Acceptance Model (TAM), which underpin the NVM's fundamental concepts of perceived benefits and

risks [26]. Based on the premise that individuals make rational decisions, the NVM posits that users assimilate diverse information and consider ramifications and predictable outcomes before making a decision [27]. However, user behaviour that is assumed to be rational can be influenced by two different constraints: passive behaviour influenced by external factors [28, 29], and active behaviour characterised by deliberate strategies [27]. Thus, NVM is useful for analysing variations in user behaviour in different contexts of perceived benefits and risks [26, 30]. Its application spans diverse research domains, such as social media [26, 31] and smart home technology [32], to elucidate user intentions and decision-making processes.

In contemporary society, despite the facilitation of advanced technologies, users require instrumental rationality to see the connection between their actions and desired outcomes [27]. This is especially true when the reliability of the technology is in question, which requires users to deliberate and decide. When faced with new technologies, products or services, users naturally invest additional time in weighing the expected benefits against the costs of adoption, with perceived benefits and risks playing a key role in shaping their decisions. If significant benefits are perceived, users are more likely to overcome barriers and adopt the product or service [33]. At the same time, perceived risk accentuates a user's assessment of the potential harm associated with a product or service. Featherman et al. [34] suggest that perceived risk has two dimensions: the likelihood of adverse outcomes and the severity of the potential harm. Research by Li et al. [26] confirms that both perceived risk and benefit significantly influence users' behavioural intentions. The NVM can shed light on the potential impact of MCH on users' offline experience intentions. Using the bootstrapping concept within the NVM, the hypothesis development phase will identify factors that influence the impact of MCH on users' offline experiences and the interplay between these factors.

Variables relevant to the study

Creativity and perceived benefits

MCH is a diverse, open community that promotes communication and consensus building around CH, emphasising its role as a leader in creating meaning and value [17, 35]. Creativity, which is often seen as culturally contingent and varying across different backgrounds [36, 37], is also seen as a universal trait [38]. This suggests that creativity, or its level, should conform to majority judgement, potentially acting as a mediator between market orientation and new product success [39] and encapsulating the divergent thinking behind novel ideas [40, 41]. Such perspectives highlight the interplay between creativity and user perceptions, suggesting that the appeal of MCH depends on an innovative approach to CH design and content, beyond mere digital replication. For example, Terras et al. [42] discuss the use of CH data, the design of virtual artefacts, the construction of digital content and the use of digital technologies to enhance CH collaboration. Increased creativity in CH is likely to have a positive impact on user perceptions, leading to the formulation of two hypotheses.

H1 Creativity design is positively related to perceived benefits.

H2 Creativity content is positively related to perceived benefits.

Entertainment and perceived benefits

Venkatesh [43] posits that users' perceptions of entertainment act as a conceptualised expression of intrinsic motivation, influencing their evaluation of a system's utility [44]. Entertainment, defined as the pleasure derived from experiential processes regardless of outcome [43, 45], has been shown to elicit enjoyment and promote positive behaviours [45–47]. MCH's immersive entertainment environment, in which entertainment plays a crucial role [48], may positively influence users' behavioural decisions [49]. This hypothesis is consistent with previous research.

H3 Entertainment is positively related to perceived benefits.

Narrative and perceived benefits

Narrative is recognised as an important tool for constructing CH knowledge and linking it to contemporary relevance [50–52]. MCH uses narrative to emphasise the dimensional structure of the metaverse and the interplay between the physical and virtual realms of CH. MCH not only simulates and generates visual and structural information, but also organises CH-related stories, customs and socio-historical contexts, an area ripe for exploration [17]. The role of narrative in CH investment and research is increasingly recognised as a key driver of user engagement [53], leading to the proposition of hypothesis H4.

H4 Narrative is positively related to perceived benefits.

Privacy data and perceived risks

Privacy is emerging as a critical concern in CH, with users wary of the security risks associated with the use of mobile devices and operating systems [54]. Practices involving the collection and use of user data, such

as camera surveillance, geolocation tracking, biometric scanning, and the use of personal information for marketing purposes, can violate privacy and risk data breaches, potentially leading to identity theft and other violations [55]. Inadequate protection of private data increases users' concerns about the risk of MCH, leading to hypothesis H5.

H5 Privacy data is positively related to perceived risks.

Performance ethic and perceived risks

While the technological advances of the metaverse have enriched CH, they have also sparked ethical debates, particularly around technological fairness and its implications for the equality of user experience. Jia et al. [55] highlight that inequalities are mainly manifested in the integrity and transparency of the user experience, noting that VR technology may exclude users with certain physical or neurological conditions, such as visual impairment, epilepsy or motion sickness, from fully engaging with MCH. In addition, algorithmic recommendations tailored to user preferences could create 'blind spots' or inadvertently misguide user participation, compromising the transparency of the MCH experience. These unresolved ethical issues could influence users' perceived risk, leading to the formulation of hypothesis H6.

H6 Performance ethic is positively related to perceived risks.

Negative psychology and perceived risks

MCH can evoke negative emotions in users. While MCH can evoke a sense of time travel, an excessive focus on the past can hinder users' engagement with the present [56]. The digital recreation of historical objects, such as traditional decorations, costumes and artefacts, can induce nostalgia, which can have negative psychological effects [57, 58]. In addition, MCH has the potential to enrich visitors' experiences, although it can also create a disconnection from the actuality of CH, reducing user satisfaction [59]. Such negative psychological effects may increase users' discomfort and perceived risk. Hypothesis H7 is therefore proposed.

H7 Negative psychology is positively related to perceived risks.

Perceived benefits, perceived risks and intentions of the experience

MCH strives to provide rich CH information and online experiences that deepen users' understanding of CH and promote its diffusion and offline engagement. However, the unpredictability of product or service experiences requires users to make strategic assessments of perceived risks and benefits [60]. Users' perceived benefits, the positive outcomes of engaging with technological services, contrast with perceived risks, the negative outcomes that encompass various uncertainties [61]. Studies suggest that when perceived risks outweigh benefits, users may be reluctant to seek or share information and may reject products or services [61–64]. Thus, perceived benefits and risks influence users' intentions to engage with MCH and CH offline. The digital representation of MCH and CH content may also encourage offline participation. Consequently, hypotheses H8 to H12 are proposed, with Fig. 1 illustrating the conceptual model.

H8 Perceived benefits are positively related to the intention to experience MCH.

H9 Perceived risks are negatively related to the intention to experience MCH.

H10 Perceived benefits are positively related to the intention to experience offline.

H11 Perceived risks are negatively related to the intention to experience offline.

H12 The intention to experience MCH is positively related to the intention to experience offline.

A case of the Yuanyuzhou platform

Yuanyuzhou, a digital heritage platform in Henan Province, China, has developed an MCH using technologies such as digital avatars, AIGC, 3D, digital twins and VR to recreate Henan's heritage sites, including Longmen Grottoes, Yingtian Academy, Laojun Mountain, Shaolin Temple, Taihao Temple, etc., intending to provide an online matrix for heritage tourism, as shown in Fig. 2. Users can immerse themselves in Henan's cultural heritage through various digital interfaces and VR glasses (pico4 enterprise version or consumer version by August 2023).

In Yuanyuzhou, users can access virtual heritage sites through the map (Fig. 2). For example, as shown in Fig. 3, an avatar visits the Longmen Grottoes, one of the most famous artistic sculptures in the Chinese sculpture group, which was inscribed on the World Heritage List in 2000 [65]. In addition, the platform provides social and interactive features to enable multiple interactions between users and the scene through avatars to enhance the entertainment of the cultural heritage experience. 1) As shown in Fig. 4, users can upload photos to create personalised and exclusive avatars and adjust the gender, skin colour, hairstyle and clothing of the avatars; 2) As

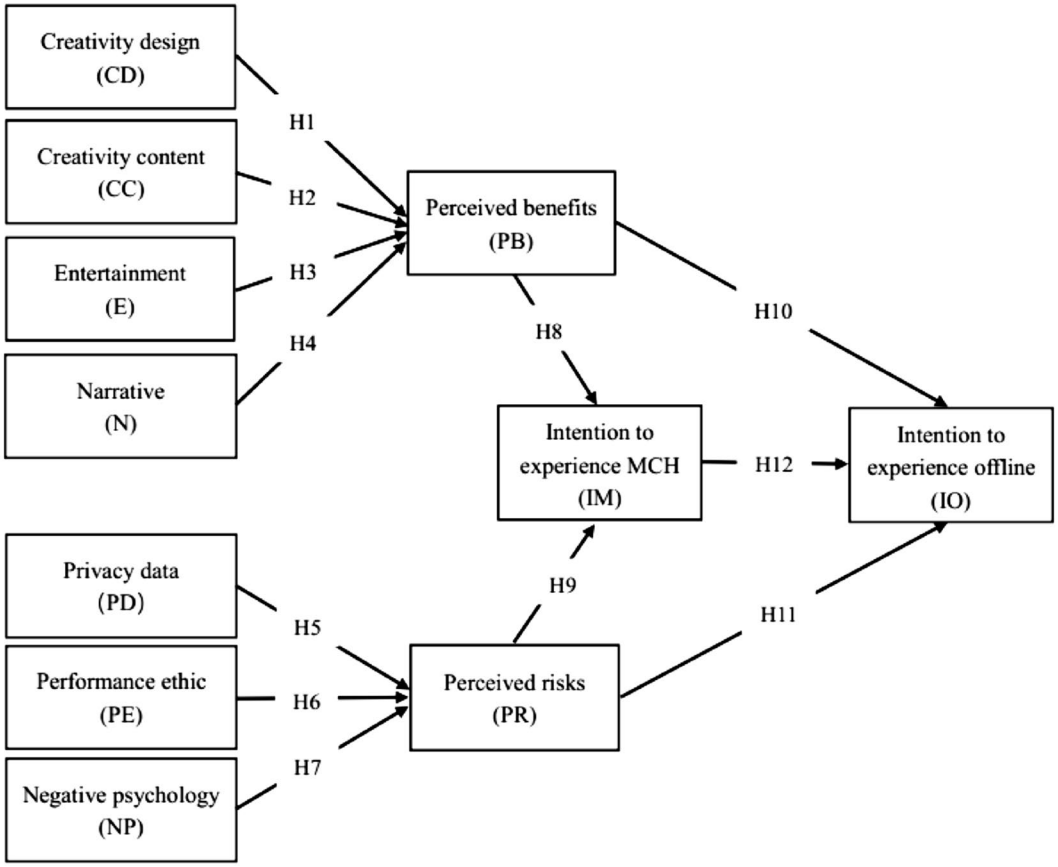


Fig. 1 Research model based on NVM

Fig. 2 Cultural heritage map of Yuanyuzhou

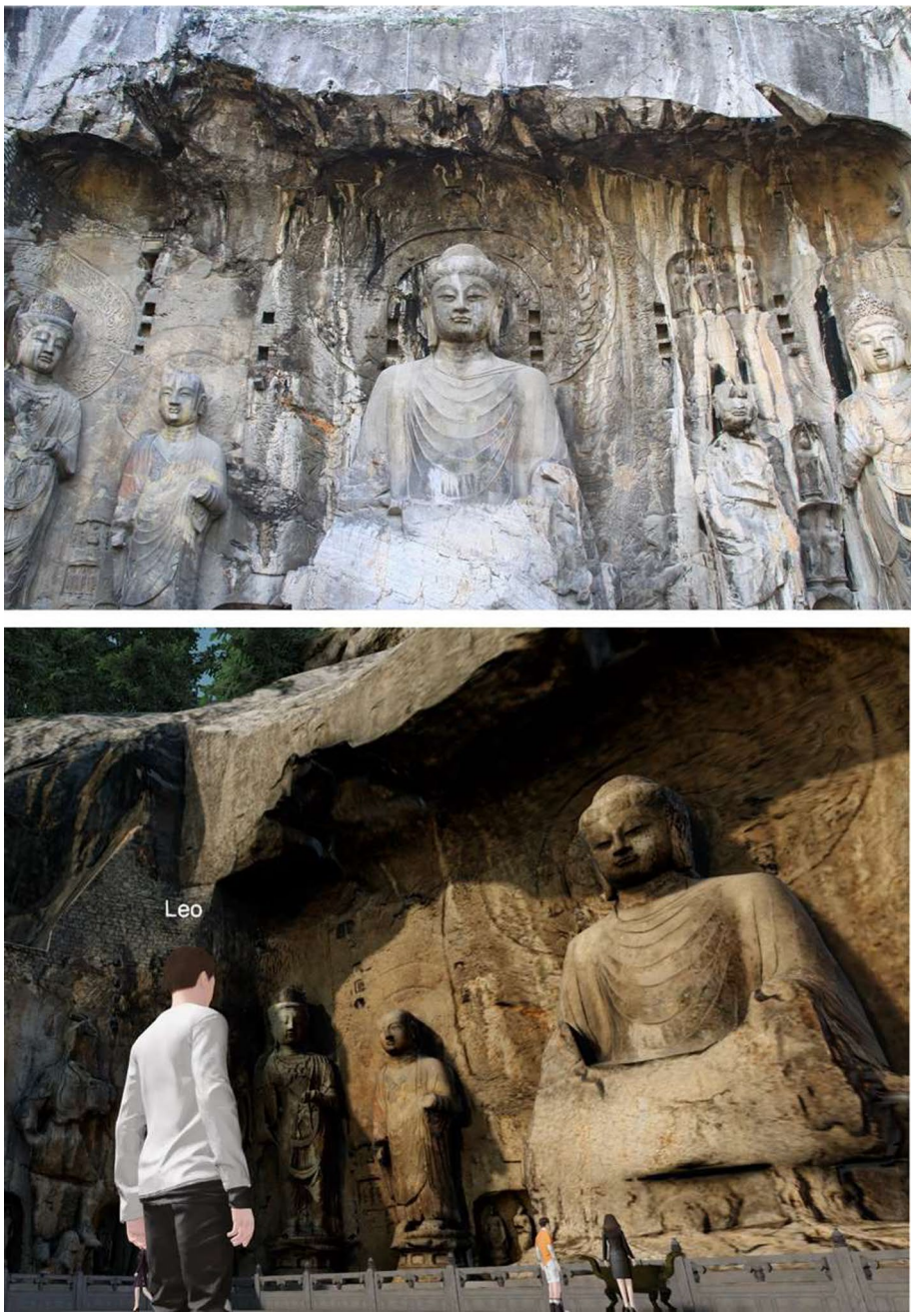


Fig. 3 Longmen Grottoes in Yuanyuzhou and real-world scene

shown in Figs. 5 and 6, users can interact with each other through text and video, actions, facial expressions, pop-ups and other features.

Overall, Yuanyuzhou is valuable for the development of MCH. (1) In terms of business model, the commercialisation revenue is shared by the scene creator, the cultural heritage IP owner and the platform operator, which realises the enthusiasm of the scene creator and the benign operation of the platform. (2) In terms of service mode, it can simultaneously meet the needs of government promotion of cultural and tourism resources, scenic brand promotion and user conversion, and tourism destination experience selection. Yuanyuzhou innovates the new mode of "online + offline" scene fusion, in the three-dimensional virtual digital space collection of virtual scenes, virtual images, virtual objects and other core

Fig. 4 Yuanyuzhou's avatars

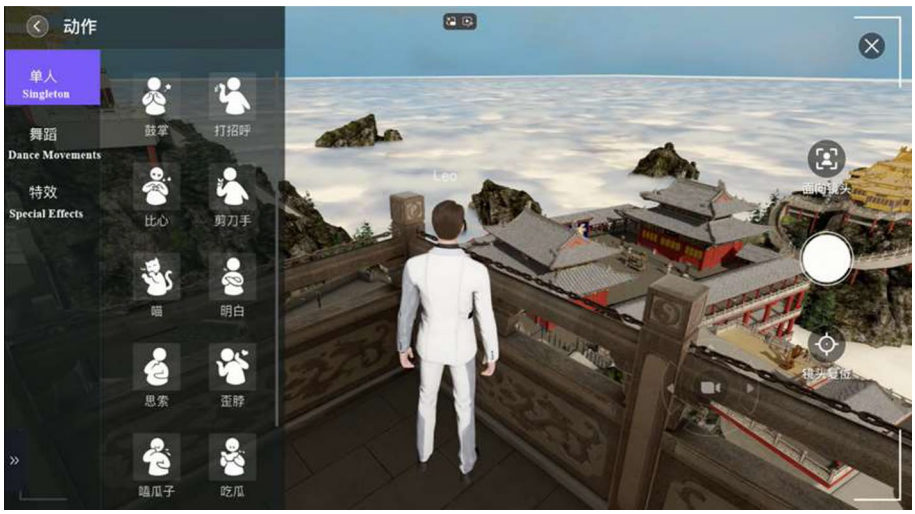


Fig. 5 Yuanyuzhou's user action selection (Laojun Mountain)

elements of the metaverse, with a highly realistic style replica, reproduction of Henan CH scenes, to create an immersive culture and tourism experience of the real and the virtual integration of the new experience. Through VR technology, users can experience CH in an interactive, playful and immersive way, which will provide references for their choice of travel destinations. (3) In terms of technical applications and functions, it has developed an AI intelligent character creation system, realised a variety of social functions such as text, video, barrage and other innovative functions such as the AIGC free creation platform to build a highly immersive and social MCH space. (4) It has built a result-depositing platform that integrates five functions, such as cultural tourism digital T-table, immersive cultural tourism map, digital cultural tourism new workshop, tourism visiting living room on the cloud and digital twin laboratory, to further achieve the goal of attracting and converting from online to offline and from virtual to reality, comprehensively innovating online industrial ecology, product supply, participation mode, experience form and communication mode, and attracting the younger generation of users to participate deeply.

Methodology

Research process steps

This study combines qualitative and quantitative research methods, with the theoretical research part discussing

Fig. 6 Yuanyuzhou's online functional area (DongJing of the Northern Song Dynasty)

the NVM framework and specific cases, and the quantitative research part conducting two-stage SEM-ANN empirical analyses of the questionnaire data. The research process is shown in Fig. 7, which includes six main steps: (1) constructing and discussing the NVM framework, proposing a research model and hypotheses; (2) researching a specific case; (3) designing a questionnaire based on all the hypotheses of the model and surveying the users of the case; (4) conducting SEM analysis of the questionnaire data to verify the model and hypotheses; (5) introducing the variables and their data into the ANN analysis, based on the hypotheses supported by the SEM results, to measure the stability of the results and the normalised importance of the independent variables; (6) discussing the implications of the results.

Questionnaires and data collection

The research questionnaire, consisting of 38 items rated on a 5-point Likert scale, asked respondents to rate their experiences of MCH. Following a pre-test with 50 participants, adjustments were made to refine the focus. The final questionnaire, detailed in Appendix A.1, includes two sections: demographic information (gender, age, education, income) and 27 items assessing the conceptual model. The survey was conducted from September to October 2023 and yielded 989 valid responses from a distribution of 1000 questionnaires, giving a validity rate of 99%.

Appendix A.2 shows the demographic characteristics of the respondents. The sample consisted of 563 males (56.9%) and 426 females (43.1%). The age distribution of the respondents was as follows: 18.1% were under 20 years old, 41.4% were between 20 and 35 years old, 23.7% were between 36 and 50 years old and 16.9% were over 50 years old. In terms of educational attainment, 21.9% of respondents had a high school diploma or less, 36.6% had a bachelor's degree, 22.8% had a master's degree and 18.7% had a doctorate or higher. In terms of income, 39.8% of respondents earned less than 5000 RMB per month, 25.3% earned between 5000 and 10,000 RMB per month, 21.1% earned between 10,000 and 20,000 RMB per month, and 13.8% earned more than 20,000 RMB per month. The sample characteristics reflect the diversity of MCH users and provide a suitable basis for testing the research hypotheses.

Analysis and findings

Measurement model

SPSS 26 and AMOS 26 were used as the main analytical tools in this study. At the reliability testing stage, each construct of the questionnaire passed both internal and external reliability tests. As shown in Table 1, the Cronbach's alpha value (CA) for the questionnaire as a whole and for each independent variable was greater than 0.75, and the composite reliability (CR) of each variable was greater than 0.70, which met the reliability requirements [26, 72], indicating that the questionnaire had satisfactory reliability. In addition, as the sample in this study was collected using a single method, the data were tested for common method variance (CMV) using Harman's single-factor test. The test results using SPSS 26 showed that the maximum variance explained by one factor was 17.8%, which was well below the threshold of 40%, indicating no significant CMV concerns [73].

In the validity testing stage, three main categories were examined: content validity, convergent validity and discriminant validity [74]. Firstly, all latent variables and measurement items in this study were obtained based on

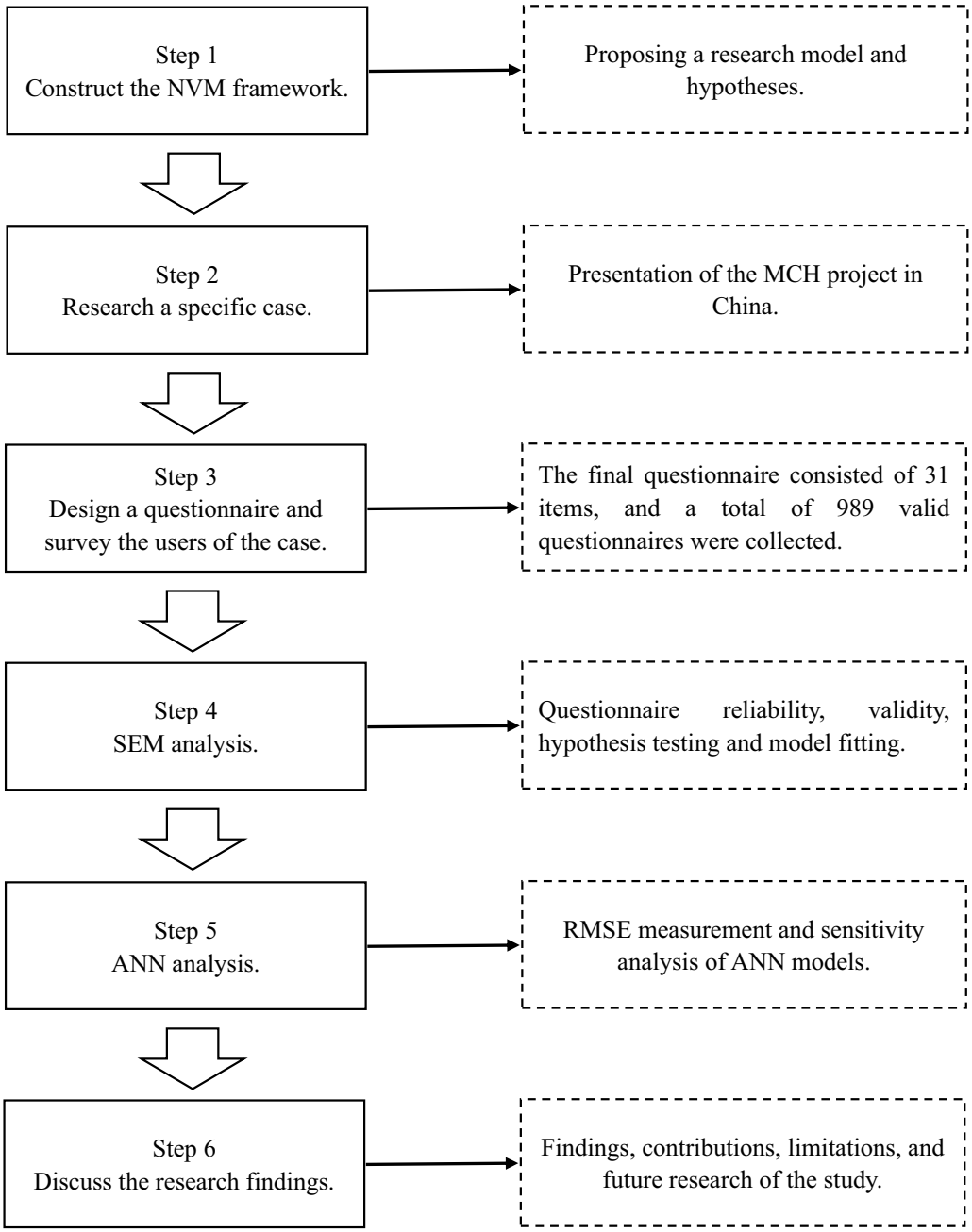


Fig. 7 Steps in the research process

the combination of previous literature, and previous literature had validated the appropriateness of these variables, therefore the questionnaire had qualified content validity. Secondly, Table 1 shows that the factor loadings of all items were greater than 0.70 and the average variance extracted (AVE) values of all variables were greater than 0.50, which met the requirements of convergent validity [72, 75]. Thirdly, the correlation coefficients between the variables were less than 0.75 and the square roots of the AVEs were greater than the corresponding correlation coefficients [72], supporting discriminant validity. The results are presented in Table 2.

Model fitting and hypothesis testing

The model was fitted by maximum likelihood and yielded goodness-of-fit indices that met established criteria: $\chi^2/df = 2.267$, RMSEA = 0.036, GFI = 0.954, AGFI = 0.940, CFI = 0.980, NFI = 0.965 and TLI = 0.976,

Table 1 Confirmatory factor analysis of the conceptual model for the study

Construct	Items/questions	FL (factor loadings)	CA (Cronbach Alpha)	AVE (average variance extracted)	CR (composite reliability)
Creativity design (CD)	3	0.893	0.880	0.761	0.905
		0.848			
		0.875			
Creativity content (CC)	3	0.940	0.943	0.868	0.952
		0.925			
		0.930			
Entertainment (E)	2	0.898	0.787	0.812	0.896
		0.904			
Narrative (N)	3	0.946	0.938	0.887	0.959
		0.945			
		0.934			
Privacy data (PD)	2	0.916	0.818	0.841	0.914
		0.918			
Performance ethic (PE)	2	0.930	0.858	0.865	0.928
		0.930			
Negative psychology (NP)	3	0.884	0.835	0.749	0.900
		0.870			
		0.842			
Perceived benefits (PB)	2	0.914	0.923	0.840	0.913
		0.919			
Perceived risks (PR)	2	0.952	0.938	0.905	0.950
		0.951			
Intention to experience MCH (IM)	3	0.931	0.957	0.881	0.957
		0.944			
		0.940			
Intention to experience offline (IO)	2	0.923	0.918	0.847	0.917
		0.918			

Table 2 Descriptive statistics, square-root of AVEs and correlation matrix

Construct	M	SD	CD	CC	E	N	PD	PE	NP	PB	PR	IM	IO
CD	3.854	1.150	**0.872**										
CC	3.959	1.255	0.327**	**0.932**									
E	3.234	1.163	0.077*	− 0.005	**0.901**								
N	3.756	1.242	− 0.001	0.049	0.017	**0.942**							
PD	3.412	1.141	− 0.05	0.015	0.080*	− 0.02	**0.917**						
PE	3.275	1.395	− 0.006	0.022	0.031	0.064*	0.037	**0.930**					
NP	3.401	1.090	0.039	0.026	0.03	− 0.019	− 0.023	− 0.053	**0.865**				
PB	3.347	1.326	0.261**	0.216**	0.163**	0.101**	− 0.054	− 0.009	0.059	**0.917**			
PR	3.034	1.474	− 0.158**	− 0.066*	0.037	− 0.042	0.084**	0.121**	0.103**	− 0.214**	**0.951**		
IM	3.217	1.389	0.202**	0.089**	0.083**	0.092**	− 0.034	− 0.003	0.031	0.310**	− 0.167**	**0.939**	
IO	3.831	1.143	0.261**	0.067*	0.127**	0.024	− 0.052	0.126**	0.016	0.310**	− 0.153**	0.334**	**0.920**

***Correlation at 0.001 level, **Correlation at 0.01 level, *Correlation at 0.05 level

The bold and underlined values are the square roots of the AVEs

all in accordance with criteria that require χ^2/df below 5, RMSEA below 0.08 and other indices above 0.90 [76, 77]. All 12 hypotheses were empirically supported, as shown in Table 3.

Artificial neural networking (ANN) analysis

Artificial neural networks (ANNs) are algorithms that are adept at modelling human behaviour or decision-making without being influenced by covariate-independent variables and without requiring the assumption of a linear relationship to predict dependent variables from diverse inputs [78, 79]. ANNs are robust to noise, outliers and small sample sizes, and can accommodate both linear and non-linear relationships without the need for data normality [80]. Through the training process, ANN algorithms can predict analysis results with minimal feedforward path error [81]. To mitigate potential SEM errors, the widely used feedforward backpropagation multilayer perceptron (MLP) was used in this study to train the data and assess the significance of the predictor variables, using a sigmoid function as the activation mechanism [82].

As the SEM results confirmed all hypotheses, each variable was included as a predictor in the ANN models. A tenfold cross-validation was performed to avoid model overfitting, with 90% of the sample (n = 890) used as the training set for network training and the remaining 10% (n = 99) used as the test set [83]. Inputs and outputs were normalised to the range [0, 1] to increase training efficiency, reduce training time and improve performance [84]. The final ANN models, detailed in Appendix B, include Model A for assessing perceived benefits, Model B for perceived risks, Model C for measuring intention to engage in MCH, and Model D for intention to engage in offline activities. These models confirm the robustness of the SEM findings and allow for deterministic prediction.

The root mean square error (RMSE) values serve as an indicator of the predictive accuracy of the models [85, 86]. Table 4 shows that the average cross-validated RMSEs for the training models were 0.217, 0.251, 0.229 and 0.185, while the test models had RMSEs of 0.227, 0.256, 0.218 and 0.171. This demonstrates the reliability of the four ANN models in capturing the numerical relationships between predictors and outcomes.

Sensitivity analysis quantifies the importance of an independent variable and its normalised importance. The importance of an independent variable is measured by the extent to which it changes the predicted outcome of a network model [83]. Normalised importance represents the proportionate importance of each independent variable relative to the most significant variable. According

Table 3 Evaluation and analysis of hypotheses

Hypotheses	Detail	Beta (β)	T	Significance	Result
H1	CD → PB	0.264	6.177	***	Supported
H2	CC → PB	0.158	4.215	***	Supported
H3	E → PB	0.218	4.614	***	Supported
H4	N → PB	0.104	3.040	0.002**	Supported
H5	PD → PR	0.124	2.253	0.024*	Supported
H6	PE → PR	0.141	3.932	***	Supported
H7	NP → PR	0.210	3.652	***	Supported
H8	PB → IM	0.325	9.168	***	Supported
H9	PR → IM	− 0.108	− 3.422	***	Supported
H10	PB → IO	0.199	6.576	***	Supported
H11	PR → IO	− 0.051	− 2.008	0.045*	Supported
H12	IM → IO	0.216	7.915	***	Supported

***Correlation at 0.001 level, **Correlation at 0.01 level, *Correlation at 0.05 level

Table 4 RMSE values of artificial neural networks

ANN	Model A		Model B		Model C		Model D	
	Train	Test	Train	Test	Train	Test	Train	Test
ANN1	0.2164	0.2267	0.2537	0.2560	0.2278	0.2186	0.1836	0.1725
ANN2	0.2174	0.2257	0.2519	0.2556	0.2276	0.2168	0.1877	0.1704
ANN3	0.2175	0.2273	0.2514	0.2562	0.2287	0.2170	0.1855	0.1710
ANN4	0.2164	0.2261	0.2501	0.2561	0.2294	0.2186	0.1863	0.1716
ANN5	0.2170	0.2270	0.2515	0.2560	0.2297	0.2180	0.1857	0.1713
ANN6	0.2178	0.2273	0.2510	0.2551	0.2303	0.2187	0.1852	0.1711
ANN7	0.2168	0.2265	0.2505	0.2555	0.2293	0.2169	0.1855	0.1708
ANN8	0.2172	0.2265	0.2523	0.2552	0.2293	0.2178	0.1844	0.1718
ANN9	0.2165	0.2267	0.2496	0.2552	0.2279	0.2178	0.1836	0.1719
ANN10	0.2172	0.2265	0.2511	0.2560	0.2302	0.2175	0.1844	0.1714
Mean	0.2170	0.2266	0.2513	0.2557	0.2290	0.2178	0.1852	0.1714
SD	0.0007	0.0005	0.0012	0.0004	0.0010	0.0007	0.0013	0.0006

to Table 5, in the four ANN models predicting perceived benefits, perceived risks, intention to engage in MCH and intention to engage in offline activities, the most influential predictors were creativity design, performance ethic, perceived benefits and intention to engage in MCH.

Discussion and conclusion

Discussion

This research used a two-stage SEM-ANN empirical approach to investigate the factors that influence the desire to engage with MCH and participate in offline activities. The first SEM phase confirmed all twelve hypotheses and provided the basis for the subsequent ANN phase. The ANN phase consisted of firstly, segmenting the SEM model and constructing separate ANN models for the predictive analysis of each segment; secondly, using all the supported factors as predictors alongside the full dataset; thirdly, conducting a sensitivity analysis on each model to determine the significance of the predictors. A comparison of the results from Tables 3 and 5 shows the consistency between the two phases of analysis. The SEM-ANN results confirm the positive impact of MCH on offline experiences and delineate the contribution levels of the different factors.

First, creativity, entertainment and narrative within MCH are important in shaping positive user perceptions. While current MCH initiatives emphasise technical aspects such as virtual props and games to enhance user interaction [48, 51], they often lack content and narrative innovation [17], reducing their long-term appeal. Successful MCH should not only stimulate the senses and disseminate knowledge but also engage users with innovative content and compelling narratives. Developers should adopt a dynamic approach to MCH, ensuring that it not only authentically replicates CH, but also evolves with societal changes and user preferences, incorporating modern narratives and immersive interactions to fully exploit the potential of the metaverse in CH.

Second, privacy data, performance ethic and negative psychology pose risks within MCH. Collecting user data for marketing or referrals can raise privacy and data protection concerns [55]. Surveys confirm these concerns, so MCH designers need to prioritise privacy, anticipate ethical dilemmas and eliminate wilful ignorance. Negative psychological responses to MCH, such as historical over-indulgence leading to social strife, are detrimental to the legacy and development of CH [58]. MCH should be designed to maximise digital technology and cultural dissemination while mitigating privacy, ethical and psychological impacts.

Additionally, the findings highlight the importance of users' intentions to engage with MCH in enhancing their offline experience. MCH serves as a conduit for audience engagement and a key element of CH innovation, offering a creative economy business model that generates value through cultural and artistic creation [55]. Managers and marketers are therefore advised to integrate MCH with offline activities, designing interlinked online and offline experiences to stimulate user interest.

Conclusion, limitations and future research

This study highlights the importance of users' intentions to engage with MCH as a catalyst for offline experiences and posits MCH as a vital medium for presenting CH. As a result, the digitisation of CH resources is advocated, encouraging managers to engage a wider audience through the development and operation of MCH, thus providing access to those who are constrained by

Table 5 Neural network sensitivity analysis

ANN	Model A				Model B			Model C		Model D		
	CD	CC	E	N	PD	PE	NP	PB	PR	PB	PR	IM
ANN1	0.371	0.266	0.246	0.117	0.340	0.463	0.197	0.738	0.262	0.441	0.120	0.438
ANN2	0.406	0.230	0.224	0.140	0.321	0.407	0.273	0.790	0.210	0.389	0.225	0.386
ANN3	0.303	0.274	0.275	0.148	0.291	0.326	0.383	0.762	0.238	0.384	0.264	0.352
ANN4	0.433	0.169	0.276	0.123	0.281	0.383	0.034	0.688	0.312	0.340	0.248	0.412
ANN5	0.414	0.281	0.252	0.054	0.200	0.388	0.412	0.698	0.302	0.423	0.213	0.364
ANN6	0.327	0.354	0.222	0.097	0.202	0.586	0.212	0.671	0.329	0.379	0.215	0.406
ANN7	0.382	0.256	0.248	0.114	0.240	0.513	0.247	0.893	0.107	0.354	0.240	0.406
ANN8	0.364	0.259	0.267	0.110	0.313	0.554	0.132	0.808	0.192	0.360	0.181	0.459
ANN9	0.387	0.252	0.216	0.145	0.233	0.418	0.349	0.773	0.227	0.371	0.145	0.484
ANN10	0.416	0.286	0.227	0.072	0.306	0.423	0.271	0.732	0.268	0.452	0.109	0.439
Average importance	0.380	0.263	0.245	0.112	0.273	0.446	0.251	0.755	0.245	0.389	0.196	0.415
Normalized importance (%)	100	69	65	29	61	100	56	100	32	94	47	100

economic, time or geographical limitations. In addition, this research contributes an analytical framework based on the Net Valence Model for MCH that examines the factors and dynamics that influence user interaction, whether through perceived benefits or risks. This analysis provides MCH developers and designers with actionable insights to enhance the user experience by managing elements such as creativity design, creativity content, entertainment, narrative, privacy data, performance ethic and negative psychology, thereby increasing the propensity to engage offline. It is imperative to further explore the determinants that shape the long-term evolution of MCH, with the aim of refining MCH, which is in its formative stages, to improve service quality and user experience, and to promote a deeper understanding, dissemination and preservation of CH among diverse audiences.

Limitations of the study include the short duration of the sample collection, which may not capture longitudinal changes, and the exclusion of cross-cultural groups, which may affect the generalisability of the findings. In addition, the sample was limited to one MCH platform and, despite a high response rate, may not reflect the full range of MCH users. In addition, demographic differences such as gender, ethnicity, education and religious affiliation may have influenced the results differently.

Future research should explore the nuanced aspects of the identified influencing factors, such as improving the creative design and content to increase the appeal and immersion of the MCH. It should also explore strategies to synergize real-world cultural heritage with its virtual counterpart, ensuring continuity of content and coherence of experience. A comparative analysis of different MCH platforms and international user bases could pave the way for a universally accessible MCH and encourage global collaboration between heritage sites. Furthermore, this study lays the groundwork for advancing digital product development and metaverse marketing strategies to increase the income of heritage sites.

Appendix A

A.1 The measures for each construct

Construct	Code	Items	From
Creativity design (CD)	CD1	This MCH combines Virtual Reality (VR) and Augmented Reality (AR) technology to allow me to "be there"	Waqar et al. [66]
	CD2	The MCH supports virtual prototyping and I think the interactive experience is great	
	CD3	I found the MCH easy to navigate and use	
Creativity content (CC)	CC1	I think the content of MCH is really "out of the ordinary"	Im and Workman [39]
	CC2	The content of MCH can be described as fulfilling	
	CC3	I find the content of MCH refreshing	
Entertainment (E)	E1	I enjoy visiting the MCH	Park et al. [67]
	E2	I would like to experience different cultural activities at the MCH	

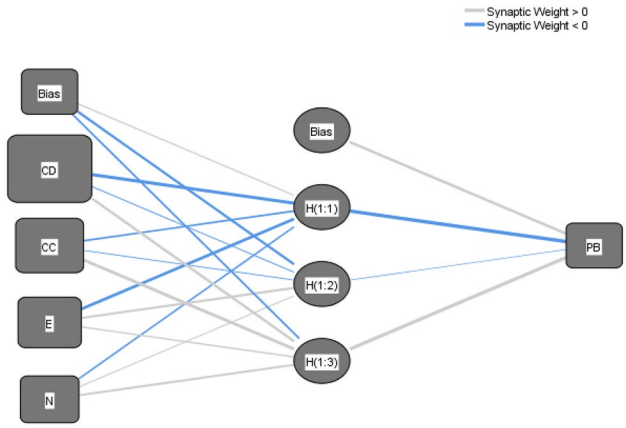
Construct	Code	Items	From
Narrative (N)	N1	The stories described in MCH appeal to me more than the real world	Busselle and Bilandzic [68]
	N2	In MCH, my body was in reality, but my mind was in the world created by the story	
	N3	It was as if MCH created a new world, but at the end of the experience I felt that this new world had suddenly disappeared	
Privacy data (PD)	PD1	I am concerned that this MCH may record everything that is done	Busselle and Bilandzic [68]; Lee and Chaney [69]
	PD2	I think this MCH may be collecting information about me all the time	
Performance ethic (PE)	PE1	Prolonged use of this MCH can make me dizzy and even nauseous	
	PE2	At the current level of this MCH, it's probably better for others than for me	
Negative psychology (NP)	NP1	I don't like to stay long at the MCH, it's easy to get lost	
	NP2	The MCH is great, but I prefer to experience it in reality	
	NP3	I think the MCH is trying to please more people, and although it makes for a more enjoyable experience, it seems a bit much	
Perceived benefits (PB)	PB1	The MCH has increased my understanding of cultural heritage	Li et al. [26]
	PB2	I find it useful to visit MCH regularly	
Perceived risks (PR)	PR1	There is a high risk that my expectations of the MCH will not be met	
	PR2	Overall, there are many uncertainties about the MCH	
Intention to experience MCH (IM)	IM1	I will continue to visit MCH	Zhang et al. [70]; Zhang et al. [71]
	IM2	I will recommend this MCH to my friends and relatives	
	IM3	I will learn relevant CH information through this MCH	
Intention to experience offline (IO)	IO1	I will participate in offline activities related to MCH	
	IO2	I plan to come and experience MCH	

A.2 Demographic characteristics of the sample

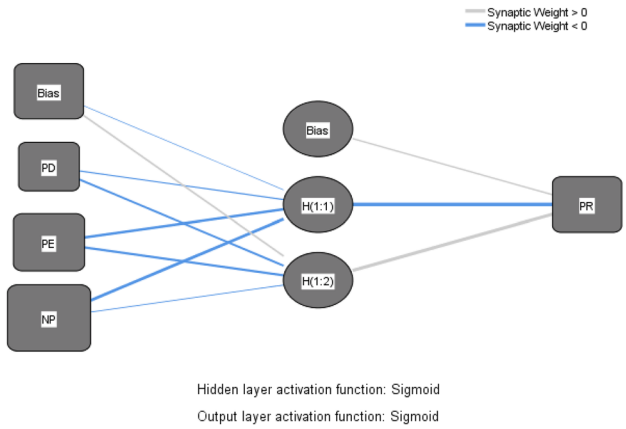
Characteristic	Detail	N	Percentage
Gender	Male	563	56.9
	Female	426	43.1
Age	Under 20	179	18.1
	20–35	409	41.4
	36–50	234	23.7
	Above 50	167	16.9
Education	Under bachelor	217	21.9
	Bachelor	362	36.6
	Master	225	22.8
	Above master	185	18.7
Inconme (RMB)	Under 5000	394	39.8
	Above 5000 to 10,000	250	25.3
	Above 10,000 to 20,000	209	21.1
	Above 20,000	136	13.8

Appendix B

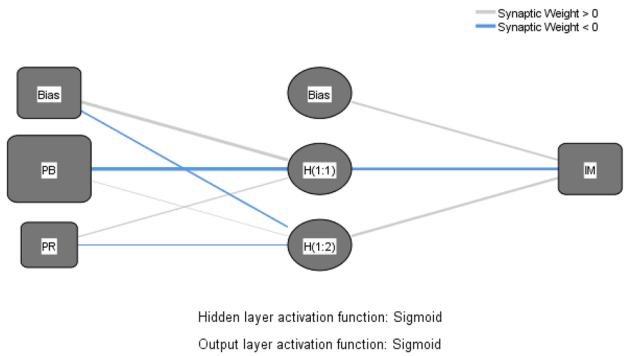
B.1 Model A



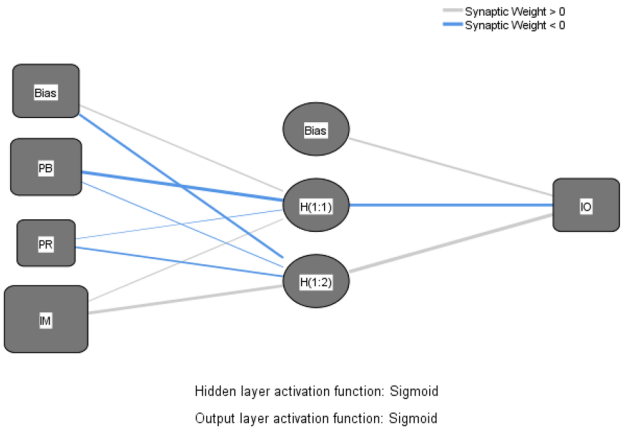
B.2 Model B



B.3 Model C



B.4 Model D



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Author contributions
H was the first and corresponding author, who developed the idea for the study, drafted the introduction, literature review, and study questionnaire, and analysed and interpreted the data collected. Q was the second author, who drafted the conclusions and recommendations section and reviewed or proofread the entire manuscript after the study was completed. All authors read and approved the manuscript for submission to the journal.

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Availability of data and materials
The datasets analysed in the current study are not publicly available, but can be obtained from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The research proposal was reviewed and approved by an ethics committee made up of several professors from the college. Participants in the research were assured that their responses would be kept strictly confidential and that any information provided would only be used for academic purposes.

Competing interests
The authors declare that they have no competing interests.

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