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Research article

Users' willingness to adopt metaverse drawing on flow theory: An empirical study using PLS-SEM and FsQCA

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ABSTRACT

As a rapidly developing information technology in recent years, the metaverse has significantly transformed how we live, learn, and work. In order to accelerate the use of metaverse technology and promote users' acceptance of the metaverse, this study constructs an integrated model based on flow theory and use and satisfaction theory, to further explore the factors affecting users' acceptance of the metaverse. A total of 265 valid questionnaires were obtained through a situational questionnaire survey. Considering the limitations of a single analysis technique, we use two methods to analyze the data. Among them, the symmetric PLS-SEM method is mainly used to analyze the effects of single variables, while the asymmetric fsQCA method is used to analyze the combined effects of variables. The PLS-SEM results manifest that flow experience, perceived risk, and personal innovation directly influence users' acceptance of the metaverse, while perceived cost has no effect. Simultaneously, interactivity, presence, and social presence indirectly affect users' acceptance of the metaverse, while informativeness and enjoyment have no indirect effect. Significantly, fsQCA unveiled five configurations resulting in a high user acceptance of the metaverse, as well as six configurations leading to a negative acceptance. The complementary findings from PLS-SEM and fsQCA offer valuable insights for both theoretical understanding and practical implementation.

1. Introduction

The term 'Metaverse' refers to a virtual, interconnected, and shared digital universe that incorporates elements of augmented reality (AR), virtual reality (VR), extended reality (XR), and the Internet [1–3]. The Metaverse, a concept popularized by science fiction, has gained significant attention from the technology companies, gaming industry, and virtual reality developers in recent years as technology has advanced [4,5]. In the Metaverse, users can interact with one another and digital objects, access various virtual experiences, and engage in activities in a simulated, immersive environment. It presents numerous potential opportunities for several important areas [2,6,7], e.g., marketing [3,8–10], tourism [11], museums and art exhibitions [12–14], education [15–18], gaming [19,20], retail, entertainment, business, and even scientific research. However, the "true" metaverse is still a vision, and there is a gap between expectation and reality about metaverse development [21]. Actually, although virtual reality and augmented reality technology have existed for some time, many people are still hesitant to adopt these technologies because of the negative aspects of these

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Table 1
Empirical studies on metaverse acceptance.

Reference	Topic	Theory	Antecedent conditions	Dependent variables
Lee, Trimi [31]	Metaverse service	Innovation diffusion theory (IDT), and the Bass model	Innovation diffusion*, imitation diffusion*	Metaverse service adoption
Nah, Eschenbrenner [32]	VR	Flow theory, telepresence theory, positive emotions theory, and brand equity theory	Telepresence*, enjoyment*, Brand equity*, and 2D/3D+	Behavioural intention
Li, Liu [33]	Online games	Uses and gratifications theory (UGT)	Enjoyment*, fantasy*, escapism*, social interaction*, social presence*, achievement*, and self-presentation	Continuance Intention
Jang and Park [19]	VR Games	/	Presence*, enjoyment*, perceived cost+, service & display+, interactivity+	Continual intention to use
Zhao, Wang [15]	Massive open online courses	Flow theory, and S–*O*-R framework	Flow*, social presence*, telepresence+, interactivity+, media richness+, and sociability+	Continuance intention
Kim, Lee [34]	Tourism virtual reality	IDT, and UGT	Authentic experience*, subjective well-being*, simplicity+, benefit+, compatibility*+, informativeness+, social interactivity+, and playfulness+	Behavioural intention
Kaur, Dhir [35]	Mobile instant messaging	UGT	Information seeking, escape, entertainment*, exposure*, social sharing, and affection*	Purchase intention /Continuation Intention
Ball, Huang [36]	VR	UGT	Perceived impacts*, and social interactivity*	VR use intention/VR purchase intention
Qin [20]	AR games	Self-determination Theory (SDT)	Enjoyment*, presence, autonomy need satisfaction+, competence need, satisfaction+, and relatedness need satisfaction+	Gameplay length
Akour, Al-Maroof [25]	Metaverse	TAM	User' satisfaction*, perceived ease of use*, perceived usefulness*, perceived trialability+, perceived observability+, user' compatibility+, and personal innovativeness+	User's intention to use the MS
Lee and Kim [28]	Metaverse	UTAUT	Perceived expectancy*, effort expectancy*, social influence*, facilitating conditions, and satisfaction*	Usage/Purchase /World of mouth intention
Almarzouqi, Aburayya [26]	Metaverse	TAM	Perceived usefulness*, user's satisfaction*, perceived ease of use*, personal innovativeness+, perceived observability+, user's compatibility+, perceived trialability+	Intention to use
Hwang, Shim [27]	Metaverse	UGT	Informativeness*, interactivity*, enjoyment*, and telepresence+	Intention of continuous use

Note: "+" denotes a significant effect on variables other than the dependent variables, while "*" signifies a significant effect on the dependent variables.

technologies such as cost or concerns about privacy and security [6]. For the metaverse to go mainstream in the marketplace, Consequently, there exists significant importance for both industry and academia to delve into the key factors influencing user acceptance of metaverse technologies.

Since the emergence of metaverse technologies, researchers have focused on the attitudes and acceptance of these technologies by consumers in different contexts, such as AR [10], VR, XR [22], Blockchain, and NFTs [23,24]. However, most empirical studies on consumers' adoption willingness towards the metaverse are based on a single theory or model, e.g., TAM [17,25,26], the uses and gratifications theory (UGT) [27], and UTAUT [18,28]. Since a single theoretical viewpoint falls short of providing a thorough analysis and a more profound comprehension of the adoption decision process, it becomes imperative to amalgamate diverse theories or incorporate supplementary constructs tailored to the unique context. This augmentation serves to enhance the model's explanatory power [29]. Furthermore, the prevailing approach adopted in the majority of empirical investigations to analyze the relations between independent and dependent constructs revolves around traditional symmetric methodologies including regression analysis, covariance-based structural equation modelling (CB-SEM), and partial least squares SEM (PLS-SEM). However, these traditional techniques, which focus solely on the aggregate impacts of individual variables, have faced criticism due to concerns about multicollinearity and symmetry. Although VB is not impacted by multicollinearity in the measurement model, it must be analyzed when VB is utilized to test the hypothesis of the structural model. The reason is that the estimation of path coefficients in the structural model is based on OLS regressions of each endogenous latent variable on its corresponding predecessor constructs. Just as in a regular multiple regression, the path coefficients might be biased if the estimation involves critical levels of collinearity among the predictor constructs [30]. Simultaneously, it is worth noting that the actual relationships between antecedents and consequences often exhibit a high degree of asymmetry. Therefore, to address the limitations posed by causal complexity and to embrace a more comprehensive perspective, a qualitative comparative analysis (QCA) has been suggested. This holistic approach seeks to mitigate the shortcomings associated with traditional methodologies by aligning with the principles of causal complexity theory.

Based on the above, this study raises the following research questions: What factors influence user acceptance of the metaverse? How can users' acceptance of the metaverse be improved? This research is dedicated to addressing these two questions in order to promote the utilization and advancement of metaverse technology, its application across various fields, harnessing the advantages of new quality productive forces, and fostering high-quality economic development. To address the aforementioned issues and research gaps, we explore users' adoption behaviour towards the metaverse from an integrated theoretical perspective. Specifically, we use multiple integrated theories including flow theory, and uses and gratifications theory to determine why users adopt the metaverse and the most significant factors influencing their usage intentions. Moreover, we strive to achieve a more profound comprehension of the metaverse acceptance through two data analysis methods involving PLS-SEM and fsQCA, examining both net effects and combination effects of various factors.

The study is organized as follows. Section 2 provides a comprehensive review of adoption research and the main theoretical basis of the meta-universe. Section 3 establishes the research model for this study and presents relevant hypotheses. Section 4 outlines the research design for data collection. Section 5 conducts empirical analysis of the questionnaire data. Section 6 discusses the empirical results, and Section 7 offers a brief summary of this study.

2. Literature review

2.1. Acceptance of metaverse

The term "metaverse" is a fusion of "meta," signifying the virtual realm, and "universe," symbolizing a comprehensive worldview. It denotes a rapidly evolving technological concept propelled by the contemporary emphasis on online engagements and activities [1]. Functioning as a collective and immersive experience, the metaverse represents a perpetually connected digital realm in which participants can engage in various activities such as shopping, social interaction, participating in work training, playing games, attending classes, participating in meetings, and experiencing various cultures [28]. In response to rapidly growing market demand, enterprises in various fields also seek innovation and competitive advantage by introducing the metaverse [3,27]. However, due to the lack of a well-defined set of services catering to both enterprises and users on the metaverse platform, it becomes imperative to delve into individuals' motivations and purpose for using the metaverse. By identifying the factors shaping users' intent to utilize the metaverse, we can subsequently offer recommendations to metaverse providers, devise metaverse products with enhanced recognizability, and enhance the metaverse's utilization rate.

In recent years, research on the adoption behaviour of the metaverse has gradually increased alongside the metaverse's development. Scholars have studied users' use intention, user behaviour, and continuous use behaviour of metaverse-related technologies and services such as metaverse, metaverse technology, metaverse game service, metaverse travel service, metaverse office, and metaverse education. It is found that many factors, including hedonic, interactivity, social sharing, social existence, escape psychology, telepresence, perceived cost, perceived expectation, and perceived usefulness, exert a significant influence on the adoption intention and behaviour of users' metaverse-related technologies and services. Table 1 shows specific research content.

2.2. Flow theory

Flow experience serves as an indicator of a user's cognitive and emotional state within the metaverse environment and may influence their behavioural responses [8]. Therefore, we applied flow theory to study consumers' willingness to use the metaverse.

"Flow" is a concept introduced by Csikszentmihalyi in the 1970s, encompassing an overall feeling experienced by individuals when they are completely engrossed in an activity. When individuals enter this subjective flow state, they can focus significantly on the current activity, feel happy, feel the time passing quickly, and enjoy the process immensely [37,38]. People first used this concept to analyze the optimal state when engaging in everyday activities, such as rock climbing, playing chess, and learning. Flow phenomenon is typically categorized into three distinct stages: flow antecedents, flow experience, and flow consequences. Different dimensions of flow antecedents influence flow experience and can bring inevitable flow consequences. Individuals immersed in the state of flow experience often find themselves completely absorbed in the activity they are participating in. In this state, individuals can experience changes in attitudes, intentions, and behaviours [15,39–42].

Another essential area of research on flow focuses on its antecedents. Finneran et al. investigated the antecedents of flow in the computer-mediated environment. They proposed the person-artifact-task (PAT) model, which summarizes the predictors of the flow experience from the dimensions of individual, tool, and task [43]. Based on Finneran's PAT model, Moon, Kim [44] explored how individual personality traits influence the flow experience. They suggested that individuals with extraverted personality traits are inclined to experience flow while engaging with user-generated content websites, while Heller, Bullerjahn [45] found that individuals possessing extraverted and neurotic personality traits are more prone to achieving a state of flow during amateur vocal learning. Some scholars have explored the factors that impact individual flow experiences within virtual worlds, and research has found that various factors, including social consciousness and telepresence, play a significant role in generating personal flow experiences [46–48]. Other studies on the antecedents of flow are scattered in different fields related to the use of information technology, including online shopping, social media, instant messaging, digital games, and so on. These studies have identified various factors that influence flow, including perceived complexity, clear goals, immediate feedback, emotional regulation, enjoyment, curiosity, authenticity, telepresence, interactivity, social presence, and so on, making significant contributions to the exploration of the antecedents of flow [42,47,49–53]. We continue this research by exploring the factors contributing to users experiencing flow within the metaverse environment.

The metaverse has a rich and immersive environment [21], and the immersive experience felt by users in the metaverse will focus their attention on the virtual reality experience, giving them a sense of being there and forgetting their awareness of being in a virtual space, feeling very pleased. Existing research on information behaviour has found that user and tool dimensions factors can affect the results of information activities. Still, there is less research on the causal pathways of these factors [43]. The highly focused subjective state described by flow is undoubtedly a positive user experience, and the explanation of the phenomenon in information behaviour research often requires theories from disciplines such as psychology and communication. The introduction of flow theory can provide theoretical support for potential influencing mechanisms of variables. However, a literature review found that most scholars focus on users' technological perception of the metaverse and ignore the subjective emotional expression of flow, which is also essential. Therefore, this study applies flow theory to explore the intention to use the metaverse, contributing to adopting the metaverse and flow research.

2.3. *Uses and gratifications theory*

The uses and gratifications theory explores the reasons behind individuals' utilization of specific information technologies and postulates that audiences actively opt for new technologies driven by motivation, rather than adopting them passively [54]. This theory proposes that users are motivated to use a particular technology and fulfil their requirements through active selection. In other words, UGT elucidates the factors guiding consumers' preference for one information technology over another, as well as the emotional desire that drives them to adopt certain information technology services while rejecting others [55]. Research has shown that UGT helps illustrate how information technology can meet the requirements of individuals pursuing varied objectives [56]. As an illustration, the method can be used to describe users' continuous intention to use virtual games [33].

Previous studies have shown that users have various demands for each specific online platform and choose platforms to achieve their goals. Previous VR-related research has indicated that motivation for using VR includes enjoyment, social interaction, sharing, information, challenge, and achievement. Dhir and Tsai [57] concur with the notion that users exhibit diverse uses and gratifications (U&G) depending on their usage patterns. These encompass a range of motivations, such as deriving pleasure, experiencing enjoyment, seeking relaxation, pursuing social and self-status enhancement, engaging with emotions, embracing convenience, sharing socially, gaining exposure, seeking information, curating online self-representation, and seeking an escape from real-life issues. In addition, Li, Liu [33] categorized these distinct U&Gs into four major types: content U&G, process U&G, social U&G, and technology U&G. Through the study of U&G, research on how and why individuals use information technology products may provide clues for us to understand the needs, where the demands come from, and how to satisfy these needs.

As a combination of various emerging technologies, we believe that users consciously opt to engage with the metaverse, rather than passively accept it. Over time, in tandem with societal progress, new information technologies will be gradually accepted and popularized by the public and eventually even become mandatory use, such as smartphones and 5G technology. However, as a new technology product, the metaverse remains in its initial development stage. It is entertainment and consumption-oriented rather than widely popularized as a basic infrastructure. Its usage is mainly due to the user's active choice. Thus, UGT can explain this well. In our study, drawing on UGT, the motivation factors for individuals to use the metaverse in personal consumption scenarios are proposed: informativeness, interactivity, and enjoyment, which influence users' intention to adopt the metaverse through flow experience.

3. Conceptual model and hypotheses

3.1. U&G factors and flow experience

3.1.1. Informativeness

Informativeness is the motivation for users to seek out and utilize new information. It refers to the level of awareness an individual has in the metaverse to access and use information that fulfils their requirements and interests [27]. In the digital age, users seek information to adapt to their environment [13]. They need to acquire guidance or information from relevant media to understand structure, order, and knowledge. When using new information technologies, users are most likely attracted to personalized voices and information generated in a broader range of entertainment backgrounds. For instance, users of metaverse games are susceptible and interested in information that protects their gaming content data. At the same time, those involved in virtual trading are more focused on product information, seller information, and information about the financial risks to their account [34,35].

In the metaverse, information production and dissemination productivity and speed are greatly enhanced. User interaction with information has become very easy, and it is imperative to accurately grasp the needs and interests of users in the massive pool of information to achieve precise information service delivery. The combination of virtual and natural elements, multi-level stereoscopic connections, decentralized free structures, real-time interactive communication, and fast information flow in the metaverse enable information to circulate, spiral, iterate, and cascade between users and others they communicate with. This precise information dissemination mechanism characterizes the “looping pattern” of the real-world information exchange process and provides users with a sufficiently realistic experience [28]. Therefore, the more exciting information individuals perceive they can obtain in the metaverse, the more they will focus on seeking information, immersing themselves in it, and experiencing the flow state. In summary, we hypothesize that.

H1. Informativeness positively influences the generation of individual flow experiences in the metaverse.

3.1.2. Interactivity

Interactivity pertains to the degree of interaction between the user and virtual objects, as well as the degree of real-time participation in modifying the environment or content of the intermediary [11]. The technological structure determines it as a stimulus-driven variable [58,59]. Within the metaverse, users engage with the virtual realm by means of their avatars. Using avatars to depict user identity is exciting because users are no longer bound by their physical identity, opening up a new world for self-expression [60]. Users modify their metaverse environment and customize their virtual self’s appearance through their avatars. Through avatars, users exist in the metaverse, display themselves, and make their interaction with the metaverse more real [61]. For example, in real life, people may dress more casually when hanging out with friends, while they dress more formally at work. It can also be reflected in the metaverse. The metaverse has various virtual scenes, and users can interact with the system to modify their avatars to fit different settings. When users believe that the avatar in the metaverse is an extension of themselves, it significantly increases their sense of self-development, identity, and willingness to participate [62]. This deep fascination with interaction and exploration in the metaverse leads to the loss of users’ self-awareness, causing distortions in space and time, making the metaverse experience more exciting and enhancing the flow experience. Therefore, we assume.

H2. Interactivity positively influences the generation of individual flow experiences in the metaverse.

3.1.3. Enjoyment

Enjoyment within the metaverse context pertains to the degree to which users perceive pleasure and satisfaction while utilizing the virtual environment [20,27]. Research has shown that enjoyment serves as an intrinsic motivation driving users to engage with new technologies. Users hope to derive pleasure and enjoyment from utilizing new information technologies. Scholars have obtained similar results through empirical studies. Enjoyment significantly affects users’ engagement with virtual games and other virtual goods [63]. In the conceptual framework of integrated research elucidating the factors that exert influence over users’ decisions to purchase virtual goods, enjoyment serves as a foundational factor for discerning users’ behaviours and experiences within the realm of virtual reality [11,13,14,17,19,27,64]. Users hope to enjoy the metaverse’s entertainment elements and innovative technologies and expect to get new experiences from the metaverse, such as location-based AR navigation systems [63]. Therefore, the motivation to use the metaverse is to enjoy this kind of experience. For example, when using the metaverse for tourism, tourists hope to visit places that they cannot reach in reality and feel the immersive experience during the sightseeing process, bringing new experiences in vision, hearing, and touch, and gaining a sense of pleasure and relaxation as if they were in nature. When people feel happy in the metaverse, they are often internally induced to accept and thus enhance the sense of experience [19]. The flow experience is considered pleasurable, enjoyable, and exciting. Hence, an elevated level of pleasure perceived by users within the metaverse corresponds to an increased probability of encountering a state of flow. Thus, we hypothesize.

H3. Enjoyment positively influences the generation of individual flow experiences in the metaverse.

3.2. Metaverse experience factors and flow experience

3.2.1. Telepresence

“Telepresence” denotes the subjective sensation of being deeply engaged and immersed within the metaverse environment, representing a specific instance of immersive experience. It encapsulates the extent to which individuals sense their presence within a virtual environment, as opposed to their immediate physical environment [58]. Users who experience telepresence direct their attention towards the virtual realm, narrowing their focus to within this environment and effectively disregarding the physical environment [50]. Telepresence stands as a crucial factor in generating flow experience, a proposition that has been fully verified in previous studies [47]. Pelet, Ettis [50] believed that telepresence by social media in the process of users' service can enhance positive emotional experiences. Kim and Ko [47] found that the immersive and interactive nature provided by VR technology significantly influenced the generation of flow experience among sports audiences. In other studies, because telepresence can be interpreted as an immersive feeling felt by users, telepresence is regarded as one of the performance characteristics of flow experience [52]. The 3D metaverse environment provides more sensory inputs and outputs than the 2D environment. In the metaverse, the five senses of the natural world will gradually be digitized, data modes will continue to emerge, and the dimension of information will increase progressively. In this space where emotions and physical presence can be felt, tactile and motion capture technologies are used to simulate the presence and surrounding environment. This study considers telepresence as the function of immersion that the metaverse can provide, and the stronger the telepresence, the more users will focus on their actions and feel that they are controlling the environment. They will feel like they are in a real scene, thus producing a pleasant immersion sensation and promoting the generation of flow experiences. Therefore, we hypothesize that.

H4. Telepresence positively influences the generation of individual flow experiences in the metaverse.

3.2.2. Social presence

Social presence denotes the perception of personal, warm, intimate, social, or sensitive levels of social interaction in the metaverse [15,59]. In the metaverse, social presence can be understood as individuals perceiving that other users are interacting or responding to them when they engage in activities in the metaverse. Previous research has found that social presence significantly affects flow experiences in real and virtual worlds [13,63,65]. Furthermore, Ryan and Grolnick [66] discovered that the existence of social presence has the potential to generate a feeling of psychological closeness or nearness, subsequently fostering the emergence of the flow experience. Social presence in online entertainment or educational activities can help participants evaluate activities more positively, promoting feelings of happiness, competitiveness, and satisfaction [31]. In the metaverse, social presence is realized through interactions between users who participate in the metaverse, and of course, this requires technological support. Within the metaverse environment, it is possible to establish interpersonal relationships and forge social connections akin to those in the physical world. Users who engage in social interaction and develop intimate relationships in the metaverse are likely to be immersed to some extent, focusing and investing in a way that causes them to forget about time and space and not to notice various events happening in the real world. This makes role-playing and identity management in the metaverse more enjoyable, contributing to generating a flow experience. Consequently, we assume that.

H5. Social presence positively influences the generation of individual flow experiences in the metaverse.

3.3. Influencing factors of metaverse willingness to use

3.3.1. Flow experience

Individuals who experience a flow state will feel a sense of comfort and enjoyment, and beneficial experiences will be accompanied by positive experiential qualities [15]. Therefore, it can be argued that using the metaverse can promote the feeling of the best experience for individuals, and users can perceive the value of pleasure from it. On the contrary, the metaverse is considered to be applicable by users who value technology use, as it is a “virtual space” supported by various new information technologies. This perception arises after experiencing a pleasant flow state and recognizing its practicality. When users evaluate the experience, they rate it as valuable [50]. As users' flow experiences increase, the perceived value of pleasure and practicality will increase their satisfaction with the metaverse. According to the expectancy confirmation theory, a positive correlation exists between user satisfaction and usage intention as indicated by Leventhal [67]. This implies that when metaverse users find their experience gratifying, they are more likely to express a desire for continued usage. Therefore, we assume.

H6. Flow experience positively influences individuals' willingness to use the metaverse.

3.3.2. Personal innovation

Personal innovation (PI) denotes an individual's inclination to explore novel information technology services, as defined by Agarwal and Prasad [68]. Personal innovation is an essential concept in innovation diffusion theory, which significantly impacts the diffusion and adoption of new information technology services [17], because it mirrors how individuals naturally response to the adoption of new technologies across various dimensions. Personal innovation is a unique trait of individuals. Generally speaking, those with solid innovation ability tend to hold favourable attitudes toward innovative services and contemplate their adoption. According to the research of Lu, Liu [69], individuals with elevated levels of PI tend to exhibit adventurous, pursuing novelty and stimulation, so they may be more actively willing to accept or use innovations. As an emerging trend in the past two years, the metaverse combines new infrastructure such as digital twin technology, blockchain technology, cloud computing, 5G/6G, and edge computing, as well as new terminal devices such as XR, VR, AR, mixed reality (MR) wearables, and new content applications such as brain-computer interfaces, to create a new virtual space. This subverts traditional concepts of consciousness, leading to a higher likelihood of individuals spontaneously experiencing innovation, with a greater acceptance of information exchange and economic transaction activities during the experience. Therefore, we assume that.

H7. Personal innovation positively influences the individual's willingness to use the metaverse.

3.3.3. Perceived cost

In the private environment of personal user adoption, cost becomes an integral part of the model and, in related research, cost-driven constructs are considered as one of the biggest obstacles to the adoption of new information technology, as high prices are one of the main reasons why consumers have not yet adopted that technology or service [70]. In our study, perceived cost is defined as encompassing the expenses associated with purchasing, maintaining, and operating metaverse technology and related services and equipment [71,72]. In the field of metaverse products, some scholars have also attempted to explain better consumer willingness to use specific metaverse products and services through the concept of perceived cost. For example, Solomon and others found that the economic burden of using metaverse products was substantial in their willingness to use them. If the paid cost exceeds what they consider reasonable or the financial cost paid does not correspond to the service provided, consumers will no longer continue to use Metaverse products [73]. When considering new or innovative technology services, Akbar et al. found that the cost of the game significantly influences gamers' willingness to use mobile games, and users are likely to consider whether the benefits of a specific service outweigh the costs [74]. Therefore, perceived costs play an essential role in changing user-specific information behaviour.

This study explores the willingness to use metaverse technology and products in the personal consumption scenario. In this scenario, metaverse technology is not accessible in most cases, and the users are the same people who pay for it. Therefore, there is an excellent chance that cost will be considered when users consider whether to use the metaverse. When users face the new technical service of the metaverse, if they perceive that the economic cost invested does not match the specialized experience obtained, they may experience apprehensions and reservations regarding metaverse usage, potentially exerting an adverse influence on metaverse adoption rates. Therefore, in summary, we believe that.

H8. Perceived cost negatively influences individuals' willingness to use the metaverse.

3.3.4. Perceived risk

Perceived risk was proposed by Bauer [75], which conceptually defines risk from the perspective of uncertainty tied to end-user behaviour. Scholarly investigations have consistently affirmed the influential role of perceived risk in shaping users' propensity to adopt novel entities. When users harbour uncertainties regarding information technology services, their apprehensions extend beyond technology's utility, encompassing reservations about potential problems brought about by technology [76,77]. In recent years, research on perceived risk has focused on different types of risks in people's various information technology activities, and other scholars have defined perceived risk from different perspectives. Early studies mainly focused on product quality risk, but in recent years, perceived risk has been more measured by a "multidimensional construct". In general, risk can be divided into performance and psychology. Cunningham further divides risk into three dimensions: economy, time, and performance [78]. This classification has also been acknowledged by subsequent scholars. Later, scholars proposed other dimensions of risk based on different information technology backgrounds, such as privacy, security, and so on. Research has found that the adoption of information technology by users is impacted by factors such as performance, privacy, and psychological risks [77,79,80]. For example, Debb found that people's attitudes and behaviours towards network security are related to their perception of network risks [81]. Chloe's research found that innovators, early adopters, and the early majority segments focus on performance risks in mobile payment adoption, while innovators, early adopters, and the late majority segments focus on security risks in mobile payment adoption [82].

Therefore, in this study, perceived risk is introduced into our conceptual model for the emerging technology and services of the metaverse. Using the metaverse involves not only paying certain costs but also involves user data information. In the metaverse, users create avatars and interact with the system and other members, producing data intertwined with their authentic identities. The massive amounts of information relevant to the user create a near-realistic "simulated space" in the metaverse, which will involve user privacy. Metaverse users are concerned about their privacy being leaked or abused without their knowledge. Therefore, the perceived risks discussed in this study primarily refer to user privacy being leaked or disused in uncertain circumstances.

H9. Perceived risk negatively influences individuals' willingness to use metaverse.

3.4. Research model

Although flow theory stands as a powerful and concise framework that can effectively explain the adoption of information technology [40,41], the factors that produce flow will vary depending on the information medium studied. Flow experience is a positive intermediate result we pursue; another important factor is the factor that creates this positive result [47,49]. Merely relying on conventional flow theory falls short of accurately capturing the distinct influence of technical and contextual elements that could influence user adoption. Consequently, it is imperative to account for alternative adoption models or supplementary variables. In order to comprehensively elucidate user receptivity towards the metaverse, we introduce a comprehensive framework that integrates flow theory with other constructs such as uses and gratifications theory, innovation diffusion theory, and metaverse technological environment characteristics, as well as other external factors get up and do comprehensive research—specifically, considering the motives of consumers to use. The metaverse technologies can offer three factors related to UGT proposed as the antecedents of flow experience: informativeness, interactivity, and enjoyment [33,56,57]. Furthermore, considering the crucial antecedents of flow and the uniquely immersive experience of the metaverse, the two experience factors of telepresence and social presence are also incorporated into the ancestors of flow [15,47,50,65]. In addition, we consider the personal innovation emphasized by the innovation diffusion theory and believe that personal innovation plays a vital role in users' spontaneous experience of the metaverse [68,69]. In addition, the two opposing factors of cost and risk will also influence the user's inclination to adopt the metaverse [73,74]. Therefore, we introduce personal innovation, perceived cost, and perceived risk to improve the model. Our comprehensive model is depicted in Fig. 1.

4. Methodology

4.1. Research design

Building upon the underpinning theoretical model, we developed and validated a quantitative questionnaire. Subsequently, the scale was tested using the PLS-SEM measurement model [83]. The PLS-SEM structural model was employed to verify our models and hypotheses. Additionally, acknowledging the limitations of symmetrical statistical techniques and the emergence of complex causal relationships, we utilize fsQCA to calibrate and analyze the same data to explore the intricate causal relationships between conditions and outcomes. This approach provides a comprehensive vantage point on the interplay of common influencing factors contributing to metaverse acceptance. The subsequent sections elaborate on instrument development, data collection, and the rationale behind selecting PLS-SEM and fsQCA methodologies.

4.2. Instruments development

In order to enhance content validity, we tailored the scale based on existing literature and adjusted it to align with the metaverse context. With the assistance of Google Translate software and guidance from mentors and scholars, the translation and retranslation method is employed to ensure the preservation of the original language sentence's meaning and achieve semantic equivalence [30]. The measurement of these constructs was conducted using a seven-point Likert scale (see Table 2).

With the participation of several graduate students, the instrument improves comprehension by modifying ambiguous items in a pretest. Then, 17 graduate students were used as a pilot sample to verify the scale's reliability, validity, and translation equivalence.

4.3. Data collection

The study population includes potential customers of the Metaverse technologies and services who have not previously been aware of or used Metaverse. This study was approved by the Ethics Committee of Shandong Provincial Natural Science Foundation Committee Office, with ethics approval reference. In addition, for ethical considerations, we included a consent form and information for participants at the beginning of the online survey, in order to familiarize the participants with the study's purpose, the voluntariness nature of the participation, the anonymity and privacy of the participants' identities, the number of items and the length of the survey, the confidentiality assurance of research data, the research findings and other details. All participants agreed to the invitation and received a $5 red envelope as a reward. After the questionnaire was issued, a total of 280 questionnaires were finally collected. In the process of viewing and screening the questionnaire data according to the corresponding standards, substandard questionnaires such as

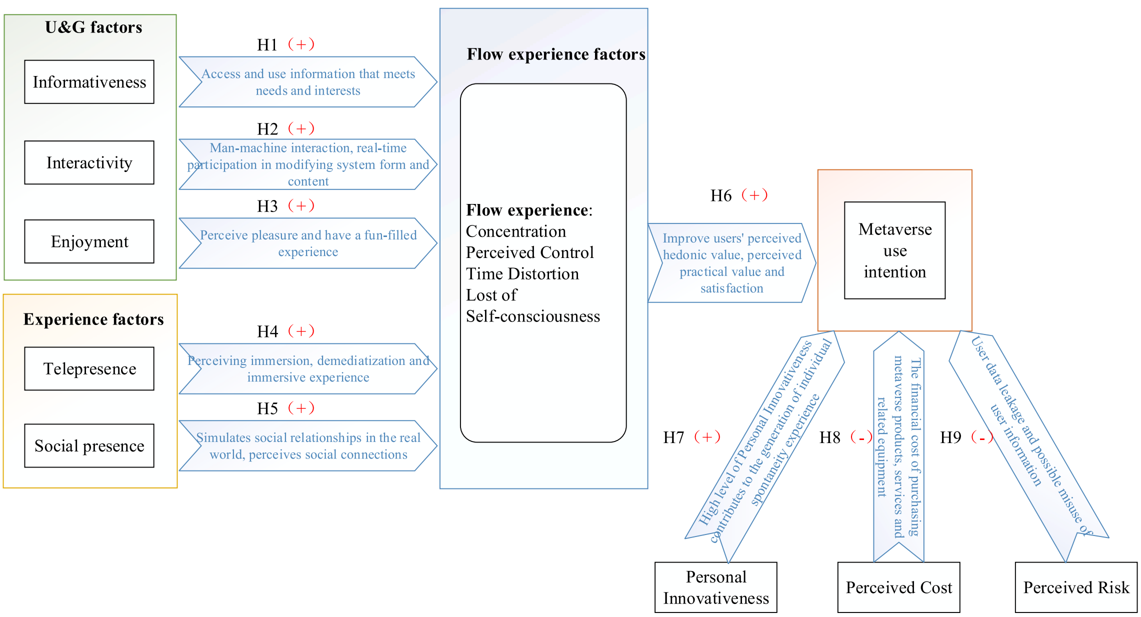

Fig. 1. The research model.

Table 2
Measurement scale.

Constructs	Items	Description
Personal Innovativeness [68]	PI1	Upon learning about a new technology, I would actively seek opportunities to engage in experimentation with it.
	PI2	Among my peers, I typically take the initiative to be an early adopter of new information technologies.
	PI3	Generally speaking, I tend to exhibit reluctance when it comes to experimenting with new information technologies.
Informativeness [27,34]	INF1	I appreciate all kinds of things in the metaverse related to attractions.
	INF2	I can get more attractions, information, and experience using the metaverse.
	INF3	Utilizing the metaverse provides me with diverse knowledge, such as the culture of scenic spots.
	INF4	I gather all kinds of information I'm interested in using the metaverse.
Interactivity [59]	INT1	The tools furnished by the metaverse empower me to modify the content within its realm.
	INT2	The tools furnished by the metaverse enable me to generate any desired content.
	INT3	I think users can manipulate a multitude of objects within the metaverse.
	INT4	Within the metaverse, I am able to alter or impact the visual aspects of the environment.
Enjoyment [20]	ENJ1	I really enjoy socializing and playing games in the metaverse.
	ENJ2	Metaverse was fun to use.
	ENJ3	I thought using Metaverse was a boring activity.
	ENJ4	I would describe using the metaverse as very interesting.
Telepresence [50,58]	TP1	While engaging with the metaverse, I experience a sense of immersion within a world created by the system.
	TP2	When I'm immersed in the metaverse, I tend to lose awareness of my immediate environment.
	TP3	To me, the metaverse world feels more like a "somewhere I visit" rather than just something I observe."
	TP4	During my time in the metaverse, a new world unfolded before me, only to vanish suddenly when I ceased my engagement.
Social Presence [15,59]	SP1	I was able to cultivate a feeling of community
	SP2	I felt that other users in the metaverse acknowledged my point of view.
	SP3	Interacting with fellow users in the metaverse felt comfortable to me.
	SP4	The metaverse fostered a sense of online community.
Flow Experience [53]	FE1	I experienced a sense of control during my presence in the metaverse.
	FE2	I lost my normal sense of time while I was immersed in the metaverse.
	FE3	I found it difficult to disengage from the metaverse, even when I had other tasks to attend to beforehand.
	FE4	My attention was fully directed towards my current activity.
Perceived Cost [71,72]	PC1	I think the cost associated with incorporating the metaverse in daily life is relatively substantial, such as buying related equipment.
	PC2	I think it would be a financial burden for me to buy metaverse-related products or services.
Perceived Risk [84]	PR1	Engaging with the metaverse could potentially compromise privacy, as the information involved might be utilized without my awareness.
	PR2	In general, I believe using metaverse is a bit risky.
	PR3	I worried metaverse might misuse the user data.
Intention to Use [34]	ITU1	In the future, I am interested in engaging in metaverse technologies and services related to tourism, education, gaming, etc.
	ITU2	I would suggest metaverse technologies and services to my friends and others.
	ITU3	I want to share the positive aspects of metaverse technologies and services with others.

Table 3
Demographic profile.

Characteristics		Number	Percentage
Gender	Male	168	63.40 %
	Female	97	36.60 %
Age	Less than 18	4	1.51 %
	18–25	149	56.23 %
	26–30	86	32.45 %
	31–45	22	8.30 %
	46–60	1	0.38 %
	More than 60	3	1.13 %
Education	High school and below	10	3.77 %
	Junior College	48	18.11 %
	Undergraduate	158	59.62 %
	Graduate (Master)	48	18.11 %
	Graduate (Ph. D.)	1	0.38 %
Monthly household income (CNY)	Less than 3001	48	18.11 %
	3001–5000	47	17.74 %
	5001–8000	85	32.08 %
	8001–12000	59	22.26 %
	12,001–20000	17	6.42 %
	20,001–30000	5	1.89 %
	More than 30,000	4	1.51 %
Knowledge of the metaverse	Not at all	14	5.28 %
	Know a little about	95	35.85 %
	In the ordinary	47	17.74 %
	Know better	73	27.55 %
	Know it well	36	13.58 %

the answer time being much lower than the normal time, the selection of antisense items, and all questions being the same option were removed. Finally, 265 valid questionnaires were obtained in this study. The effective recovery rate was 94.6 %.

We conducted a contextual questionnaire survey to validate the model and hypotheses, following these specific procedures. Firstly, a brief description and elucidation of the Metaverse platform "Frog's 3DVR" was provided. Then, the invitees were allowed 15 min of autonomous appreciation and exploration in a created "Art Museum Metaverse Space". After 15 min, the invitees autonomously discussed and exchanged their impressions and favourite pieces in the museum. Finally, after experiencing the Metaverse platform "Frog's 3DVR" for a sufficient amount of time, they answered the questionnaire. The demographic data of the interviewees are displayed in Table 3.

As shown in Table 3, there were more males in the sample, accounting for two-thirds, possibly due to their greater interest in metaverse technology and the higher quality of the sample. The age is biased towards young people, especially those aged 18–30, who account for about 88 % of the sample, and the level of education tends to be higher education. The respondents' monthly income predominantly centred within the range of 5000–12,000 yuan, reflecting the average monthly income of young people with higher education. Regarding prior knowledge of the metaverse, 35.85 % of respondents indicated they knew a little, and some had seen or followed it online, while 27.55 % of respondents felt more knowledgeable. However, consumers' awareness and use of the metaverse as a new technology is disproportionate overall.

4.4. *Data analysis approach*

We employed PLS-SEM to analyze our data and estimate both measurement and structural models. Additionally, fsQCA was utilized to uncover the configuration of antecedent conditions for the outcome [30,85].

4.4.1. *PLS-SEM approach*

PLS-SEM was employed as the primary method for data analysis. PLS-SEM is a technique suitable for both measurement and structural model analysis. Unlike covariance-based structural equation models, PLS-SEM does not necessitate a large sample size and does not require a normal distribution of samples. This characteristic allows for increased flexibility in modelling and data requirements [30]. As a result, PLS-SEM has become extensively utilized as a data analysis tool in social science empirical analysis research [86]. We believe that PLS-SEM is well-suited for testing the research model in this study. Hence, we employed the SmartPLS

Table 4
Indicator reliability: Outer loadings and cross-loadings.

	FE	PI	PC	PR	INF	INT	ENJ	TP	SP	BI
FE1	**0.832**	0.573	0.127	−0.151	0.679	0.651	0.637	0.703	0.643	0.646
FE2	**0.795**	0.499	0.041	−0.170	0.538	0.524	0.538	0.571	0.562	0.624
FE3	**0.760**	0.505	0.084	−0.140	0.456	0.491	0.442	0.530	0.570	0.534
FE4	**0.799**	0.431	0.095	−0.114	0.420	0.459	0.422	0.549	0.509	0.496
PI1	0.573	**0.877**	0.067	−0.253	0.600	0.598	0.588	0.505	0.672	0.545
PI2	0.588	**0.895**	0.055	−0.269	0.582	0.588	0.611	0.557	0.641	0.563
PI3	0.471	**0.810**	−0.098	−0.345	0.499	0.479	0.542	0.515	0.570	0.475
PC1	0.150	0.082	**0.952**	0.208	0.147	0.153	0.097	0.130	0.071	0.122
PC2	0.000	−0.120	**0.801**	0.335	0.007	0.018	−0.028	0.049	−0.020	0.062
PR1	−0.152	−0.307	0.256	**0.865**	−0.213	−0.230	−0.228	−0.150	−0.228	−0.229
PR2	−0.183	−0.291	0.245	**0.899**	−0.198	−0.202	−0.258	−0.212	−0.239	−0.288
PR3	−0.117	−0.255	0.214	**0.836**	−0.159	−0.161	−0.179	−0.096	−0.121	−0.124
INF1	0.577	0.573	0.112	−0.204	**0.845**	0.630	0.645	0.609	0.611	0.606
INF2	0.520	0.524	0.082	−0.133	**0.794**	0.595	0.646	0.595	0.575	0.585
INF3	0.583	0.546	0.096	−0.206	**0.850**	0.642	0.669	0.644	0.616	0.682
INF4	0.548	0.534	0.078	−0.201	**0.849**	0.616	0.671	0.656	0.553	0.663
INT1	0.489	0.519	0.122	−0.201	0.475	**0.745**	0.443	0.491	0.535	0.462
INT2	0.547	0.519	0.036	−0.174	0.695	**0.802**	0.666	0.591	0.573	0.633
INT3	0.572	0.533	0.135	−0.192	0.626	**0.839**	0.618	0.614	0.589	0.617
INT4	0.544	0.499	0.088	−0.179	0.569	**0.804**	0.621	0.517	0.578	0.546
ENJ1	0.566	0.588	0.102	−0.247	0.685	0.632	**0.817**	0.618	0.631	0.630
ENJ2	0.573	0.568	0.107	−0.168	0.684	0.654	**0.854**	0.678	0.623	0.682
ENJ3	0.530	0.614	−0.028	−0.283	0.662	0.603	**0.875**	0.587	0.607	0.611
ENJ4	0.570	0.560	0.023	−0.222	0.684	0.658	**0.903**	0.658	0.640	0.671
TP1	0.646	0.561	0.122	−0.189	0.649	0.612	0.612	**0.826**	0.625	0.593
TP2	0.607	0.484	0.085	−0.152	0.612	0.606	0.617	**0.805**	0.565	0.617
TP3	0.604	0.471	0.099	−0.131	0.567	0.487	0.569	**0.812**	0.598	0.556
TP4	0.574	0.474	0.062	−0.152	0.622	0.563	0.615	**0.827**	0.594	0.571
SP1	0.640	0.567	0.019	−0.243	0.578	0.578	0.570	0.621	**0.823**	0.626
SP2	0.586	0.668	0.065	−0.191	0.603	0.634	0.645	0.631	**0.830**	0.642
SP3	0.610	0.618	0.032	−0.202	0.602	0.604	0.611	0.609	**0.851**	0.642
SP4	0.559	0.583	0.035	−0.166	0.568	0.556	0.594	0.564	**0.826**	0.611
BI1	0.610	0.501	0.098	−0.209	0.612	0.589	0.630	0.595	0.629	**0.844**
BI2	0.582	0.533	0.102	−0.231	0.688	0.620	0.643	0.624	0.644	**0.843**
BI3	0.683	0.551	0.092	−0.252	0.663	0.625	0.671	0.628	0.681	**0.893**

software as our tool.

4.4.2. QCA approach

Qualitative comparative analysis (QCA) was proposed by Ragin [87]. QCA utilizes empirical data to construct causal relationships of research topics from small sample data. Grounded in set theory and Boolean algebra, this approach scrutinizes the relationship between conditions and outcomes from a combined perspective rather than a correlation one. The Boolean algebra algorithm formalizes the logical process of problem analysis. QCA strives to surpass traditional case study methods by systematically examining the causal interactions and possible combinations among the generating factors of internal events. This endeavour aims to explain the key factors contributing to the occurrence of events and the complex causal combinations among these factors to deepen the understanding of the complex causal relationships that lead to event occurrence [85].

In daily life, the cause of events is often not a single correlation, but a complex causal relationship composed of multiple factors. Therefore, correlation regression analysis alone cannot explain this complex combination of causes [87]. QCA mainly includes three specific operational methods: crisp set, fuzzy set, and multi-value set. We use fsQCA to analyze the causal process, provide a configuration of how causal factors combine to yield an outcome, and address the notable causal complexity [88].

The principles of PLS-SEM and fsQCA diverge in their methodologies. PLS-SEM, as a variable-oriented method, employs regression analysis to ascertain the net effects and significance of individual independent constructs on the dependent construct [89]. However, it does not discern the constructs that are either sufficient or necessary for a specific outcome. In contrast, QCA possesses the capacity to comprehensively analyze the diversity of social phenomena and causal complexity. It can delineate the influence of diverse factor combinations on outcomes, aiding researchers in delving deeper into the interaction mechanisms between antecedents and results, thereby facilitating more profound investigations [88]. Therefore, in many empirical studies, scholars choose to use mixed methods to evaluate the model, namely, PLS-SEM and fsQCA [29,83,90]. This study employed PLS-SEM to validate the path and significance of variable effects, and fsQCA to investigate the complex causal mechanism between multiple independent variables.

5. Data analysis and results

5.1. PLS-SEM analysis results

Following the two-step procedure recommended for PLS-SEM evaluation [30], we employed measurement models to assess instrument reliability and validity, while structural models were applied to estimate hypotheses and models.

5.1.1. Measurement model

The assessment of the reflective measurement model encompasses indicator reliability, internal consistency reliability, convergent validity, and discriminant validity [86]. When squaring the external loadings of reflective constructs, the resultant indicator reliability vividly portrays the relationship between latent variables and their measurements. As indicated in Table 4, the external loading for each construct surpasses 0.708 [30], thereby affirming the acceptability of indicator reliability.

Internal consistency reliability is evaluated by Cronbach's alpha (CA) and composite reliability (CR) [30,91]. It can be seen from Table 5 that all indicators surpass the threshold of 0.7, signifying satisfactory measurement reliability.

Convergent validity was assessed employing the average variance extracted (AVE) [91]. As shown in Table 5, the AVE surpasses 0.5, confirming the strong convergent validity [30].

Discriminant validity was evaluated employing the Fornelle-Larcker criterion [91]. As indicated in Table 6, the square root of AVE surpasses the correlation between variables, affirming enhanced discriminant validity [30].

5.1.2. Common method bias

By drawing on the research methods of Podsakoff et al. [92], Williams et al. [93] and Liang et al. [94] for the common method bias test, we incorporated a common method factor into the PLS model. This factor included all indicators of the principal constructs and calculated the variance explained by each indicator, both substantively by the principal construct and by the method. As shown in Table 7, the results demonstrate that the average substantively explained variance of the indicators is 0.706, while the average

Table 5
CA, ρ_A, CR, AVE, and VIF.

	CA	ρA	CR	AVE	VIF(BI)	VIF(FE)
FE	0.809	0.817	0.874	0.635	1.703	
PI	0.826	0.834	0.896	0.742	1.822	
PC	0.735	0.977	0.872	0.775	1.116	
PR	0.844	0.921	0.901	0.752	1.235	
INF	0.855	0.857	0.902	0.697		3.498
INT	0.810	0.814	0.875	0.638		2.884
ENJ	0.885	0.885	0.921	0.744		3.468
TP	0.835	0.836	0.890	0.668		2.995
SP	0.852	0.854	0.900	0.693		2.811
BI	0.824	0.829	0.895	0.740		

Table 6
Discriminant validity.

	FE	PI	PC	PR	INF	INT	ENJ	TP	SP	ITU
FE	**0.797**									
PI	0.635	**0.861**								
PC	0.110	0.015	**0.880**							
PR	−0.182	−0.331	0.278	**0.867**						
INF	0.668	0.652	0.111	−0.224	**0.835**					
INT	0.675	0.647	0.119	−0.233	0.744	**0.798**				
ENJ	0.650	0.675	0.061	−0.265	0.788	0.740	**0.863**			
TP	0.745	0.610	0.114	−0.191	0.750	0.695	0.738	**0.818**		
SP	0.721	0.731	0.045	−0.243	0.706	0.713	0.726	0.729	**0.832**	
ITU	0.728	0.614	0.113	−0.269	0.760	0.710	0.753	0.715	0.757	**0.860**

Note: The bold diagonal line represents the square root of AVE.

Table 7
Common method bias analysis.

Construct	Indicator	Substantive Factor Loading (R1)	$R1^2$	Method Factor loading (R2)	$R2^2$
ENJ	ENJ1	0.821[a]	0.674	0.088	0.008
	ENJ2	0.848[a]	0.719	0.091	0.008
	ENJ3	0.894[a]	0.799	−0.101	0.010
	ENJ4	0.915[a]	0.837	−0.066	0.004
FE	FE1	0.812[a]	0.659	0.268[a]	0.072
	FE2	0.790[a]	0.624	0.025	0.001
	FE3	0.768[a]	0.590	−0.062	0.004
	FE4	0.810[a]	0.656	−0.251[a]	0.063
INF	INF1	0.824[a]	0.679	−0.054	0.003
	INF2	0.795[a]	0.632	0.025	0.001
	INF3	0.842[a]	0.709	0.058	0.003
	INF4	0.859[a]	0.738	−0.028	0.001
INT	INT1	0.750[a]	0.563	−0.136	0.018
	INT2	0.798[a]	0.637	0.170[b]	0.029
	INT3	0.839[a]	0.704	−0.025	0.001
	INT4	0.815[a]	0.664	−0.016	0.000
BI	BI1	0.842[a]	0.709	−0.065	0.004
	BI2	0.846[a]	0.716	0.055	0.003
	BI3	0.887[a]	0.787	0.010	0.000
PC	PC1	0.893[a]	0.797	0.077[b]	0.006
	PC2	0.892[a]	0.796	−0.077[b]	0.006
PI	PI1	0.868[a]	0.753	0.038	0.001
	PI2	0.885[a]	0.783	−0.013	0.000
	PI3	0.826[a]	0.682	−0.026	0.001
PR	PR1	0.878[a]	0.771	−0.039	0.002
	PR2	0.859[a]	0.738	−0.027	0.001
	PR3	0.895[a]	0.801	0.065[b]	0.004
SP	SP1	0.835[a]	0.697	0.075	0.006
	SP2	0.833[a]	0.694	0.138	0.019
	SP3	0.853[a]	0.728	−0.031	0.001
	SP4	0.838[a]	0.702	−0.184[b]	0.034
TP	TP1	0.809[a]	0.654	0.103	0.011
	TP2	0.806[a]	0.650	0.111	0.012
	TP3	0.831[a]	0.691	−0.166[b]	0.028
	TP4	0.829[a]	0.687	−0.044	0.002
Average		**0.840**	**0.706**	**−0.0004**	**0.010**

[a] $p < 0.001$, $^{**}p < 0.01$.
[b] p,0.05.

method-based variance is 0.010. The ratio of substantive variance to method variance is about 67:1. In addition, most method factor loadings are not significant. Given the small magnitude and insignificance of method variance, we contend that the method is unlikely to be a serious concern for this study.

5.1.3. *Structural model*

Standard evaluation criteria for structural models include R^2, significance, and correlation of path coefficients [30].

Before evaluating structural models, multicollinearity needs to be examined by the variance inflation factor (VIF). It can be seen from Table 5 that all VIF values range from 1 to 3.498, which is below 5. This observation signifies the absence of a multicollinearity problem [30].

Following 5000 resampled PLS bootstrapping iterations, the results of the structural model are displayed in Fig. 2.

As shown in Fig. 2, interactivity (β = 0.167, $p < 0.05$), telepresence (β = 0.379, $p < 0.001$), and social presence (β = 0.290, $p < 0.001$) have statistically significant impacts on flow experience. Thus, the hypothesis of interactivity (H2), telepresence (H4), and social presence (H5) as predictors of flow experience was supported and explained 63.8 % of the variation in flow experience, indicating moderate explanatory power. In contrast, the relationship between informativeness (β = 0.070, $p > 0.05$), enjoyment (β = −0.018, $p > 0.05$) variables, and flow experience was not significant. The possible reason is that users have access to the information offered by the metaverse via alternative channels. The user's access to information in the metaverse will not produce a better experience than other channels. In addition, the user's demand for enjoyment may be more generated in the actual field. Hence, H1 and H3 are not supported. Regarding the direct impact of each variable on the willingness to adopt the metaverse, the results of Fig. 2 show that flow experience (β = 0.558, $p < 0.001$), personal innovation (β = 0.220, $p < 0.01$), and perceived risk (β = −0.117, $p < 0.01$) significantly explain the metaverse's willingness to adopt, thus, H6, H7, and H9 are supported. In contrast, the relationship between the perceived cost (β = 0.080, $p > 0.05$) and the willingness to adopt the metaverse is not significant. On the one hand, people pay more attention to high-level life experiences. People expect higher costs for trying new technologies and will not deny a technical service because of the cost. Therefore, H8 is not supported.

The research results show that interactivity (β = 0.093, $p < 0.05$), telepresence (β = 0.212, $p < 0.001$), and social presence (β = 0.162, $p < 0.001$) have significantly indirect effects on the willingness to employ metaverse. On the contrary, scientific significance, informativeness (β = 0.039, $p > 0.05$), and enjoyment (β = −0.010, $p > 0.05$) had no indirect effects on the metaverse adoption. In summary, our model's explained variance of the metaverse is 58.2 % (R^2), indicating that our model has a moderate level of explanatory power. The results for nine hypotheses are consolidated in Table 8.

5.2. Qualitative comparative analysis results

The critical steps of the fsQCA study encompass model construction, sampling, data calibration, necessary condition analysis, sufficient condition analysis, and result interpretation.

5.2.1. Calibration

Data utilized in PLS-SEM must be calibrated into fuzzy sets for fsQCA. First, the items that constitute variables are combined into one variable according to the path coefficient's weight, and then calibrated as a fuzzy set. The range of fuzzy sets is continuous from 0 to 1, where the 5 % quantile corresponds to full non-set membership, and the 95 % quantile signifies full membership. Given the non-normal distribution of our actual data, we designate a 50 % quantile of each condition as the crossover point [89]. The process of data calibration is automatically computed using the fsQCA 4.0 software (see Table 9).

5.2.2. Necessary conditions analysis

The necessary conditions analysis examines whether any causal factor can be deemed necessary for generating a particular outcome. As suggested by previous studies, there needs to be a condition when its agreement must exceed 0.9 [85,89]. As depicted in Table 10, there is no single factor that is deemed necessary for adopting the metaverse ("BI"). Furthermore, there is no single condition that negates the adoption of metaverse ("~BI"). It turns out that a single condition by itself cannot cause the output "~BI".

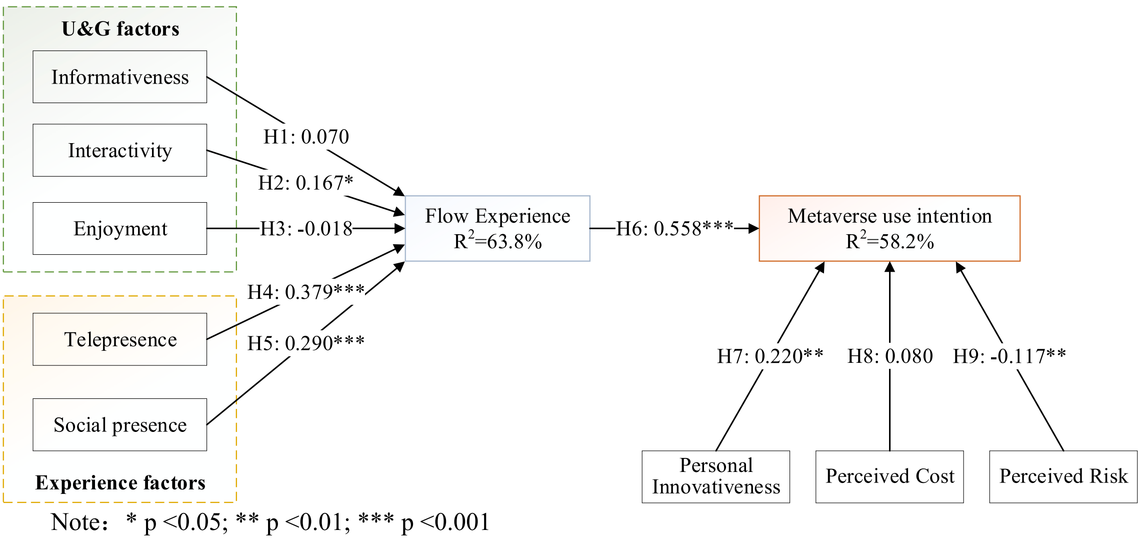

Fig. 2. Results of the structural model.
Note:*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 8
Summary of the hypothesis test.

	β	Mean	STDEV	T values	P values	Supported
FE→BI	0.558***	0.558	0.049	11.321	0.000	Yes
PI→BI	0.220[b]	0.222	0.070	3.150	0.002	Yes
PC→BI	0.080	0.082	0.052	1.540	0.124	No
PR→BI	−0.117[b]	−0.120	0.042	2.757	0.006	Yes
INF→FE	0.070	0.067	0.074	0.940	0.347	No
INT→FE	0.167[a]	0.172	0.078	2.146	0.032	Yes
ENJ→FE	−0.018	−0.022	0.077	0.238	0.812	No
TP→FE	0.379[c]	0.381	0.075	5.042	0.000	Yes
SP→FE	0.290[c]	0.289	0.072	4.052	0.000	Yes

Note.
[a] $p \leq 0.05$.
[b] $p \leq 0.01$.
[c] $p \leq 0.001$.

Table 9
Calibration.

	Full nonmembership	Crossover point	Full membership
FE	3.58	5.02	6.75
PI	3.92	5.34	7.00
PC	2.03	4.91	6.54
PR	1.33	4.35	6.34
INF	3.72	5.51	7.00
INT	3.73	5.23	7.00
ENJ	3.48	5.50	7.00
TP	4.00	5.25	7.00
SP	3.57	5.25	7.00
BI	3.68	5.65	7.00

Table 10
Analysis of necessary conditions.

Outcome	BI (Metaverse use intention)		~BI (Negation of Metaverse use intention)	
Conditions	Consistency	Coverage	Consistency	Coverage
FE	0.850457	0.808375	0.493872	0.478737
~FE	0.451600	0.466645	0.802317	0.845475
PI	0.851905	0.870823	0.393498	0.410206
~PI	0.423018	0.406147	0.876084	0.857812
PC	0.697790	0.674451	0.620703	0.611831
~PC	0.598399	0.607381	0.669731	0.693254
PR	0.621189	0.582684	0.714201	0.714201
~PR	0.662271	0.694398	0.563752	0.602813
INF	0.860519	0.846771	0.434006	0.435536
~INF	0.426372	0.424850	0.847310	0.861016
INT	0.829649	0.839245	0.436174	0.449962
~INT	0.456250	0.442424	0.844171	0.834811
ENJ	0.847637	0.849191	0.405830	0.414630
~ENJ	0.415701	0.406893	0.852392	0.850865
TP	0.847637	0.841099	0.422945	0.427999
~TP	0.423552	0.418512	0.842975	0.849450
SP	0.418512	0.833564	0.466517	0.453074
~SP	0.425686	0.438968	0.828626	0.871413

5.2.3. Sufficient conditions analysis for metaverse acceptance

A truth table is a tool used to represent the possible combinations of conditions that could lead to a particular outcome. It helps to identify the most likely combinations of conditions and to prioritize the most important factors for consideration. Therefore, before conducting a standardized analysis, it is necessary to construct a truth table. In QCA, if there are n antecedent conditions, there will be 2^n configurations formed, and each row in the truth table represents one configuration. The frequency threshold for consistency is usually set at 0.8, where a value greater than 0.8 indicates the presence of the result (coded as 1), while a value less than 0.8 indicates the absence of the result (coded as 0). Since the number of questionnaires collected in this study is sufficient, a value of 2 is chosen as the critical value for case frequency. The truth table for the existence (absence) of user metaverse acceptance is shown in Table 11 and

Table 11
Truth table of high metaverse acceptance.

PI	INF	INT	ENJ	PC	PR	TP	SP	FE	number	BI	raw consist.	PRI consist.	SYM consist
1	1	1	1	1	0	1	1	1	23	1	0.984822	0.965585	0.96892
1	1	1	1	0	0	1	1	1	23	1	0.981519	0.958376	0.970195
1	1	1	1	0	0	1	1	0	3	1	0.980609	0.898551	0.89855
1	1	1	1	1	1	1	1	1	20	1	0.976674	0.941586	0.961686
1	1	1	1	1	0	1	1	0	2	1	0.972857	0.85764	0.85764
1	0	1	1	0	1	1	1	1	2	1	0.969851	0.80191	0.80191
1	1	1	1	0	1	1	1	1	8	1	0.968031	0.889961	0.900391
1	1	1	1	1	1	1	1	0	2	1	0.967762	0.803468	0.835672
0	0	0	1	0	1	0	0	0	2	1	0.832049	0.139021	0.139021
0	0	0	0	1	1	1	0	0	2	1	0.823744	0.143248	0.143248
0	0	0	0	0	1	0	0	1	3	0	0.740383	0.100573	0.100655
0	0	0	0	1	0	0	0	0	5	0	0.673142	0.074716	0.074716
0	0	0	0	1	1	0	0	0	11	0	0.618526	0.045977	0.045977
0	0	0	0	0	1	0	0	0	11	0	0.572665	0.037788	0.037788
0	0	0	0	0	0	0	0	0	28	0	0.549561	0.041206	0.041253

Table 12
Truth table of negation of metaverse acceptance.

INF	INT	ENJ	PC	PR	TP	SP	FE	PI	number	~BI	raw consist.	PRI consist.	SYM consist
0	0	0	0	1	0	0	0	0	11	1	0.983218	0.962213	0.962212
0	0	0	1	1	0	0	0	0	11	1	0.981616	0.954023	0.954023
0	0	0	0	0	0	0	0	0	28	1	0.980104	0.95765	0.958747
0	0	0	1	0	0	0	0	0	5	1	0.973606	0.925284	0.925284
0	0	1	0	1	0	0	0	0	2	1	0.972881	0.86098	0.860979
0	0	0	0	1	0	0	1	0	3	1	0.970734	0.89861	0.899345
0	0	0	1	1	1	0	0	0	2	1	0.97053	0.856752	0.856753
0	1	1	0	1	1	1	1	1	2	1	0.877951	0.198091	0.19809
1	1	1	1	1	1	1	0	1	2	1	0.861884	0.157996	0.164328
1	1	1	1	0	1	1	0	1	2	1	0.836478	0.14236	0.14236
1	1	1	0	0	1	1	0	1	3	1	0.828255	0.10145	0.10145
1	1	1	0	1	1	1	1	1	8	0	0.738082	0.098456	0.09961
1	1	1	1	1	1	1	1	1	20	0	0.615665	0.037513	0.038314
1	1	1	1	0	1	1	1	1	23	0	0.572637	0.030973	0.03108
1	1	1	0	0	1	1	1	1	23	0	0.569079	0.029442	0.029805

Table 12.

Following the “standard analysis” process of fsQCA 4.0, the software automatically generates complex, intermediate, and simple solutions. Given that the intermediate solution aligns most coherently with theoretical explanations [30], we employ it for our analysis. The combinations of conditions leading to the willingness to adopt metaverse behaviours are outlined in Table 13. It is noteworthy that no condition in isolation is sufficient for ‘BI’. Moreover, the consistency of 5 equal configurations exceeds 0.8,

Table 13
Solutions for high metaverse acceptance.

Conditions	Configurations				
	1a	1b	1c	2	3
FE			●	○	○
PI	●	●	●	○	○
PC		●	○	○	●
PR	○		●	●	●
INF	●	●		○	○
INT	●	●	●	○	○
ENJ	●	●	●	●	○
TP	●	●	●	○	●
SP	●	●	●	○	○
Raw coverage	0.499	0.495	0.270	0.206	0.224
Unique coverage	0.120	0.097	0.030	0.019	0.029
Consistency	0.978	0.963	0.964	0.832	0.824
Solution consistency	0.732				
Solution coverage	0.884				

Note: Solid black circles ("●“) and hollow circles ("○“) represent the presence and absence of a condition, respectively. Additionally, prominent and minor circles indicate core and peripheral conditions correspondingly. Blank cells denote a “don’t care” scenario.

implying that all of them are sufficient. Furthermore, each configuration's coverage value (similar to R^2 in the regression method) is greater than 0, indicating empirical correlation [85]. To satisfy the criteria set by Ragin [85], both the solution consistency (0.732) and solution coverage (0.884) exceed 0.7 and 0.25 correspondingly. Additionally, the solution coverage showed that total solutions accounted for 88.4 % of the sample associated with high levels of metaverse adoption.

As indicated in Table 13, enjoyment and telepresence are listed as the core conditions in different configurations. This result indicates that consumers have a specific purpose (enjoyment) for using the metaverse, and the experience of telepresence in the metaverse is an essential and significant condition for fostering consumers' heightened inclination toward metaverse adoption.

Solution 1a demonstrates that enjoyment and telepresence as the core conditions, coupled with the absence of perceived risk and the presence of personal innovation, information, social presence, and interactivity as peripheral conditions, can achieve a high metaverse adoption rate. Moreover, among the five causal pathways displaying empirical correlation, Solution 1a emerged as the most pivotal (unique coverage = 0.120). Solution 1b suggests that the presence of conditions such as personal innovation, perceived risk, informativeness, social presence, interactivity, enjoyment, and telepresence can collaboratively generate outcomes. Solution 1c indicates that a higher level of acceptance of the metaverse can be achieved by taking enjoyment and telepresence as core conditions and combining them with factors such as flow experience, personal innovation, interactivity, social presence, perceived risk, and the absence of perceived cost. Solution 2 demonstrates that, with enjoyment as the core condition, perceived risk present, and other variables absent as peripheral conditions, there is sufficient configuration to meet a higher willingness for metaverse adoption. Solution 3 shows that, by taking telepresence as the core condition and perceived risk and perceived cost as peripheral conditions, with other factors being absent, it is sufficient to lead to a substantial level of adoption.

It can also be seen from the results of fsQCA that the existence or absence of any factor is not necessary to adopt the metaverse. Among the five configuration paths, no element is continuously present or absent. In addition, in Solutions 1a, 1b, 1c, and 2 of fsQCA, the existence of enjoyment is a core condition, while in PLS-SEM, the effect of enjoyment on metaverse adoption intention is not statistically significant, which also shows that fsQCA supplements the net effect view.

In contrast to traditional methods like SEM and regression models, fsQCA excels in addressing causal asymmetry [85]. Consequently, this study delved into implementing the same threshold setting to ascertain which conditions worked together to negate the outcome (~BI), yielding the results detailed in Table 14. The tabulated results reveal that the six identified configurations prove to be sufficient and empirically relevant. This assertion is corroborated by the fact that each configuration boasts consistency and coverage exceeding 0.8 and 0 correspondingly. Furthermore, all configurations account for 88 % of the sample, thereby negating the propensity to adopt the metaverse.

Observing Tables 14 and it becomes evident that six configurations (categorized into three types according to core conditions) negate the adoption of the metaverse. Among the six configurations that deny the willingness to adopt the metaverse, the absence of information and the absence of flow experience emerge as core conditions that are asymmetrical to the result of the willingness to adopt the high-level metaverse. Therefore, the presentation of this series of results also experienced causal asymmetry.

6. Discussion

6.1. Findings

For the antecedents of flow in the context of the metaverse. Flow is a positive subjective emotional state that is experienced when fully engaged in an activity. It has been found to yield positive flow outcomes, such as increased brand loyalty and trust, driving purchasing behaviour, and enhancing willingness to use, among others [46,47]. Most of the research on flow has focused on its positive outcomes. Once this relationship is established, another critical aspect should be to focus on the causes of flow. The results of our PLS-SEM analysis reveal the significant influences of interactivity, telepresence, and social presence on user flow in the metaverse context. This finding is consistent with prior research [47,95], indicating that a positive interactive experience, immersive

Table 14
Solutions for the negation of metaverse acceptance.

Conditions	Configurations					
	1a	1b	1c	2a	2b	3
INF	○	○	○	○	○	●
INT	○	○	○	○	●	●
ENJ	○		○	○	●	●
PI	○	○	○	○	●	●
PC		○	●	○	○	●
PR		●	●	●	●	
TP	○	○		○	●	●
SP	○	○	○	○	●	●
FE	○	○	○		●	○
Raw coverage	0.608	0.433	0.427	0.441	0.181	0.215
Unique coverage	0.118	0.005	0.009	0.014	0.010	0.011
Consistency	0.973	0.979	0.973	0.979	0.878	0.816
Solution consistency	0.700					
Solution coverage	0.880					

environment, and social aspects perceived by users in the metaverse can capture users' attention and create a sense of physical presence. This leads to a state where users forget they are in a virtual space and experience great joy, resulting in flow experiences and significantly increasing their willingness to embrace the metaverse. These three factors can be attributed to the entertainment and social purposes of users, indicating that the metaverse is not simply an online virtual technology. The motivation for users' demand for the metaverse is not only online communication but also the establishment of a new social network in the metaverse space parallel to the real world, enabling dynamic interactions between individuals and objects [28]. These research findings have made efforts and contributions to investigating the precursors of flow in the metaverse context.

Our findings also explain why users accept the metaverse, namely, high levels of flow experience and personal innovation, as well as low levels of perceived risk. Furthermore, through the configuration analysis of fsQCA, the influence configurations of different factors leading to high and low acceptance levels of the metaverse by users were obtained.

For the antecedents of metaverse adoption. Combining the results of PLS-SEM and fsQCA, we identify the following key design factors. The user's flow experience in the metaverse is a significant factor in the ultimate acceptance of the metaverse, and the lack of flow experience is a fundamental condition for users to reject the metaverse, highlighting the importance of flow experience. This result also confirms the findings of previous scholars [96]. Therefore, when designing the metaverse, it is essential to focus on the factors that generate flow: interactivity, telepresence, and social presence [47,95]. The metaverse design should emphasize aspects such as the sense of experience and participation, ensuring ease of operation, smoothness, and low latency during user interactions with the metaverse environment system [15]. Telepresence must be achieved through virtual reality technologies, such as VR, AR, and other devices, all of which assume a pivotal role. Additionally, the manifestation of social aspects in the metaverse is critically important, as it involves users engaging in communication and interactions with others using their avatars, thus creating a social network [47]. Therefore, in designing the metaverse, the user's identity and role information should be exclusive and unique to give the user a sense of belonging.

On the other hand, although the PLS-SEM results did not find any impact of informativeness and enjoyment on flow and intention to use the metaverse, which differs from previous studies [28]. This suggests that in the specific context and application scenario of this study, informativeness and enjoyment may not be the primary determinants influencing users' acceptance of the metaverse. However, the fsQCA results indicate that when combined with other variables, enjoyment plays a central role in shaping users' acceptance of the metaverse, providing new insights into previous research [97,98]. This suggests that when conditions such as telepresence, interactivity, and social presence are met, the perceived enjoyment of users can enhance their intention to use the metaverse, providing them with an expanded experience. The lack of informativeness was found to be a core condition in users' refusal to use the metaverse. This leads us to consider that users may not specifically use the metaverse for information retrieval. However, if they do not receive any useful or interesting information from using the metaverse, they may be more inclined to refuse to use it [27]. This finding indicates the need to pay attention to the information delivery and dissemination mechanisms in metaverse design and to provide precise delivery and communication to users. Another finding is that perceived cost is no longer a significant factor influencing users' intention to adopt metaverse, which is inconsistent with prior studies [70]. Within a reasonable range, users exhibit a willingness to pay for the experience of the metaverse. However, Risk factors should be taken seriously, and this result is consistent with previous studies [77,79,80]. In the era of information technology, there have been numerous cases of user data leakage and misuse, which have led to adverse consequences. This has made users hesitant when trying out new technologies. Our results indicate that this is still an important issue and has a significant negative influence on metaverse utilization. This highlights the need to emphasize data security and privacy in metaverse design, possibly requiring the use of NFT and data encryption technologies. Additionally, users' level of personal innovation can influence their acceptance of the metaverse, providing suggestions for metaverse promotion [69].

In summary, the results of PLS-SEM indicate that flow experience, personal innovation, and perceived risk can increase users' acceptance intention but also identify the predictive factors of flow experience, namely interactivity, telepresence, and social presence. In addition, the results of fsQCA are used as a complementary analysis to strengthen the findings of PLS-SEM, providing deeper and novel insights, thus demonstrating the need to consider combinations of conditions to explain results in complex causal research. In the fsQCA results, we identified five configurations of "BI" and six configurations of "~BI", which cannot be captured by PLS-SEM, thus proving the causal asymmetry and complementing the research results. Upon comparing this study with previous research, some of our findings are consistent with existing literature, indicating that certain factors are widely recognized as important by scholars and cannot be overlooked. However, our results also reveal differences from prior studies in areas such as the impact of informativeness, enjoyment, and perceived cost on users' acceptance of the metaverse. This discrepancy can be attributed to the specific scenario upon which our study is based and the use of a more comprehensive analysis method. Furthermore, it is evident that the influence of certain factors has evolved with societal and temporal developments. Therefore, this study aims to offer new insights into metaverse development and advocate for the utilization of metaverse technology for the betterment of human society.

6.2. Theoretical implications

Firstly, our research focuses on the adoption of the metaverse. Since 2021, the metaverse has emerged as a collection of new technologies and has sparked intense discussions. Summarizing previous literature on the metaverse, there is no systematic genre or research in metaverse adoption. Our study fills the research gap and contributes to the understanding of the factors influencing individuals' intention to adopt the metaverse by linking the metaverse with user behaviour. The conclusions drawn from this study ascertain the substantial impact of flow experience on users' metaverse adoption intentions, which establishes the importance of positive subjective emotional experience (flow) in shaping user behavioural intentions in the metaverse context, enriching the field of research. Additionally, another essential theoretical contribution is the revelation of three crucial factors, interactivity, telepresence, and social presence, that can generate user flow experience in the metaverse. This finding extends previous research on antecedents of flow and provides theoretical guidance.

Secondly, our research adopts a holistic and integrative approach to explore the acceptance of the metaverse and contributes to the literature and research on metaverse acceptance. A single perspective is insufficient to reveal the relationships involved comprehensively. Therefore, we use multiple theories to explain the acceptance of the metaverse. While previous literature has discussed the acceptance of the metaverse to some extent, our study stands out by incorporating the characteristics of the remediation of the metaverse and immersive virtual experiences and combining them with flow theory to explore the impact of flow experience, a subjective and pleasurable feeling, on metaverse acceptance. The relationship between the two is highly significant. Additionally, we combine UGT with exploring the antecedents of flow experience and introducing innovation diffusion theory and perceived risk theory to support our model when considering factors that directly influence metaverse acceptance. The empirical results demonstrate that our comprehensive model surmounts the limitations of a single model and enriches the comprehension of metaverse acceptance through the lens of flow theory. Our model has an R^2 of 58.2 % for metaverse acceptance, indicating a high level of explanatory power.

Lastly, considering the methodological aspect, our study underscores the complementary nature between PLS-SEM and fsQCA in the realm of metaverse adoption. We observed that numerous prior investigations into the willingness to adopt the metaverse predominantly relied on an array of techniques such as multiple regression models, econometric methods, SEM, and PLS. These methods aimed to examine the net causal impacts of individual antecedents on the dependent variable; however, These approaches lack comprehensiveness [99]. Therefore, we introduced the QCA method to delve into the complexities of behavioural research. In addition to using PLS-SEM to identify critical driving factors for metaverse acceptance, we utilized fsQCA to delve deeper into different configurations of conditions that unveil the complex, non-linear, and asymmetric effects of causal conditions on the outcomes of this study.

6.3. Managerial implications

Our research provides some management insights for the metaverse platform and vendors to promote adopting metaverse technology and services in a broader mass market.

Firstly, users' flow experience significantly impacts whether they will use the metaverse. When users have a subjective and pleasurable feeling while using the metaverse, they lose the sense of time, weaken self-consciousness, and focus on activities in the metaverse. In this case, it dramatically enhances users' inclination to use the metaverse. The generation of flow experience is intricately linked to the interactivity, telepresence, and social presence the metaverse can provide. Therefore, metaverse vendors should focus on the experiential factors of the metaverse, such as better interaction with the system, a more immersive sense of telepresence, and a higher degree of social attributes, to increase users' flow experience in the metaverse. Pleasure should also be emphasized in the design of metaverse functions, as some users may choose to use the metaverse for enjoyment. On the other hand, users may not use the metaverse primarily for information acquisition, but they are likely to reject it due to the lack of informative content. Therefore, the design of information processing and dissemination mechanisms in the metaverse needs to be taken seriously.

Secondly, users' personal innovation is significantly related to their acceptance of the metaverse. Users exhibiting elevated levels of personal innovation tend to exhibit a positive disposition toward new information technology and are likely to experience the metaverse spontaneously. Therefore, metaverse platforms can target younger groups or consumers engaged on the internet when promoting to attract their attention and increase the usage rate of the metaverse.

Lastly, we ascertain that a minimal perceived risk is pivotal for fostering metaverse adoption. In our survey, users' perceived risks mainly focus on data security and privacy breaches. As a result, metaverse providers ought to prioritize mitigating technological and market ambiguity, making protecting user data security an important task to increase the metaverse's usage rate.

6.4. Limitations and future directions

Firstly, our research draws exclusively upon flow theory, UGT, and previous literature on the acceptance of metaverse to identify and evaluate several key factors. However, there may be other key factors that we have not considered that could influence consumers' willingness to use the metaverse. For example, this study focused on the subjective emotional state of flow, while previous research has identified user perceptions of metaverse such as PU, and PEOU. Future research could integrate emotions and technology perception to explore more comprehensive influencing factors and improve upon what we have not achieved. Secondly, our study was only conducted in China. It did not consider consumers' attitudes towards using the metaverse in other countries or regions, which might be different. Therefore, future research should involve surveys across multiple countries or regions for a more comprehensive and universal study.

7. Conclusion

The emergence of the metaverse has ushered in a new stage in information technology. People use the metaverse to seek alternative satisfaction in virtual worlds, promoting the development of the metaverse. As research on user acceptance behaviour in the metaverse is not yet mature, further exploration is needed. Drawing upon flow theory and uses and gratifications theory, we attempt to gain a deeper understanding of metaverse acceptance through a hybrid approach employing PLS-SEM and fsQCA, examining both conditional net effects and combination effects. The PLS-SEM results manifest that flow experience, perceived risk, and personal innovation directly influence users' acceptance of the metaverse, while perceived cost has no effect. Simultaneously, interactivity, presence, and social presence indirectly affect users' acceptance of the metaverse, while informativeness and enjoyment have no indirect effect.

Significantly, fsQCA unveiled five configurations resulting in a high user acceptance of the metaverse, as well as six configurations leading to a negative acceptance.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Yikai Liang: Supervision, Methodology, Funding acquisition, Conceptualization, Project administration, Writing – original draft. **Xiaojie Zhang:** Writing – original draft, Methodology, Investigation, Conceptualization, Data curation, Formal analysis, Visualization. **Haiqing Wang:** Writing – original draft, Conceptualization, Validation, Visualization, Writing – review & editing. **Mengqing Liu:** Writing – review & editing, Validation, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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