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Product Development and Design Framework Based on Interactive Innovation in the Metaverse Perspective

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Abstract: Based on the theory of user needs and the product development mode and framework of mobile Internet interactive innovation, a new "*reality* → *virtual* → *reality*" interactive innovation product development mode is constructed. It draws on the unique characteristics, systematic technical system, and comprehensive scientific and technological layout of the Metaverse. On this basis, a framework for product development and design based on interactive innovation from the Metaverse perspective is innovatively proposed. In the Metaverse scenario, interactive innovation knowledge can be easily and effectively transformed into design knowledge, and all groups of users truly participate in the whole process of product design. Moreover, the development of interactive innovative products in the Metaverse scenario can be combined with artificial intelligence (AI) technology to further automate the statistical analysis of user needs and preferences so as to meet the dynamic needs of users and accurately develop products that fit user needs and enterprise standards. In addition, users, designers, and enterprises can make joint decisions on product design solutions and development forms, and the Metaverse technology can also optimize the products with continuous iteration and obtain the optimal solutions. An automotive case study illustrates the feasibility and effectiveness of the model for product development innovation and enterprise digital transformation.

Keywords: Metaverse; interactive innovation; product development and design; user needs; innovation knowledge

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1. Introduction

In the era of the service economy, characterized by rapid collaborative product iteration, user needs have emerged as a crucial driver for product design evolution and a key determinant of new product direction [1,2]. The exponential growth of user-generated content (UGC), which serves as a reflection of user needs, has been facilitated by the development of the Internet. This growth has been further accelerated by the proliferation of digital technology [3], leading to the generation of vast amounts of knowledge on social media platforms every second [4,5]. Consequently, there has been a substantial increase in the personalization and diversification of user needs. As a result, both the scholarly community and industry exhibit a keen interest in investigating rapid product innovation methods that align with user needs. The achievement of this objective relies on the active involvement of users in the product design process [6]. To facilitate user participation, researchers have explored different approaches to open up the design process [7]. Interactive innovation, in particular, highlights the collaborative development of products among users, designers, and enterprises, leading to enhanced feedback effectiveness [8]. In the interactive innovation process, users contribute knowledge pertinent to product innovation within the community, serving as a vital reference for product development [9,10]. Although numerous enterprises have adopted and successfully implemented a product development model predicated on interactive innovation [11], the advent of the mobile

Internet introduces complexities in interaction, which are characterized by interactivity, self-organization, and non-linearity. Moreover, the nature of interactive knowledge becomes voluminous, dynamic, and unstructured, posing significant challenges for enterprises in the development and utilization of this innovative knowledge [12,13]. Furthermore, the model exhibits several constraints. Rapid product turnover and swiftly changing online public sentiment cause customer demands to evolve quickly [14], creating a lag in product development that fails to meet these shifting demands, thereby widening the gap between customer expectations. This discrepancy may disrupt sales, inflate development costs, and diminish both word-of-mouth and customer loyalty. In addition, existing studies rarely focus on extreme users, which are those user groups with special needs or specific usage scenarios. They ignore the fact that the needs of this group may represent the potential needs of a wider population [15].

As a next-generation immersive Internet technology, the Metaverse is expected to address existing limitations by integrating the benefits of authentic, immersive experiences with realism and accurate reflections of reality alongside facilitating access to high-fidelity environments [16,17]. Currently, the Metaverse has found successful applications across various industries including gaming, social media, film and television, education, finance, sports, office work, retail, tourism, and manufacturing [18–21]. In its exploration and application, the Metaverse has unveiled numerous novel benefits and values. For instance, it enables a seamless interaction between virtual and real worlds [22]; supports the amalgamation of virtual avatars, digital, and real identities [23]; and offers diverse characteristics, advanced digital technology [24], and boundless opportunities in time and space [25]. These features are critically sought after in product development and design that leans on interactive innovation, offering practical solutions to existing challenges. More specifically, within the Metaverse, there is potential for generating vast UGC for product development, optimizing the application of UGC, and enabling universal user participation. Additionally, it boasts benefits such as convenience, efficiency, and visualization, which can effectively address current obstacles faced in mobile Internet-driven product development. Nonetheless, there remains a significant gap in research concerning the application of the Metaverse in product development and design.

Although Metaverse scenarios demonstrate adaptability in interactive innovation-based product development and design, offering advantages to current interactive innovation dilemmas, there are still key unanswered questions. Specifically, how can the Metaverse effectively facilitate interactive innovation in product development? Additionally, how can the needs of various user groups be better integrated into the product development process within a Metaverse scenario? To tackle these inquiries, we review traditional product development and design processes alongside interactive innovation-based product development experiences using an inductive–deductive approach. We consider the current explorations and applications of the Metaverse and propose a framework for product development design rooted in interactive innovation from the Metaverse perspective. The framework encompasses a "*reality* → *virtual* → *reality*" interactive innovation product development model facilitated by Metaverse scenarios. The model facilitates extensive user engagement in design and fosters equitable co-creation among users, designers, and enterprises. It expedites the translation of user needs into design, ensuring products effectively meet evolving requirements while reducing costs. User involvement in the design process and interaction with the outcomes amplify their sense of ownership and satisfaction, boost product market visibility, and cater to users' emotional demands. As such, this paper presents several significant contributions. Firstly, it offers a comprehensive framework for product development utilizing the Metaverse, incorporating user participation throughout the design process. Secondly, it tackles the challenges posed by dynamically shifting user needs and unstructured interactive knowledge in the realm of mobile Internet, proposing innovative solutions. Thirdly, it stresses the significance of considering diverse user groups' needs, offering insights that can benefit a broader audience. Finally, it elucidates practical implications and theoretical advancements by bridging the gap between existing interactive innovation practices and emerging prospects in the Metaverse.

The remainder of this paper is structured as follows: Section 2 reviews relevant literature, providing an overview of prior research on the Metaverse and identifying research gaps. Section 3 details the synthesis process of our proposed methodology, which incorporates elements of product development design and Metaverse applications. In Section 4, a case study within the automotive industry is examined to illustrate the application of the proposed framework. Section 5 discusses the potential risks associated with implementing the framework. Section 6 highlights the theoretical contributions and practical implications of this study as well as future work.

2. Related Work

2.1. Concept and Characteristics of the Metaverse

The concept of the Metaverse was introduced in Neal Stephenson's 1992 novel *Snow Crash* [26], portraying an immersive digital environment existing alongside the real world [27]. Despite being a cutting-edge technological concept, the Metaverse has not yet acquired a universally agreed-upon definition. Zhao, in "Metaverse" [28], further elaborates that the Metaverse, enabled by wearable smart devices, represents a specific virtual spacetime formed by the integration of various advanced technologies such as rendering, AI, and 5th Generation Mobile Communication Technology (5G). Facebook, on the other hand, envisions the Metaverse as the next iteration of the Internet, possibly being its ultimate form [29]. Based on these research foundations, this paper posits that the Metaverse, in a broader sense, encompasses not only the virtual world but also the entirety of the Internet, including the realm of augmented reality [30,31]. In essence, the Metaverse represents the next evolutionary phase of the Internet, which is built upon its infrastructure.

Although the Metaverse currently lacks a standardized definition, its characteristics have been widely recognized by researchers and professionals in the field. Roblox, for instance, initially proposed a set of eight key elements essential to the Metaverse, which include identity, social connections, immersion, low latency, diversity, accessibility, economic systems, and civilization [26]. Some researchers have also further defined the characteristics and properties of the Metaverse, encompassing social and spatial aspects, technological empowerment, co-creation between humans and AI, realism and reality mapping, as well as transaction and circulation [32]. Building upon existing research and the current state of Metaverse development [33,34], this paper highlights the following eight key features: virtual identity, strong social connectivity, three-dimensional (3D) immersive experiences, open content creation, digitization of human and social relationships, integration of the physical and digital worlds, stable economic systems, and the establishment of a civilized system. These features provide the necessary conditions for an interactive and innovative product development model, following a "*reality* $\rightarrow$ *virtual* $\rightarrow$ *reality*" framework. Specifically, virtual identity refers to users obtaining one or more digital identities within the Metaverse, corresponding to their real-life counterparts. Strong socialization is facilitated by the Metaverse's built-in social network, which allows users to engage with others' digital identities in a manner resembling real-life social interactions. The 3D immersive experiences are made possible by the support of virtual reality (VR) and other technologies, enhancing users' sensory experiences within the Metaverse. The Metaverse is an open platform that facilitates the creation, expression, and interaction between users, fostering innovation and collaboration. It also supports a wide range of UGC and provides various means for expanding self-produced materials. In the digital era, the digitization of human and social relations predominantly occurs within the Metaverse. Here, the level of human–computer interaction surpasses or equals that of human–human interaction, effectively meeting the real needs of people. The integration of the physical and digital realms involves two primary aspects: the "digitization of the physical world" and the "actualization of the digital world". In essence, the Metaverse first digitizes the physical world and subsequently utilizes the digital world to solve real-world problems. These two worlds complement each other, giving rise to the concept of "*reality* → *virtual* → *reality*". The economic system within the Metaverse encompasses digital creation, digital assets, digital markets, digital currency, and digital consumption, and it gradually forms an economic framework that interrelates with the existing real-world economic system. Moreover, the Metaverse also entails the creation of a coherent civilization system where individuals can reside, form communities, establish cities, establish common regulations, and gradually evolve into a civilized society while ensuring survival.

2.2. Metaverse Technology System

The Metaverse relies on a comprehensive technology system comprising six key pillars known as "BIGANT" [35]: blockchain technology, interaction technology, video game technology, AI technology, intelligent network technology, and Internet of Things technology [36]. These pillars, illustrated in Figure 1, form the foundation for product development and design within the Metaverse, emphasizing interaction and innovation in the Metaverse scenario.

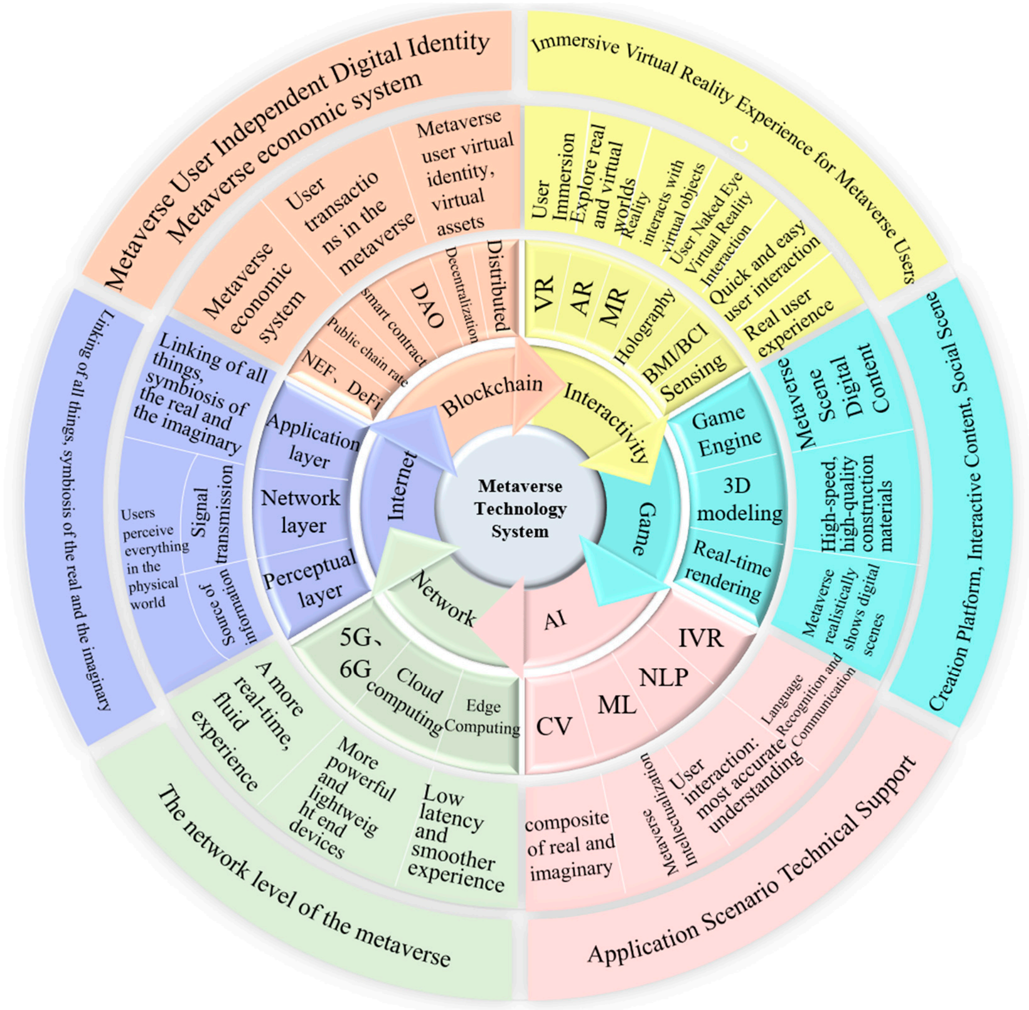


Figure 1. Metaverse technology system.

Among them, blockchain serves as a crucial foundation supporting the economic system of the Metaverse. Through the implementation of technologies like Non-Fungible Token (NFT), Decentralized Autonomous Organization (DAO), and Decentralized Finance (DeFi), blockchain empowers creators and stimulates extensive content innovation. Simultaneously, decentralization guarantees the independent digital identity of Metaverse users, enabling their unrestricted participation and exploration in the virtual world. Interaction technology can be categorized into output and input technology. Output technology encompasses head-mounted displays, tactile feedback systems, olfactory interfaces, and even neural information transmission, translating electrical signals into human senses. Input technology includes miniature cameras, position sensors, force sensors, and more. Moreover, composite interaction technologies incorporate various types of brain–computer interfaces, offering Metaverse users an immersive virtual reality experience. Video games provide a platform for content creation and a social environment in the Metaverse, facilitating user engagement and laying the groundwork for technological advancements in inter-user interaction. AI technology encompasses various levels, applications, and scenarios within the Metaverse. The integration of AI contributes to a more realistic fusion of reality and virtual reality, enabling accurate language recognition and supporting social interactions between users. Intelligent network technology, serving as a cloud-based comprehensive capability platform, forms the underlying infrastructure of the Metaverse. It ensures real-time and seamless immersive experiences for Metaverse users. IoT technology plays a dual role in the digitization of the physical world by enabling front-end data acquisition and processing. Additionally, it facilitates the symbiotic relationship between the virtual and physical worlds in the Metaverse. This technology establishes ubiquitous connections between objects and individuals, laying the foundation for the interactive and innovative product development model of "*reality* → *virtual* → *reality*".

2.3. Layout of Metaverse Technology

Industry leaders have already ventured into the Metaverse, utilizing the advancements provided by six principal technologies [37–39]. Facebook, in particular, has established a far-reaching presence within the Metaverse landscape. Their endeavors encompass the Creator content creation community, Extended Reality (XR) Oculus Quest, digital currency and commerce, and Workplace virtual workspace. Notably, Facebook has revolutionized the concept of "office space" through the introduction of Workrooms, which is a VR office environment built on Quest 2. Workrooms offers users a hybrid VR experience in which they can engage in virtual meetings using avatars. Within this immersive setting, users can collaborate on virtual whiteboards and even utilize their physical desks, computers, and keyboards to perform regular office tasks within the VR realm. The Oculus Avatar feature provides users with a wide range of appearance options for customization in various scenarios. Moreover, Workrooms provide flexible office settings and furnishings, allowing users to select meeting rooms and workspaces that cater to their specific needs. ByteDance has adopted a content-centric approach, placing emphasis on the development of a comprehensive content ecosystem and exploring the requisite technological infrastructure for the Metaverse. Tencent, on the other hand, has established a comprehensive Internet ecosystem under the "social + content" framework. Within the social aspect, platforms such as WeChat and QQ have already taken the form of Metaverse, while in the content aspect, Tencent has developed a diverse range of content centered around intellectual property (IP). This has enabled Tencent to become the largest provider of professionally generated content (PGC) in China. Similarly, Roblox has proposed a combination of UGC and underlying economic systems. NVIDIA, on the other hand, introduces NVIDIA Omniverse, which is an open cloud platform designed for virtual collaboration and real-time realistic simulations. This empowers creators, designers, engineers, and artists to work seamlessly in real time, regardless of geographical boundaries. Moreover, Omniverse adheres to the Metaverse concept of decentralization by involving multiple parties in its operation. With the continuous exploration and technological support from major enterprises, the Omniverse scene is gradually improving and providing a solid platform foundation for product development through interactive innovation within the Omniverse scene.

2.4. The Digital Identity of Metaverse Users

In the real world, most individuals possess online “digital accounts” on various platforms, such as Weibo, WeChat, and Taobao. These platforms serve different purposes: WeChat primarily stores users’ social information, while Taobao records shopping-related details [40]. However, it is important to note that these accounts and associated data do not constitute complete digital identities; they only represent a fraction of one’s digital identity. Digital accounts rely on the existence of real individuals in the physical world, and these individuals cannot exist independently across multiple platforms. Users of digital accounts must abide by platform rules and are subject to the rights and obligations determined by their physical identity. In this context, users lack actual control over their digital accounts.

Although users in the Metaverse originate from the physical world and possess real identities, their digital identities, known as “independent identities” within the Metaverse, exist separately from their physical identities with no direct mapping relationships [41]. Furthermore, users can possess multiple independent digital identities across various virtual worlds, incorporating behavioral characteristics derived from both the physical and virtual realms [42]. In the Metaverse, users exist as virtual digital personas within the virtual space, embodying their independent identities and serving as the medium for interpersonal and interactive connections among individuals and entities in the virtual realm [43]. More specifically, virtual digital personas can be classified into virtual avatars and digital representations. Virtual avatars solely exist within the virtual world and have no connection to individuals in the physical realm. On the other hand, digital representations are avatars embodying human beings who traverse into the Metaverse in the form of digital bilocation, representing the incarnation and dual presence of the user. The Metaverse, built upon this foundation, creates a truly “decentralized” world that fosters “free participation”. It enables interactions among independent individuals with digital identities, fostering the formation of new consensus and the establishment of rules within the digital realm. As a result, the Metaverse enables complete freedom and social interaction for its participants, allowing users to unleash their individual creativity and initiative, thus realizing personal ideas and promoting interactive innovation. Moreover, digital identities transcend the constraints of geography, social class, and culture, granting equal and unrestricted access to individuals from any location and at any time in the real world. This characteristic provides an advantageous environment for product development based on interactive innovation within the Metaverse space.

2.5. Applications of the Metaverse

The Metaverse is still in its infancy at the moment, but it is already widely used in several fields such as tourism, real estate, fashion branding, education, healthcare, gaming, the automotive industry, hospitality, and shopping [18–21,44]. Metaverse tourism is currently in the experimental stage, which can enhance the awareness, positioning, and branding of tourism purposes through digital twin technology, while enabling coordination and effective management [20]. A number of Metaverse real estate projects have emerged, such as Decentraland and Cryptovoxels, which are virtual reality platforms based on the Ethereum blockchain, and they even offer digital economy systems for property transactions [45]. In addition to virtual property, the Metaverse also facilitates real-life property transactions by allowing consumers to take a 360-degree tour of a house without leaving their homes through head-mounted VR devices [46]. The Metaverse has also attracted the interest of fashion brands, which are increasingly appearing in virtual worlds and online games. Nike created its branded Metaverse, NIKELAND [47]. Gucci was also a pioneer in integrating the Metaverse with the launch of the digitally-specific trainer Gucci Virtual25, and fashion powerhouses such as Givenchy, Ralph Lauren, and Tommy Hilfiger are opening up sales of digital goods on Roblox [48]. The Metaverse is shaping the future of education, driving innovation and transforming the way learning and teaching takes place, including virtual educational site visits, virtual immersion language environments, remote tutoring, and professional development opportunities for teachers [18]. The Metaverse has also been used extensively in the field of smart healthcare. These include Metaverse hypnosis, Metaverse motion rehabilitation, AI-based screening and early warning of Chinese medicine for untreated diseases, medical online consultation, medical simulation training, virtual doctors, virtual psychological rehabilitation, and life self-care ability training [44]. Automobile manufacturers have also started to explore the application of Metaverse technology. Deveci et al. investigated three alternative implementations of self-driving cars in the Metaverse [49]. Liu et al. introduced the Metaverse into in-vehicle networks, and the in-vehicle Metaverse can provide users with real-time immersive experiences based on augmentation technology [50].

2.6. Research Summary

Summarizing the existing research, it becomes evident that the Metaverse seamlessly integrates the physical and digital realms. Characterized by virtual identities, robust social features, 3D immersive experiences, opportunities for open content creation, and the digitization of human and societal relationships, alongside the fusion of physical and digital worlds, it ensures economic and civilizational system stability. These attributes not only furnish the Metaverse with the capacity to offer highly immersive experiences but also facilitate open content creation, fostering innovation and collaboration. Its potential for application and success across various domains is already evident. This confluence of potential and advantages lays a solid foundation for product development and design, adopting interactive innovation models. The Metaverse's digital technology enhances virtual spaces' realism, encouraging a symbiotic relationship between reality and virtuality, thus leading to an increasing overlap between the two realms. This intersection provides an ideal environment for "*reality* $\rightarrow$ *virtual* $\rightarrow$ *reality*". Moreover, the Metaverse offers a platform where users from diverse backgrounds can freely live, socialize, and create content, fostering a comprehensive virtual space predominantly shaped by UGC. Consequently, the Metaverse proves to be more efficient and time-saving compared to mobile Internet, significantly reducing the time cost associated with product development. However, despite its demonstrated advantages, successful applications, and utility in product development and design, there remains a scarcity of research focusing on its implementation in product development and design through interactive innovation. Therefore, this study aims to leverage the Metaverse in product development design to explore a new paradigm addressing the current challenges in product development and design rooted in interactive innovation.

3. Interactive Innovation-Based Product Development and Design in the Metaverse Perspective

In this section, we innovatively propose a product development and design model based on interactive innovation in the Metaverse perspective based on inductive–deductive thinking. We begin by reviewing and summarizing established models and theories related to product development and design. This includes both traditional approaches and those that incorporate interactive innovation, with a detailed analysis of the latter. Second, we summarized the knowledge of interactive innovation in the Metaverse scenario and the practical application of Metaverse in many fields. On this basis, a framework for product development and design based on interactive innovation in the Metaverse perspective is constructed. The organizational framework is shown in Figure 2.

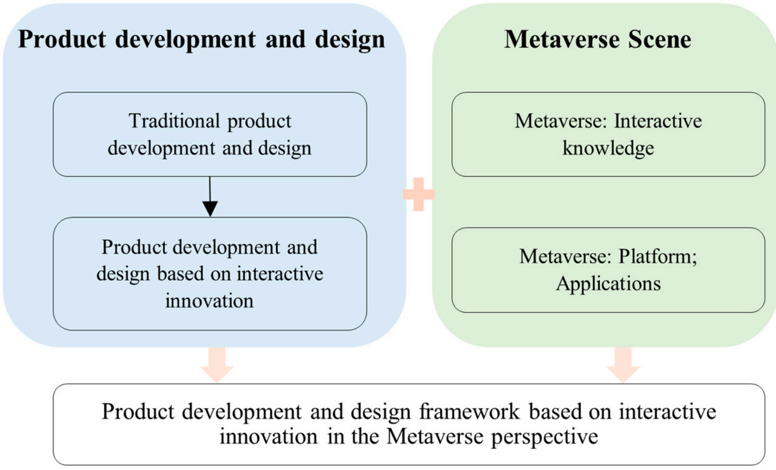


Figure 2. Organizational framework.

3.1. Product Development and Design

3.1.1. Traditional Product Development and Design

The traditional product development process comprises six distinct phases, namely planning, concept development, system design, detailed design, testing and improvement, and pilot production expansion [51–53], as depicted in Figure 3. The planning phase initiates by identifying potential opportunities based on corporate strategy, including defining the target market and business objectives. The concept development phase focuses on understanding market needs, generating and evaluating various product concepts, and selecting the most promising ones for further development and testing. The system design phase involves defining the product's architecture, breaking it down into subsystems and components, and designing key parts. This phase yields outputs such as the geometric layout, functional specifications for subsystems, and an initial assembly process flowchart. The detailed design phase entails specifying non-standard part geometries, materials, and purchased standard parts from suppliers. It results in control documentation, including component geometry, production tooling descriptions, and manufacturing and assembly flow plans. The test and improvement phase entails creating and evaluating multiple pilot production versions of the product. During the pilot production expansion phase, the product is manufactured using the designated production system. The produced products are then carefully assessed for any defects through evaluation processes conducted by the target customers.

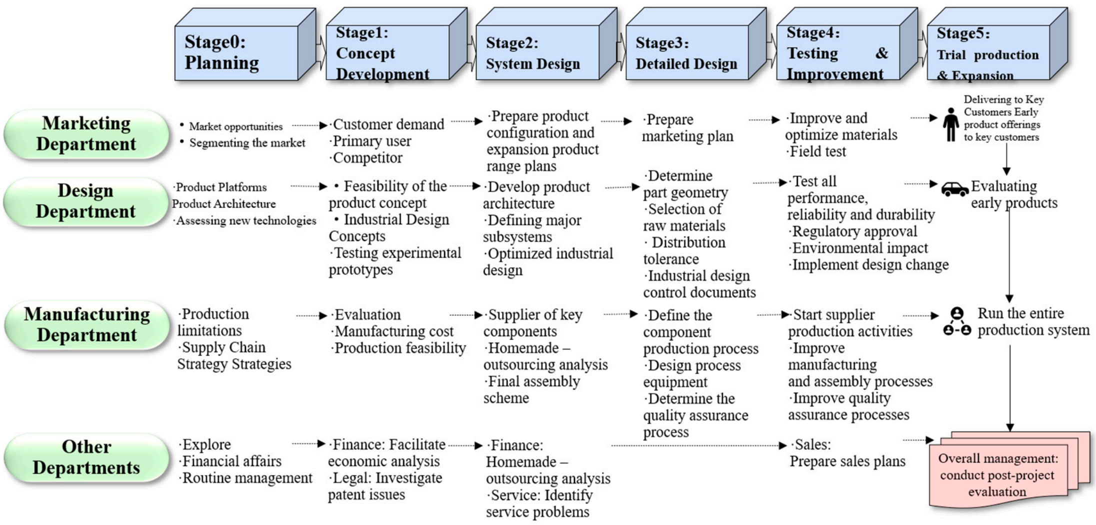


Figure 3. Product development and design process and framework.

Figure 3 highlights that the traditional "brand-centered" product development model emphasizes the holistic optimization of the system by employing a "top–down" approach for analysis and design [54]. This approach aims to ensure the coherence and consistency of the overall system and its objectives. Furthermore, it strictly demarcates the development phases with the outcomes of each phase serving as the foundation for the subsequent phases. However, the advent of the mobile Internet has rendered the advantages of this "fixed" development design as drawbacks. Nielsen emphasizes the protracted life cycle of this process, which incurs substantial time costs [55]. Additionally, the entire product development process, from design to finalization and mass production, occurs internally. Although the marketing department is responsible for gathering customer requirements during the initial stages, it only packages initial user demands. Moreover, the marketing department can only gather limited short-term user feedback at present. In the design department, engineers mechanically execute tasks based on predefined concepts, lacking knowledge of the product's applicability without user feedback [56]. Compounding the problem is the "we design, you manufacture" dynamic between the design and manufacturing departments, resulting in limited flexibility for product modifications, long development cycles, high costs, and compromised product quality. Ogawa's study further exposes the traditional product development model's inability to adequately capture user needs and its high costs [57,58], elaborating on the lengthy development cycles and inefficiencies of traditional methods. Consequently, the "top–down" product development design can no longer meet users' demands in the mobile Internet era.

3.1.2. Product Development and Design Based on Interactive Innovation

By enabling users to actively engage in the entire product design process, this enables addressing the aforementioned challenges. Adopting a product development and design approach grounded in interactive innovation facilitates the shift from a "brand-centered" to a "user-centered" focus, empowering enterprises to better meet user needs and preferences.

Interactive Innovation

Interactive innovation, initially proposed by Professor Eric Von Hippel, encompasses the collaborative process of active engagement between customers and enterprises, customers and customers, as well as enterprises and enterprises, to drive product design and innovation [59]. Within this process, enterprises leverage social media platforms to actively gather users' product experiences and explore their needs and desires. Users, on the other hand, contribute by expressing their own needs and offering creative insights and solutions. This collaborative approach fosters co-creation between users and enterprises, allowing for joint product design and cooperative efforts in technology promotion. Interactive innovation deviates from traditional development approaches by considering users not simply as consumers but as "external designers" who actively participate in product development alongside enterprises. Professor Hippel places significant emphasis on engaging with lead users who possess needs that will likely resonate in the future market and are early adopters of innovative solutions to address those needs [60]. Lead users offer valuable insights regarding multiple aspects, such as providing clear and well-defined needs, assisting in the development of new product concepts and prototypes, expediting the product development timeline, reducing costs, facilitating continuous product innovation, and promoting the widespread adoption of innovative products. Therefore, understanding the needs of lead users enables the timely identification of evolving user requirements and facilitates the development of high-potential market products. On the other hand, the proliferation of the mobile Internet has provided users from diverse backgrounds and regions with increased opportunities to engage in product discussions. In light of this, Gemser and Perks further consider the value created by the ordinary users. Ordinary users are the vast number of consumers who use products in their daily lives, and their needs and usage scenarios represent the mainstream market. Based on this, they propose an interactive innovation involving all users [61]. Additionally, surveys have revealed the considerable value and innovation captured in user reviews of competing products [13]. Moreover, potential users who have shown interest in a new product but have not yet made an actual purchase often comment on social media, and their comments also hold great value [62]. Consequently, this paper posits that interactive innovation in the mobile Internet era encompasses the collaboration between enterprises, lead users, and ordinary users. It further extends to multiple stakeholder interactions, encompassing users of competing products, potential users, suppliers, and distributors.

Product Development and Design Based on Interactive Innovation

The interaction between enterprises and users within the Internet context primarily revolves around user innovation tools [63–70]. Studies conducted on brand communities, questionnaires, and interviews explore the effects of enterprise–user interaction on enterprise innovation performance. Traditionally, companies have focused on engaging with lead users to gather insights regarding product requirements and ideas as well as to mitigate risks associated with large-scale production through small-scale testing. While this approach has proven effective during the early stages of the Internet, the emergence of the mobile Internet era has highlighted concerns regarding the limited involvement of ordinary users in the innovation process.

The mobile Internet has opened up opportunities for addressing interactive innovation challenges. Specifically, it has established a social networking platform for communication and interaction between enterprises and users. This platform increases the openness of interactive innovation in terms of boundaries, participation, and creative direction. Enterprise innovation is propelled into a new era marked by the data-driven engagement of network users as a collective whole. Furthermore, it transforms interactive innovation from a cooperation model where lead users play a central role into a mode that combines the distinctive characteristics of both leading and ordinary users for innovation. In this mode, enterprises can effectively identify, match, and acknowledge the innovative ideas from lead users while leveraging the vast behavioral data from ordinary users to gain insights into diverse and dynamically evolving demand information. This enables enterprises to make accurate market predictions and fosters more efficient and higher-quality product research and development (R&D) through interactive collaboration with users. In general, the process of user participation in product development within the mobile Internet context can be divided into three steps: establishing a user participation platform, engaging in user interaction to identify lead users, and implementing agile development and precise marketing. Figure 4 illustrates the framework of the interactive and innovative product development process in the context of the mobile Internet.

The interactive innovation product development in the context of mobile Internet is summarized in Figure 4, which consists of the following five layers. Firstly, there is the social network layer, where the mobile Internet provides a platform for enterprises to interact with users for innovation purposes. Users at different levels, including lead users, ordinary users, competing users, potential users, as well as suppliers and distributors, are invited or spontaneously join the product community to engage in interaction and communication. Through this platform, users can share product-related knowledge that can be used for product innovation. The communication includes discussions about product experiences, feedback on product issues, suggestions for product improvements, and so on. Secondly, there is the lead users' identification layer. By leveraging the big data environment of the mobile Internet, user online psychology and behavior can be analyzed. This layer provides platform tools and data for observing users' participation in innovation. By analyzing users' participation in innovation at different levels, the system can identify lead users rapidly and accurately, facilitate efficient matching, and collect credit information. Enterprises can use this information to enhance interactive innovation with lead users. Additionally, through the structural observation and analysis of ordinary users' consumption psychology and behavior, enterprises can make informed judgments about the consumption demand and direction of the ordinary user groups. Thirdly, there is the knowledge acquisition layer, which collects, recognizes, refines, and converts massive data obtained from different sources on the social network using big data technology. Furthermore, it identifies and establishes the user interactive knowledge base and enterprise innovation knowledge base based on the different interactive knowledge of lead users and ordinary users. Based on this knowledge base, enterprises, with the assistance of market analysts and mobile Internet big data technology, can extract product direction and market demand information. Fourthly, there is the designer development layer, where enterprise designers use the extracted information resources to support product innovation R&D. The designers understand the product direction and market demand information and communicate internally and interact with lead users to derive creative solutions for product innovation and develop and design new products. Finally, there is the enterprise production layer, where the enterprise department completes the production and processing tasks of product innovation and tests the products through the feedback and experience of lead users.

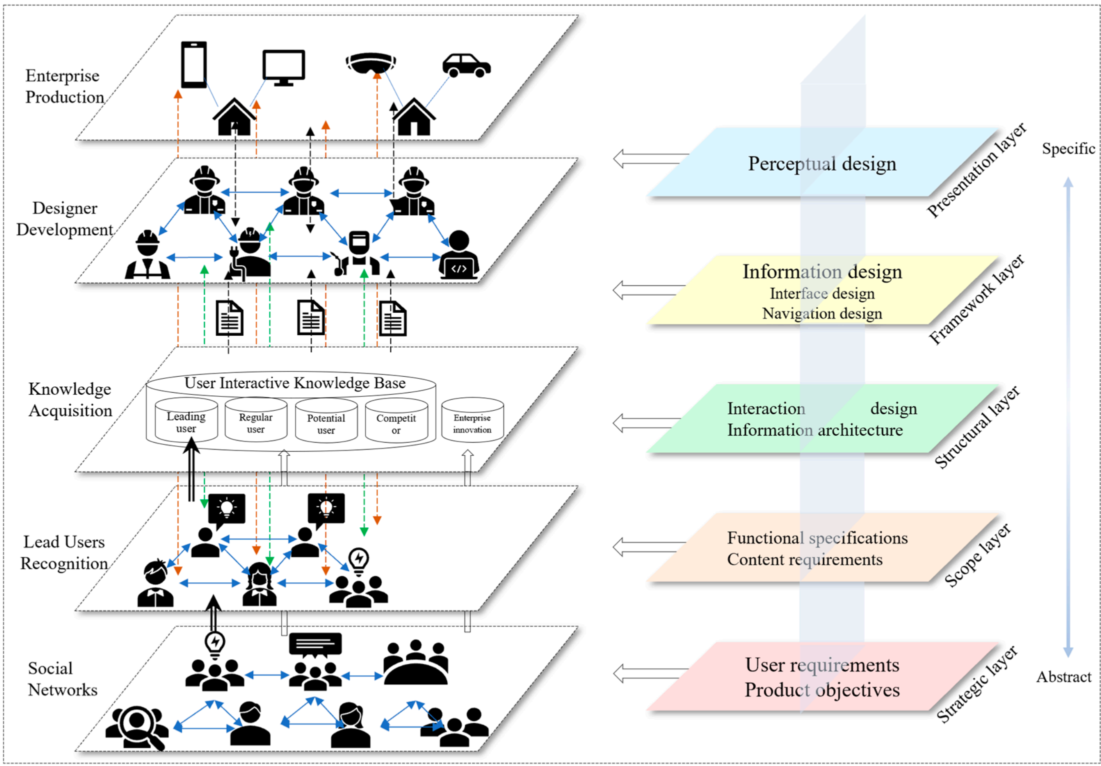


Figure 4. Framework for interactive innovation product development process in the mobile Internet environment (Short black bold double-line arrow: users identification; Long black bold double-line arrow: knowledge extraction; Blue double arrow: person-to-person interaction; Black dotted single arrow: designers extract product trends and market demands; Green dotted double arrows: designers-lead users interaction; Black dotted double arrow: designers and enterprises collaborate on new product development and production; Orange dotted double arrow: lead users testing of new products.).

Although interactive innovation product development and design based on the mobile Internet facilitates R&D driven by user needs [71], there are several limitations currently associated with interactive innovation. One common limitation is the challenge of fully extracting information from UGC, which is typically unstructured. Numerous studies have highlighted the difficulty of extracting information from user knowledge [72]. Furthermore, enterprises also face obstacles in assimilating external knowledge [73], which is primarily due to the difficulty in comprehending and effectively applying such knowledge [74]. Additionally, many high-tech SMEs in emerging economies engage in selective interaction and innovation with different partners at various stages, leading to issues of inconsistent knowledge [75]. Moreover, during the process of delivering UGC to design engineers, the information undergoes structuring and processing, which can result in misinterpretation or loss of certain details. Apart from this, design engineers, having varying levels of interactive knowledge, tend to have biases in their understanding of UGC and translating it into design solutions. Consequently, the end product may deviate from the actual needs of customers [76]. Even if UGC is well understood and applied, there remains the challenge of addressing users' dynamic needs, which current interactive innovation struggles to effectively cope with [77]. Moreover, interactive innovation primarily focuses on lead users, often neglecting other user groups. Some research has also examined the sustainability of interactive innovation and found that overdoing it can have negative consequences [78]. Consequently, despite the increasing prevalence of interactive innovations, their failure rate is also on the rise [79].

3.2. Interactive Innovation-Based Product Development and Design in the Metaverse Perspective

3.2.1. Interactive Knowledge of Virtual Digital Entities in Metaverse Space

As explained in Section 2, the term "interactive innovation" pertains to the active engagement between customers, clients, and firms to facilitate product design and innovation. Throughout this process, a multitude of interactive innovation knowledge for product development and design is generated on real-world Internet platforms. This knowledge encompasses various types of content, including UGC [80] contributed by ordinary users, PGC [81] produced by professional creators, professional user-generated content (PUGC) developed by semi-professional individuals, and occupationally generated content (OGC) created by industry professionals with some knowledge and professional background [82]. These contents primarily originate from users across all levels on social media platforms such as microblogs, forums, video-sharing websites, and online Q&A platforms. They are presented in diverse formats such as text, images, audio, and video, yielding extensive, dynamic, disorganized, unstructured, and personalized data. Different scenarios and content creators bear their own specific focuses and concerns, prompting most companies to employ an amalgamation of matching strategies in order to strike a balance between content quantity and quality. This approach enables them to acquire the most valuable knowledge to drive product interaction and innovation.

It is important to note that while enterprises may strive to achieve optimal matching combinations to maximize the value of "αUGC + βPGC + γPUGC + δOGC + …", the majority of content generated in the physical world exists in the form of text and pictures. Some knowledge can be captured in audio–video format given sufficient resources. However, the amount of valuable information that can be extracted from text and pictures is limited. Additionally, even when valuable information is extracted, biases are inevitably introduced when transforming user knowledge into the designer's understanding due to knowledge heterogeneity. Moreover, the current technology for processing and analyzing audio and video data is still in its infancy, and extracting high-value information from such formats requires substantial human and computing resources. Consequently, content consisting of text, images, audio, and video has limited value for enterprises in terms of market analysis and product innovation and development.

The Metaverse, as the next generation of immersive Internet, has the potential to overcome these limitations. Unlike the current Internet's two-dimensional (2D) visual experience limited to screens, the Metaverse offers users a 3D experience that can match or even surpass the real world. Along with the 3D visual experience, users can also engage in physical interactions that closely resemble those in the real world, such as touch and smell, through external devices like XR devices, tactile gloves, tactile clothes, and even brain–computer interfaces [83,84]. Particularly, brain–computer interface technology enables users to perform various interactions using their consciousness [85], allowing for a wide range of interaction behaviors within parallel worlds. This supports faster and more effective information access within the Metaverse. Therefore, in the virtual space of the Metaverse, with the assistance of XR, holograms, brain–computer interfaces, sensors, and other devices, users are provided with an all-encompassing sensory "connectivity" [86]. Through the support of technologies such as blockchain, interaction technology, AI, and network computing, the Metaverse allows UGC to go beyond traditional text, images, audio, and video and also include "real-time images", "thoughts", "actions", and more [87]. Specifically, within the Metaverse environment, a virtual office space is created using existing platforms like Facebook's Creator Studio, Workplace, and Workrooms; Tencent's full-fledged Internet; and Roblox, NVIDIA; and other Metaverse technology platforms. In this scenario, user groups, designers, and corporate departments can communicate and interact, sparking the generation of novel ideas. Although creative knowledge exists in vast, dynamic, and diverse forms, Metaverse technology can convert this knowledge into structured and organized data in real time, facilitating its application in product innovation and development. Furthermore, users can access "virtual laboratory", "virtual workshop", "virtual factory", and other spaces for free creation in real time, utilizing their digital identity. This grants users the ability to design and develop virtual products according to their own preferences and needs, allowing their creative content to be directly transformed into product specifications. Concurrently, the Metaverse space, supported by interaction technology, network computing technology, AI, and other technologies, can record individual and group design parameters, enabling the statistical analysis of users' design preferences and personalized needs. Throughout the entire process, designers can enter the virtual space as users to freely create and perceive user needs from their perspective. Additionally, designers can assess and evaluate UGC as professionals. Ultimately, the collaborative efforts of "user group + designer group + enterprise department + Metaverse" produces high-quality interactive innovation knowledge for product development.

3.2.2. Product Development and Design for Interactive Innovation Enabled by the Metaverse

In addition to interacting with virtual avatars and digital identities in a virtual space to generate innovative knowledge, such as text, pictures, audio and video files, real-time images, ideas, behaviors, and more, users also incorporate offline information data into the Metaverse world [88–90]. This environment further enhances the advantages of a "*reality* → *virtual* → *reality*" creation model. In this model, individuals in the physical world enter the Metaverse world to develop and design new products via interaction and communication in the virtual space. These products are then manufactured on a small scale and, subsequently, mass produced in the offline physical world. This paper proposes a product development and design approach with interactive innovation within the Metaverse perspective, which is applicable to a wide range of products, particularly those that necessitate extensive R&D and involve high costs, such as automobile products. The framework is shown in Figure 5.

The proposed framework consists of three segments. In the first segment, the groups involved in the development of interactive and innovative products in the Metaverse are identified. These groups include the user group, the designer group, and the corporate sector group. The user community consists of various types of users such as lead users, average users, extreme users, potential users, users of competing products, suppliers, and distributors. In the second segment, these three groups become virtual digital individuals in the Metaverse through the use of hardware equipment and software technology. The third segment is the Metaverse Interactive Innovative Product Development Space, where these three groups are invited to participate in interactive innovation and the development of new products. Prior to entering the space, users label their digital identity/virtualized body as "lead users", "ordinary users", "extreme users", or "potential users" based on their self-perception. Moreover, the Metaverse collects and analyzes the user's physical space data and behavioral data within the Metaverse through big data technology to accurately search for matching professionals and identify different types of users. By utilizing bilateral weighting, the data from both parties are used to determine the final virtual user portrait for an individual.

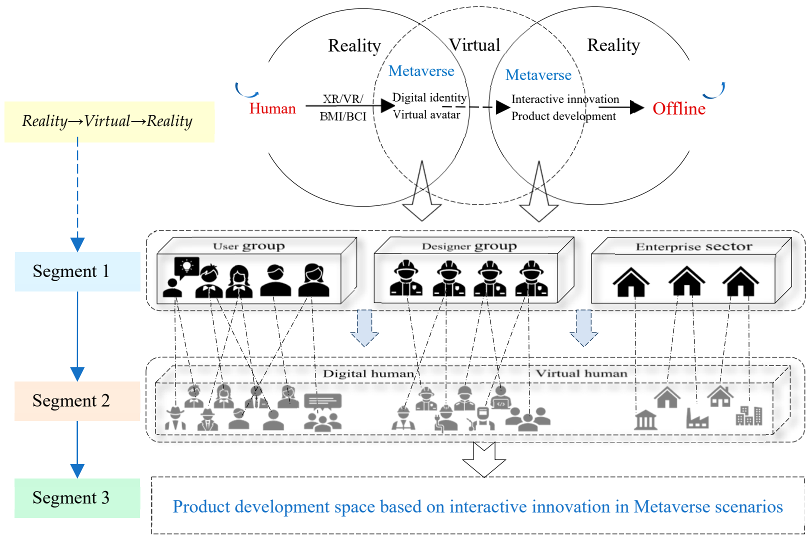


Figure 5. A design framework for interactive innovation-based product development in the Metaverse (The dashed lines represent the three groups entering the Metaverse as virtual digital individuals.).

The third segment consists of four virtual scenarios, which are referred to as "Workplaces". These scenarios encompass several crucial aspects of the innovation process, including an interactive innovation communication space, a real-time product development and design space, a virtual testing space for new product samples, and a virtual iterative decision-making office space. The layout of segment 3 is shown in Figure 6. The detailed deployment of the individual spaces within it is shown in Figure 7. The interactive innovation exchange space further comprises three preconfigured virtual scenes known as "Workrooms". Each of these Workrooms serves different purposes, catering to the specific needs of various user groups. For instance, users have the ability to enter independent virtual spaces for internal group communication and interaction. Another option available to them is to engage in interactions between pairs of groups in the "communication and learning" space. Alternatively, they can participate in interactive discussions among multiple groups in the "interactive discussion" space. These options provide flexibility for different types of engagements and facilitate the generation of effective R&D innovation knowledge. Leveraging AI technology is an integral part of this process, as it enables the assessment of interaction and innovation knowledge between designers and lead users, fostering collaboration and enhancing efficiency in R&D innovation. Moreover, in order to prevent counterfeiting, infringement, and intellectual property issues, Metaverse big data technology facilitates real-time credit inquiries on user-generated R&D ideas. The AI technology employed in this ecosystem also allows for the extraction of valuable information related to the product. This includes insights into the direction of the product market, new product market demands, user experiences with old products, and feedback on problems. By leveraging AI technology to extract and analyze this information, it significantly contributes to the formation of innovation knowledge and the conceptualization of products. These concepts serve as a foundation for user groups, designer groups, and enterprise departments to enter the development and design space. The real-time product development and design space is divided into two sections: developing industrial design concepts and building/testing experimental prototypes. This space offers a range of opportunities for creative exploration, establishing virtual laboratories, workshops, factories, and other spaces. The Metaverse performs an essential role by recording the design data of each virtual individual and statistically analyzing the design preferences of user groups. Through collaborative efforts between the three groups and the Metaverse, decisions are made regarding the final part geometry and raw materials, effectively completing the industrial design. This iterative process continues, incorporating feedback and optimization, until product test samples are generated. Subsequently, the three groups, along with the product test samples, proceed to the product experience test space. In this virtual test space, user groups, designer groups, and enterprises immerse themselves in various aspects of the product using input devices such as miniature cameras, position sensors, force sensors, and speed sensors. The utilization of head-mounted displays and output technologies that convert electrical signals to human senses enables the output of experiences, particularly from lead user groups and designer groups. The valuable insights and feedback derived from these groups play a crucial role in informing product adjustment and optimization.

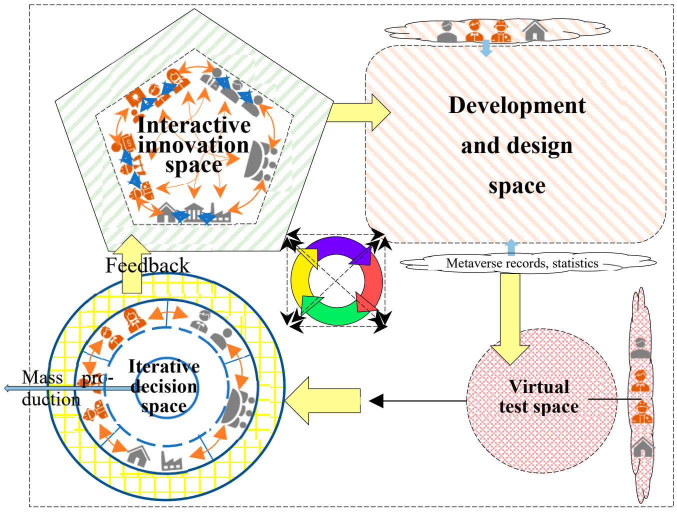
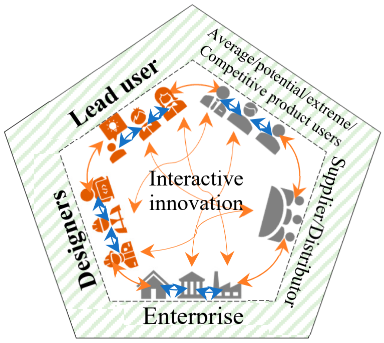
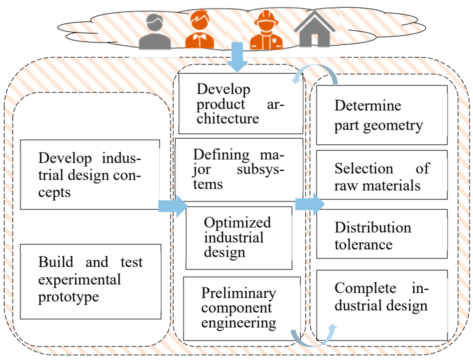


Figure 6. Segment 3: Interactive innovation-based product development space in Metaverse scenarios.

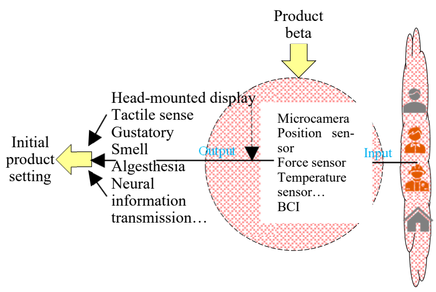
Once all groups are satisfied with the product, it can be finalized as a test sample. However, in case any group harbors doubt about the product, they have the option to return to the development and design space at any time to enhance and optimize the product. Alternatively, they can go back to the interactive innovation space to engage in discussions with other groups regarding the product's issues and potential areas for improvement. This iterative cycle of continuous product optimization ensures that the finalized sample represents the ideal product. Following the finalization, both the sample and the groups enter the virtual evaluation and decision-making office space together. The iterative decision space within the virtual environment can be divided into two distinct stages: the subjective link and the objective link. The subjective link is known as the virtual market, where the enterprise showcases and sells new products through virtual shelves. Virtual users establish connections with the enterprise through transactions, generating data on transaction behaviors and characteristics. With the support of Metaverse technology, enterprises can obtain and analyze virtual users' transaction data, forming the ability to conduct accurate, differentiated, and situational market segmentation by creating various labels based on users' purchasing behaviors. Simultaneously, the continuous interaction between enterprises and virtual users within the virtual market generates communication data with emotional characteristics. Through the iterative advancements facilitated by the Metaverse technology, the algorithm for product innovation gradually improves, optimizing the decision-making process for product development and innovation. Moving onto the objective link, within the evaluation decision space, the three groups assess the samples from their own perspectives as well as from the viewpoints of other groups, considering multiple aspects and levels based on their expertise and experience. Collaboratively, they arrive at decisions regarding the samples. Samples that successfully pass this evaluation can then be incorporated into the offline small batch trial production and mass production plan. Additionally, the product information is recorded and fed back to the interactive communication and innovation space, providing the foundation and information necessary for the subsequent stages of product optimization and development. In the event that a sample does not meet the evaluation criteria, it is returned to the interactive communication and innovation space. The group then engages in further collaboration and interaction to improve and optimize the product, striving to achieve the desired state.



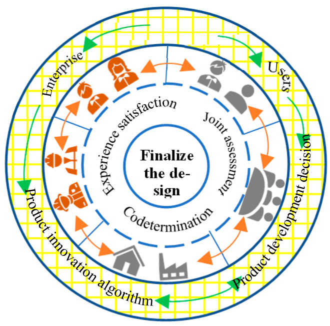
(**a**)



(**b**)



(**c**)



(**d**)

Figure 7. Four virtual scenarios. (**a**) Interactive innovation space; (**b**) Development and design space; (**c**) Virtual test space; (**d**) Iterative decision space.

4. Case Study

We use automotive development as a case study to illustrate the operational mechanism of the proposed model. The design process for general cars usually spanned 3 to 5 years in Europe and the United States, 3 to 4 years in Japan, and 5 to 15 years for independent R&D in China. The architecture phase was estimated to take approximately 18 months, the strategy phase about 6 months, the concept phase around 6 months, the development phase about 22 months, and the production maturity phase of mass production manufacturing is expected to last around 7 months [91]. Recent data from the past two years indicated that the typical development cycle for a new car has been shortened from 5–7 years to 2–3 years [92]. However, this still entailed a significant investment of time and resources. Moreover, the conventional empirical design–test–check approach employed in new car R&D was inadequate due to the complexity of automobile structures [93]. It remained difficult to ascertain whether the local and overall strengths, among other factors, meet the design requirements during the design process [94]. Consequently, repeated testing was necessary for improvement, resulting in relatively long design cycles and high costs associated with trial production [95]. As a result, market adaptability became a challenge. In addition to temporal costs, the financial expenses involved in vehicle development were substantial, ranging from millions to tens of millions of dollars. These expenses encompassed R&D costs, including those for design, manufacturing, testing, and improvement, along with various material acquisitions and equipment procurement for manufacturing purposes, labor costs, and more [96]. In contrast, within the Metaverse, the entire process from design to development is conducted within a virtual environment. By capitalizing on the Metaverse's strengths, such as robust socialization, immersive experiences, open content creation, and the use of six technology systems, it becomes possible to enhance the reliability of designed products, shorten R&D cycles, and reduce associated costs.

In the context of car development within the Metaverse scenario, it will be essential to engage multiple stakeholders from the outset. These stakeholders will encompass a diverse group including lead users, ordinary users, extreme users, potential users, users of rival products, automotive suppliers, distributors, industrial designers, UI/UX designers, engineers, and departments handling marketing, R&D, production, and legal affairs. Initially, each participant will immerse themselves in the Metaverse using VR headsets and sensors to establish their virtual identities and avatars. Subsequently, the team will conduct internal discussions within designated virtual spaces, engage in inter-user interactions for communication and learning, and facilitate cross-group exchanges in spaces focused on interactive innovation and communication. This entire process will leverage AI technology to facilitate communication between designers and lead users, while Metaverse big data will be utilized to instantaneously analyze and extract R&D ideas from users, leading to the generation of innovative knowledge and concepts for automotive products. Subsequent to this phase, participants, designers, and engineers will collaborate in real time within a product development design space, focusing on aspects such as body structure, interior layout, and the creation and testing of virtual prototypes. The Metaverse will systematically record data from each design iteration, analyze user preferences, and continually refine the industrial design. The design environment, known as the 'virtual lab', 'virtual workshop', or 'virtual factory', will provide users with the freedom to customize and innovate according to their personal preferences and requirements. Users will engage in activities such as assembling parts and selecting car colors tailored to their individual tastes within this virtual space. Subsequently, all groups will be immersed in a virtual test space utilizing VR equipment and sensors to evaluate the driving experience, seat comfort, and interface friendliness of the new car samples. Emphasizing feedback from key users and designers, adjustments will be made to the designs in real time to create satisfactory test samples. Once each group is satisfied, the new car will transition to the virtual iterative decision-making workspace. Within this virtual market segment, the company will introduce the virtual car for user test driving and purchase, collecting transaction data and analyzing buying behavior to segment the market. Following an evaluation decision-making session involving three groups, approved new car designs will advance to offline trial production and mass production planning, while unsuccessful designs will return to the interactive exchange space for further optimization. Through efficient collaboration and multiple cycles of optimization within the Metaverse interactive innovation model, the automaker will succeed in developing a new model that aligns with market demands.

5. Discussion

Since product development in the Metaverse occurs within a virtual environment and involves spontaneous customer and stakeholder interaction, the process is nearly cost-free. Additionally, thanks to the Metaverse's lack of spatial and temporal limitations and the high efficiency of its virtual platform, the development cycle can be significantly shortened. All user groups can actively participate in real-time design, development, and decision-making evaluations, resulting in products that align more closely with user needs.

Therefore, the Metaverse-enabled interactive innovation for product development and design not only surpasses the constraints of mobile Internet interactive innovation but also offers numerous advantages. Firstly, the Metaverse transcends barriers such as time, space, race, and language, supporting language recognition and accurate communication comprehension among users and systems. Users can express their thoughts through virtual avatars, enabling 24 h real-time activities within the interactive innovation realm of the Metaverse. This fosters anytime interactive communication and innovative ideation, ultimately enhancing development efficiency. Secondly, the Metaverse provides diverse creation platforms and social scenes, enabling profound and equitable interaction across user groups, designer groups, and enterprise departments. Moreover, interactive innovation knowledge can be seamlessly transformed into design knowledge, enabling real-time responses to the ever-changing dynamic customer needs. Thirdly, the Metaverse's interactive technology offers users an immersive virtual reality experience, allowing them to fully and realistically explore products within the virtual space. The product development process is highly flexible, empowering users, designers, and enterprises to make modifications and optimize designs at any time, significantly reducing development costs. Ultimately, through evaluation and decision making, products align better with users' diverse and individualized needs while meeting the production plans of enterprises. This ensures a win–win situation where user requirements are satisfied and enterprise reputation is enhanced.

However, there are some potential risks associated with the implementation of the model such as technology dependency and cost, data security and privacy, user experience, collaboration and communication, innovative knowledge management, system stability and reliability. These risks can manifest in various ways. Firstly, the development and maintenance of the Metaverse platform, as well as the related AI and big data analytics software, require significant investment. Secondly, there are risks of data leakage and misuse of user data, design data, and intellectual property information in the virtual space. Thirdly, discrepancies between the virtual environment experience and real-life usage may occur, leading to virtual test results that do not fully mirror the actual situation. Additionally, diverse backgrounds and expertise within different groups can create communication and collaboration barriers, affecting project progress. The efficient filtering and management of a large volume of user ideas and feedback are crucial to prevent information overload and decision-making challenges. Moreover, a stable network connection is essential for effective virtual collaboration, and network issues can result in work interruptions and data loss.

6. Conclusions and Future Work

User demand emerges as a significant driver in the evolution of product design, playing a crucial role in shaping the direction of new product development. This study seeks to investigate several fundamental research questions: How can the Metaverse leverage to enhance interactive innovation in product development effectively? How can the requirements of diverse user groups in a Metaverse setting more seamlessly incorporate into the product development process?

The interactive innovative product development model seeks to explore user-participatory design, fostering equal interaction amongst users, designers, and enterprises. However, interaction within the mobile Internet context typically exhibits complex attributes such as interactivity, self-organization, non-linearity, and scalability. Furthermore, interactive knowledge is often characterized by its vastness, dynamism, lack of structure, and disorderliness, posing challenges for enterprises in harnessing this innovative knowledge effectively. Additionally, the rapid pace of product turnover and the volatile nature of online public opinion contribute to dynamic customer preferences and opinions. Consequently, there is a need for an approach that can address such evolving demands. Moreover, mobile Internet interactive innovation tends to overlook certain user groups, resulting in products that do not fully align with user needs. The Metaverse, as a next-generation immersive Internet characterized by virtual identity, strong socialization, immersive experiences, and open content creation, offers a systematic technical foundation and comprehensive technological landscape, making it a promising solution for these challenges. Expanding upon this premise, this paper introduces an innovative framework for product development and design based on interactive innovation within the Metaverse. The framework is proposed after an in-depth analysis of product development and design, mobile Internet interactive innovation, and the Metaverse. Drawing on the Metaverse's capabilities, the framework establishes an interactive innovation product development mode encompassing the stages of "*reality* $\rightarrow$ *virtual* $\rightarrow$ *reality*". Leveraging Metaverse scenarios, this approach enables the meaningful participation of users at all levels throughout the product design process. Users engage in equitable interaction with designers and enterprises, collectively making decisions regarding product aesthetics. Moreover, it facilitates the seamless transformation of interactive innovation knowledge into design knowledge and enables real-time responsiveness to dynamically changing customer needs.

Our research makes significant theoretical contributions and holds practical implications. Theoretical contributions include the development of a comprehensive framework t. The framework underscores the vital role of user engagement throughout all product development stages, filling gaps apparent in existing literature on user engagement. Additionally, by catering to the needs of various user groups, including extreme users, this study enhances our grasp of how specific needs impact broader user trends. From a practical standpoint, the proposed framework empowers organizations to address ever-evolving customer needs promptly, thereby reducing product development delays. Furthermore, by facilitating efficient user engagement and knowledge transfer, the framework aids in slashing product development costs. Engaging users in the design process can heighten user satisfaction, foster loyalty, and enhance market acceptance. In essence, this paper introduces a robust framework for integrating the Metaverse into product development, offering valuable theoretical insights and practical solutions to prevailing challenges in interactive innovation.

The exploration of the Metaverse is an ongoing journey that is currently characterized by its youth and limited availability of pertinent research. The Metaverse, a rapidly developing and multifaceted concept, necessitates a more comprehensive analysis of its evolution, theoretical underpinnings, and technological advancements in future studies. In this context, the current study endeavors to propose an initial framework for product development that is specifically focused on interactive innovation within the Metaverse space. While the constraints of space prevent us from delving into the specific intricacies of each element in the virtual domain of "interactive innovation product design and development", it is imperative that subsequent research conducts a thorough and detailed analysis of the specific contents within each aspect, ensuring a deeper understanding of this innovative landscape. Finally, there may also be potential risks associated with the implementation of the model, and how to address these risks is an additional step that needs to be addressed.

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