Government in the metaverse: Requirements and suitability for providing digital public services

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Abstract: *Digital government comprises all means to enable governments to interact with their constituents digitally. The metaverse provides a virtual reality environment where various activities can be carried out without physically visiting the places of interest, including the public authorities. Yet, how governments can use the metaverse is unknown. This paper aims to extend the understanding of the metaverse architecture requirements and their suitability for digital public services provision. We used the systematic literature review, experts' assessment using the Delphi method, and quantitative analysis to attain this goal. Our research contributes to the literature by eliciting the structure and composition of the functional and non-functional requirements. The contributions include (1) identification and classification of 50 functional and 16 non-functional metaverse-related architecture requirements, (2) determination and relevancy of 15 most important functional and 6 non-functional requirements for digital public services provision, and (3) suitability assessment of the 21 services recommended for provision in the EU's metaverse platform with the highest potential to attract users. These findings show that governments pose unique requirements on the metaverse. Not all types of services are suitable for providing in the metaverse. Those focused on empowering citizens and helping them to develop are most important.*

Keywords: metaverse; requirements; architecture; digital public services; digital government; expert assessment

1 Introduction

The applications of Information and Communication Technologies (ICT) and other digital concepts have transformed the delivery of public services (Anthopoulos et al., 2007; Bertot et al., 2016; Lynn et al., 2022). Because citizens continually demand greater openness, efficiency, and responsiveness from public organizations (Lynn et al., 2022; Twizeyimana and Andersson, 2019), governments are expected by their citizens to look for new opportunities and ideas that will result in new innovations in the provision of better, faster, sustainable, and more efficient digital public services (Bertot et al., 2016; Choi et al., 2022; Osborne et al., 2015). The current strategies and plans for initiatives are driven by new technologies such as Artificial Intelligence (AI), Internet of Things (IoT), blockchain, smart cities, 5G, Virtual Reality (VR), Augmented Reality (AR), robotics, and 3D printing (United Nations, 2022). The concept of e-government serves as an umbrella term for these strategies in the public sector (Anthopoulos et al., 2007; Twizeyimana and Andersson, 2019). This concept covers digital processes and resources in the public sector that use ICT to improve the adoption of these technologies in internal operations as well as the delivery of digital public services to citizens and businesses. E-government strategies address how digital innovations are applied to transform digital government (Janowski, 2015).

The latest E-Government Survey 2022 by the United Nations Department of Economic and Social Affairs reports that countries are increasingly shifting public services to VR platforms (United Nations, 2022). However, it is always a challenge to satisfy the needs and expectations of both the governments and citizens towards improving their relationships and finding sufficient resources (Twizeyimana and Andersson, 2019). The use of ICT in e-government and their successful implementation and integration in relevant platforms are affected by numerous factors such as costs, the willingness of governments, expectations of citizens, skills and knowledge of users, ICT penetration, Internet users, broadband availability and speed etc. (Lemke et al., 2020; Lynn et al., 2022; Twizeyimana and Andersson, 2019). All these prerequisites have reached such levels in some countries (United Nations, 2022) that it is possible to consider a large-scale use of new approaches such as metaverse. The government often poses unique requirements on the use of technologies, like the ability to enable access for all (inclusion), transparency, and accountability.

The *metaverse* seems to be a promising digital concept that can enhance the interactions between citizens and public organizations (Ning et al., 2021; Park and Kim, 2022; Wang et al., 2023; Xu et al., 2023). By 2026, 25% of individuals, according to technology research and consulting firm Gartner, will spend at least an hour each day in the metaverse (Rimol, 2022). The metaverse can be viewed as a network of 3D, interconnected virtual worlds focused on socializing, learning, exploring the content etc. (Park and Kim, 2022). The emergence of metaverse into broader public use is enabled by improvements in infrastructure networks, hardware capacity and performance, computational efficiency, content availability, and the priority focus of scientific and governmental institutions (Dionisio et al., 2013; Park and Kim, 2022; Xu et al., 2023). Investments in the metaverse are influencing future public services and the use of ICT because of how important social media are for Internet users, particularly for Generation Z (Narin, 2021; Park and Kim, 2022). Several governments have announced their interest in extending their e-government and smart cities concepts by the metaverse services such as Korean Metaverse, Metaverse Seoul, or Barbados Metaverse Embassy (Choi et al., 2022; Wang et al., 2021; Xu et al., 2023).

According to Jung and Jeon (2022), the research on the metaverse has evolved through the years from the conceptual approach to the ecosystem approach that requires considering different requirements, components, and their relationships. Bertot et al. (2016) highlight the need for novel government skills to offer innovative digital public services. In the context of metaverse services, these issues were explored by Dionisio et al. (2013) as an architectural direction for a scalable metaverse. Duan et al. (2021) then emphasized that the metaverse's requirements on the architecture should cross from the physical world to the virtual world. According to Giang Barrera and Shah (2023) and Hollensen et al. (2023), the metaverse architecture emerges from the convergence of multiple technological building blocks. Components affecting the practical application of the metaverse were identified by Jung and Jeon (2022). Wang et al. (2021) focused on the requirements resulting from the challenges and standardization of the metaverse and developed a system architecture and framework. However, often the unique characteristics of government are not considered. While work on the concepts of representing e-government in the metaverse is slowly becoming a distinct academic field, there has been little focus in the research literature on developing a proper classification of metaverse-related requirements and examining its applicability to digital government service delivery.

To address this gap, the overall study's *objective* is to provide a deeper understanding of metaverse-related architecture requirements and which types of digital public services can be provided in the metaverse. A *digital public service* typically pertains to public services delivered via a digital platform (Madsen and Kræmmergaard, 2015), utilizing internet technologies (Jansen and Ølnes, 2016; Lindgren and Jansson, 2013). We will focus on both functional and non-functional requirements. A *functional* requirement can be defined as a system component carrying out a part of the system task (International Organization for Standardization, 2022). A *non-functional* requirement defines how the system should behave and operate in conjunction with users (International Organization for Standardization, 2022). An *architecture* describes the conceptual level of a system in relationship to other systems The *metaverse platform* in our study is viewed as an environment for digital public service provision. We adopted a three-fold approach toward investigating the metaverse-related architecture requirements and their suitability for the provision of digital public services, including the Systematic Literature Review (SLR), expert assessment using the Delphi method, and quantitative analysis methods. We chose the European Union's (EU) e-government system as an environment in which we evaluate the provisioning of digital public service in the metaverse.

The findings extend the theoretical grounding of the metaverse in the context of its relevance for digital public services provisioning in the EU's environment. We also contribute to the current theoretical body of literature in the field of information systems, information technology, and requirements, summarizing, structuring, and conceptualizing current research in the area of the government in the metaverse. This study reflects the composition and classification of the functional and non-functional requirements that must be met and considered when providing services to the metaverse in the e-government system. The practical contributions for key stakeholders, i.e., governments and policymakers, are the most important functional and non-functional requirements in the metaverse architecture for the defined environment and digital public services with the highest potential to attract users were recommended to be provisioned in the EU's metaverse platform. Our findings are important for a better understanding of *requirements* that should be met and which should be considered by public officials while providing the metaverse services. The developed *classification* provides valuable guidance on how to categorize and organize requirements. The insights that emerged from experts' assessment represent the recommendation for *developing* metaverse architecture and provisioning of *digital public services* in the metaverse by governments.

The structure of this paper is as follows. Section 2 provides a research background on basic terms and research of the metaverse in the public sector. The research methodology adopted in this study is presented in Section 3. The results and findings are presented in Section 4 and discussed in Section 5 together with implications. We provide concluding remarks in Section 6.

2 Research background

2.1 Metaverse: Basis terms and previous research

The metaverse is often characterized as an embodiment of the Internet and is expected to contribute towards developing novel ecosystems of service provisions (Lee et al., 2021; Xu et al., 2023). Fundamentally, it involves a computational interpretation of human users' cognition, emotion, and motivation, simplifying daily life's experience into logical and procedural rules (Bibri and Allam, 2022a; Bibri and Allam, 2022b). Metaverse is based on interactions of users with virtual environments in which they can engage in different activities (Ilyina et al., 2022) with the help of VR and AR services (Damar, 2021); provides novel models of engagement, participation, and creation through the communities established and the virtual goods offered (Giang Barrera and Shah, 2023); and offers users a unique experience of presence and immersion in a space that may be challenging to access (Choi et al., 2022). Scientific and practical interest in the metaverse first appeared in 2008 and peaked in 2010 due to the conceptualization of the connection between the metaverse and the first decentralized blockchain (Abbate et al., 2022; Damar, 2021). In 2020-2021, the metaverse again became a hot trend and attracted huge attention and discussion in academia and industry (Wang et al., 2023). Among the main areas of research in the field of the metaverse are (i) the identification of the components of the metaverse; (ii) the description of practical application opportunities; and (iii) the identification of real and potential challenges and limitations.

Identification of the components of the metaverse. The metaverse research framework and its components are presented from the perspective of state-of-the-art technologies and the metaverse ecosystem and the stages of its development are defined in the works (Jung and Jeon, 2022; Lee et al. 2021). Representative applications in infrastructure, interaction, and ecosystem were presented by Duan et al. (2021), along with a three-layer metaverse architecture that includes a concise timeline for the development of the metaverse. Further, Zarantonello and Schmitt (2023) introduced a framework that conceptualizes and explores how the technologies of the metaverse shape and influence the consumer and service experience at different stages of the consumer journey. Zhao et al. (2022) put forth a framework outlining how graphics, interaction, and visualization methods support the creation of the metaverse's visuals and user-centric exploration. Three categories of visual components that constitute the metaverse were presented along with two graphical approaches for constructing a pipeline; a taxonomy of interaction technologies founded on user actions, interaction tasks, feedback, and multiple sensory channels; and a taxonomy of visualization techniques that facilitate user awareness.

Extending the metaverse concept, Huynh-The et al. (2023) explore current AI-based approaches in AI-powered approaches in six technical aspects, which show great potential for the metaverse platform, including natural language processing, machine vision, blockchain, networking, digital twin, and neural interface. In the context of AI applications, Wang et al. (2023) and Fernandez and Hui (2022) provided a comprehensive overview of the foundations, security and privacy, ethics, and governance of the metaverse, specifically exploring the new distributed metaverse architecture and its key characteristics when interacting with the trinity of the world. Di Pietro and Cresci (2021) work examined the fundamental aspects of the metaverse, followed by an exploration of the new privacy and security challenges that have emerged because of this innovative paradigm. Additionally, they expanded the scope of their study by elucidating the far-reaching but logical implications of the metaverse on various domains.

Practical application opportunities. As noted by Dwivedi et al. (2022), the metaverse can augment the real world with tasks that are difficult to accomplish in reality, for example due to their cost (such as creating virtual offices, face-to-face classes, simulations); or because of the complexity of their technical implementation (for example, to simulate various complex technical processes in the aircraft industry, or investigation of remote areas). Many politicians and institutions are beginning to understand the importance of the metaverse and other virtual spaces in the lives of their constituents and do not want to miss this new opportunity to expand their electoral results (Ricoy-Casas, 2023). has the potential to offer novel possibilities for healthcare by tackling the issues of hospital overcrowding and critical staff shortages. The metaverse environment has the potential to alleviate psychological issues such as depression, anxiety, and cognitive impairments, as well as conditions like dementia, schizophrenia, and autism (Sun et al., 2022; Usmani et al., 2022); and can foster positive social interactions between users and facilitate the development of social skills through co-learning (Oh et al., 2023). It becomes possible to build a sufficient technical infrastructure that will support the management of energy resources and equipment products (Narin, 2021; Ning et al., 2021). In this context, it may be necessary to implement policy measures at the government level to train and guide traditional manufacturing companies to adopt new technological advancements for their survival and continuity (Dwivedi et al., 2022). Simulating social phenomena, ethical dilemmas, and political matters without bias or social discrimination is another potential benefit of utilizing the metaverse (Dwivedi et al., 2022; Hilken et al., 2022).

Challenges and limitations. Several real and potential challenges and limitations come from the first results of the application of the metaverse in the public sector. *Digital exclusion* of certain parts of society that lack the technology or skill set to participate, including the elderly, disabled and low-income groups (Schmitt, 2022; Tatavarti, 2022; Zallio and Clarkson, 2022). Over-reliance on the metaverse and creating a parallel reality instead of solidity, inclusion, and cooperation can lead to *division* and *discontent* in the population (Schmitt, 2022). It became obvious that "*in the absence of any government services designed to engage all households, the technology access gap will continue to widen and widen the social disparity of the metaverse's engagement*" (Anderson and Rainie, 2022).

Personal *security*, *safety*, and *privacy* challenges (Falchuk et al., 2018) that can be broadly categorized as risks to (i) informational privacy (refers to the protection against access by third parties to all types of information about a person such as his/her thoughts, statements, correspondence, financial, medical and educational records); (ii) risks to physical privacy (refers to a sort of refuge from third party sensory access to the body and actions of the individual); and (iii) risks to associational privacy (refers to individual control over the exclusion and inclusion of third parties in certain specific events) (Nalbant and Aydin, 2023; O'Brolcháin et al., 2016; Sun et al., 2022). Although South Korea is the only government that issued the ethical guidelines for the metaverse (Park, 2022), it did not have jurisdiction to make rules for the metaverse (Bojic, 2022).

Autonomy challenges can be described by three components: (i) Filter bubbles or cyberbalkanization can pose a threat to the *knowledge condition* of autonomy by regulating individuals' understanding and interpretation of the world, and manipulating their viewpoints through the presentation of information based on algorithmic analyses of their interests; (ii) challenges to *freedom* comes from arising the potential addiction (losing touch with external reality, developing bad social or behavioral habits, mental health issues) and from governments using information gathered from these technologies to restrict freedom; (iii) challenges of *authenticity* or being one's own person may come from increased pressure from the inner circle or the government, leading people away from real life (Dwivedi et al., 2022; O'Brolcháin et al., 2016; Rosenberg, 2022).

Unfairness is a critical challenge regarding the guidelines and principles that will be applied in the metaverse for behavioral profiling and social sorting of users in the virtual world. This is primarily due to the fundamental vision of the metaverse based on algorithmic methods and strategies of engagement in a constantly observed urban society. In this regard, the metaverse should consider algorithmic fairness as a core value of its projects and support procedural fairness to perform governance roles (Lee et al., 2021; Woodruff et al., 2018). *Abusive* and *objectionable* behavior, including user harassment, sexualization of avatar interactions, data use, and unregulated gambling (Dwivedi et al., 2022; Jamison and Glavish, 2022) can also be a challenge for the metaverse.

Challenges related to *laws, regulations, and protections* of intellectual property of metaverse's users (Mourtzis et al., 2022). The financial obstacle is rooted in the complications that arise from utilizing cryptocurrencies within the metaverse, which already has an unregulated payment system. A potential solution to this issue is implementing a central bank digital currency (Mourtzis et al., 2022). The establishment of a *standard* for the metaverse that involves creating guidelines that cover all processes, protocols, hardware, and software, with a focus on incorporating interoperability as a critical element in the design and execution of the metaverse, should be considered (Mourtzis et al., 2022; Wang et al., 2021).

2.2 Research of a metaverse in the public sector

Governments use virtual-world environments to connect with citizens through novel means, foster internal collaboration, facilitate training and simulations, attract personnel, and promote economic growth (Eom, 2022; Wyld, 2008). Most of the applications in the public sector setting are focused on tourism destinations, telemedicine, social service centers, city halls, virtual embassies and consulates etc. (Wiederhold and Riva, 2022; Xu et al., 2023). The metaverse perspective for governments also applies to address pressing urban issues such as urban planning (such as modelling development proposals), the use of accessible urban spaces (such as participation in social and musical events), creating new job opportunities, and education. In addition, the implementation of metaverse blockchain has the potential to enhance the effectiveness and transparency of public notary services, document certification and authentication, as well as public administration registry management (Scutella et al., 2022). Thus, Dubai and Switzerland have used blockchain to create digital passports compatible with smart doors and scanners (D'Cunha, 2017). It is also expected that in the future, city authorities will be able to manage without the need for a physical presence, such activities as face registration and identity verification on virtual platforms, and the metaverse will make the whole process authentic (Allam et al., 2022).

The metaverse can present local governments with possibilities (i) to improve interactions with citizens by offering prompt, efficient, and real-time services, as well as improved management of assets like urban spaces, (ii) for new revenue streams (implementing complex and capital-intensive projects), and (iii) to restructure existing urban planning models (to cover human and social aspects) (Allam et al., 2022). The widespread introduction of new networked digital technologies, numerous applications for smartphones and social networks, the sharing economy, and data-driven e-government platforms underlie the desire to develop and update the metaverse through platformization. This entails the integration of digital platforms' infrastructures, economic processes, and government structures into different areas of the economy and aspects of life and involves the restructuring of cultural practices and concepts related to these platforms (Bibri and Allam, 2022b; Poell et al., 2019). The Korean government has established its own e-government framework and operating environment (Choi et al., 2022). Seoul, South Korea, proposes adopting the metaverse concept for using some public services and cultural products in the digital environment (Squires, 2021). With the help of VR headsets or AR glasses, Seoul residents can file civil complaints, and virtually tour some of the city's assets, such as virtual social halls, museums, and parks (Allam et al., 2022; Gaubert, 2021). For Korean government agencies to utilize the metaverse, it is crucial that it is set up and maintained within a specialized cloud environment, utilizing the e-government framework (Choi et al., 2022; Um et al., 2022).

The value of the metaverse in tourism for the government lies in the fact that it offers opportunities to improve the efficiency of public services and reduce costs in terms of smart tourism and economic society (Chen et al., 2023; Um et al., 2022; Wei, 2022). In Switzerland, to address the fragmentation of the tourism sector, the creation of a national public blockchain platform is recommended based on the results of interviews with professionals (Fragnière et al., 2022). Implementing a public transportation system into the metaverse is becoming increasingly possible (Deveci et al., 2023). By incorporating the metaverse into everyday activities such as public transportation, it becomes possible to gather data about the starting and ending points of journeys using virtual representations of people known as avatars. By including transportation options within the metaverse, advantages such as reducing traffic demand and minimizing negative effects on road networks, improving public transportation safety and operation, and enhancing traffic flow can be achieved (Pamucar et al., 2022). Huynh-The et al. (2023) noted that creating a metaverse ecosystem that includes administrative services like environment, education, transportation, culture, and other civil services is a crucial and difficult undertaking for the metropolitan government. The utilization of AI technologies to analyze big data from various authenticated sources within the boundaries of agreed rules of use, ethics, and security can enhance and deliver numerous government services in the metaverse, ensuring a secure environment (Zhang et al., 2023). However, the metaverse development also may be constrained by significant economic and political barriers, i.e., government-controlled worlds (Dionisio et al., 2013). Establishing regulatory foundations, governance models, and processes that mitigate all mentioned in the previous subsection's metaverse challenges and limitations is not an easy task (Rosenberg, 2023).

3 Research methodology

This section consists of the following: Section 3.1 presents Research Questions (RQs) and provides the research framework. Section 3.2 describes the strategy of the SLR. Section 3.3 introduces the process of the assessment of the metaverse-related architecture requirements and digital public services.

3.1 Research design

Our research study seeks to provide a deeper understanding of metaverse-related architecture functional and non-functional requirements and which types of digital public services can be provided in the metaverse. To this end, we formulated three RQs to guide this study:

RQ1: *What metaverse architecture functional and non-functional requirements can be found in the literature? And how can they be classified*?

RQ2: *What are the most important functional and non-functional requirements for a metaverse architecture in terms of relevance for digital public services provisioning in the EU's environment*?

RQ3: *What digital public services have the most potential to attract users and thus should be provisioned in the EU's metaverse platform among the first ones*?

This study considers the metaverse as the e-government sub-system including its components and relationships that influence the provision of digital public services. The e-government system can be defined on the city, regional, national, supranational, or international level. The components comprising the e-government system and their relationships were derived from Lnenicka et al. (2022) and adapted for the objective of this study. We distinguish between functional requirements, which are components of the system that perform specific tasks, and non-functional requirements, which dictate how the system should interact with users. Our research focuses on the metaverse platform within the EU's e-government system, emphasizing its role in delivering digital public services. The research framework presented in Figure 1 aims to enhance our comprehension of the metaverse and its constituent elements within the context of relationships in the e-government system.

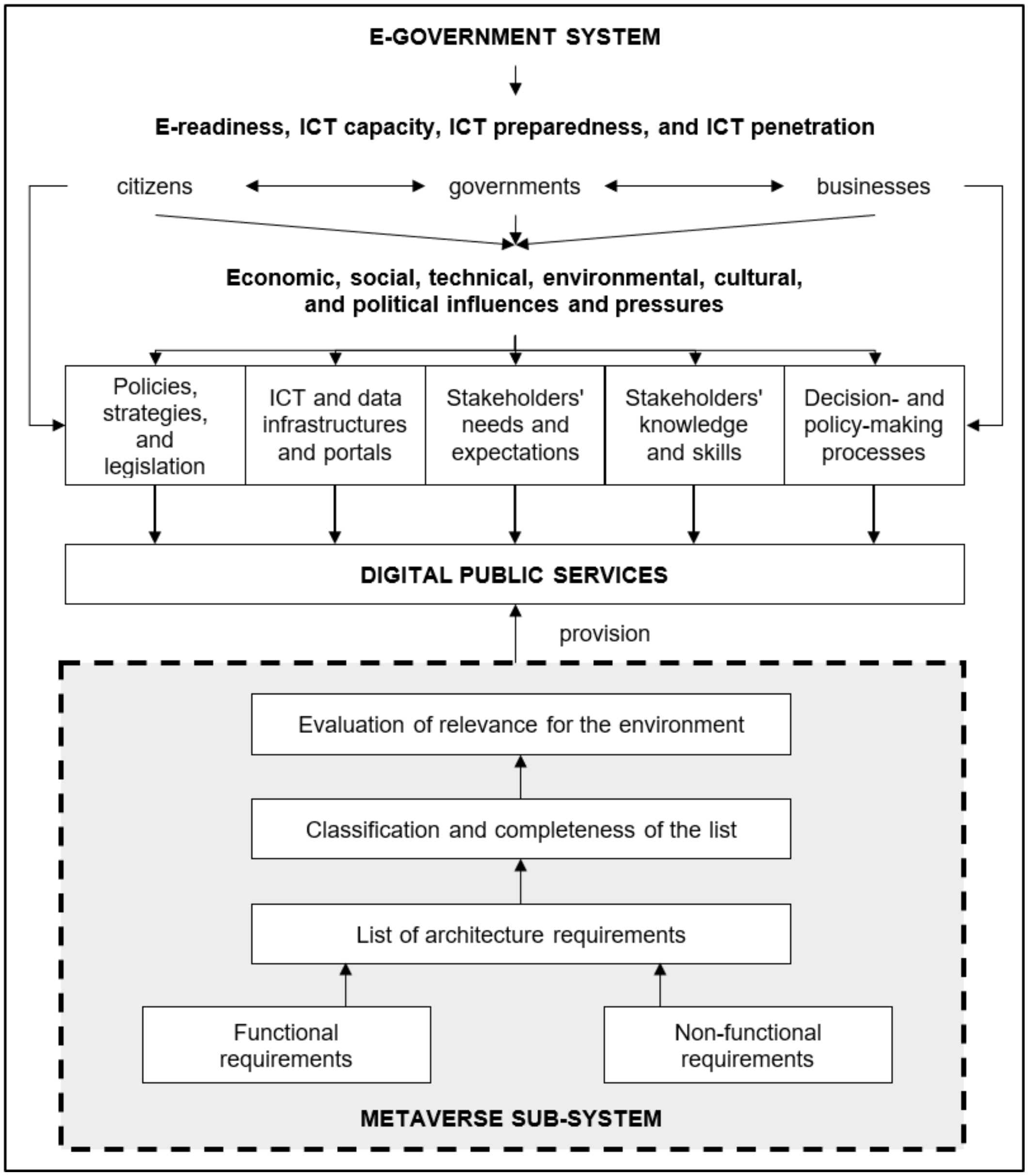

Figure 1. The research framework (source: own elaboration)

Method-wise, a three-fold triangulation approach was used in this study. First, the *SLR* included studies collection and selection, content analysis, and systematic synthesis to identify relevant requirements, classify them to develop the metaverse architecture and assess their relevant contribution to providing digital public services in the e-government system (RQ1). Second, to assess the metaverse-related architecture requirements and digital public services, the *experts' assessment* using the Delphi method was applied (RQ2 and RQ3). As the method of inquiry, we chose an online expert questionnaire to collect data directly from ten experts, involved in several research and consulting projects on information systems, software engineering, and data management in digital transformation and e-government. Third, we used *quantitative analysis* to process and summarize the results received by both the SLR and experts' assessment approaches.

3.2 Systematic literature review

Figure 2 gives an overview of the research stages. In the *1. Stage* of our methodology, we followed the SLR approach proposed by Webster and Watson (2002) and Brous et al. (2020) to methodologically analyze and synthesize relevant literature and to answer RQ1. The goal of the SLR is the analysis of the concept and applications of the metaverse to identify relevant requirements and classify them to develop the metaverse architecture. In the process of the SLR, three main steps were conducted.

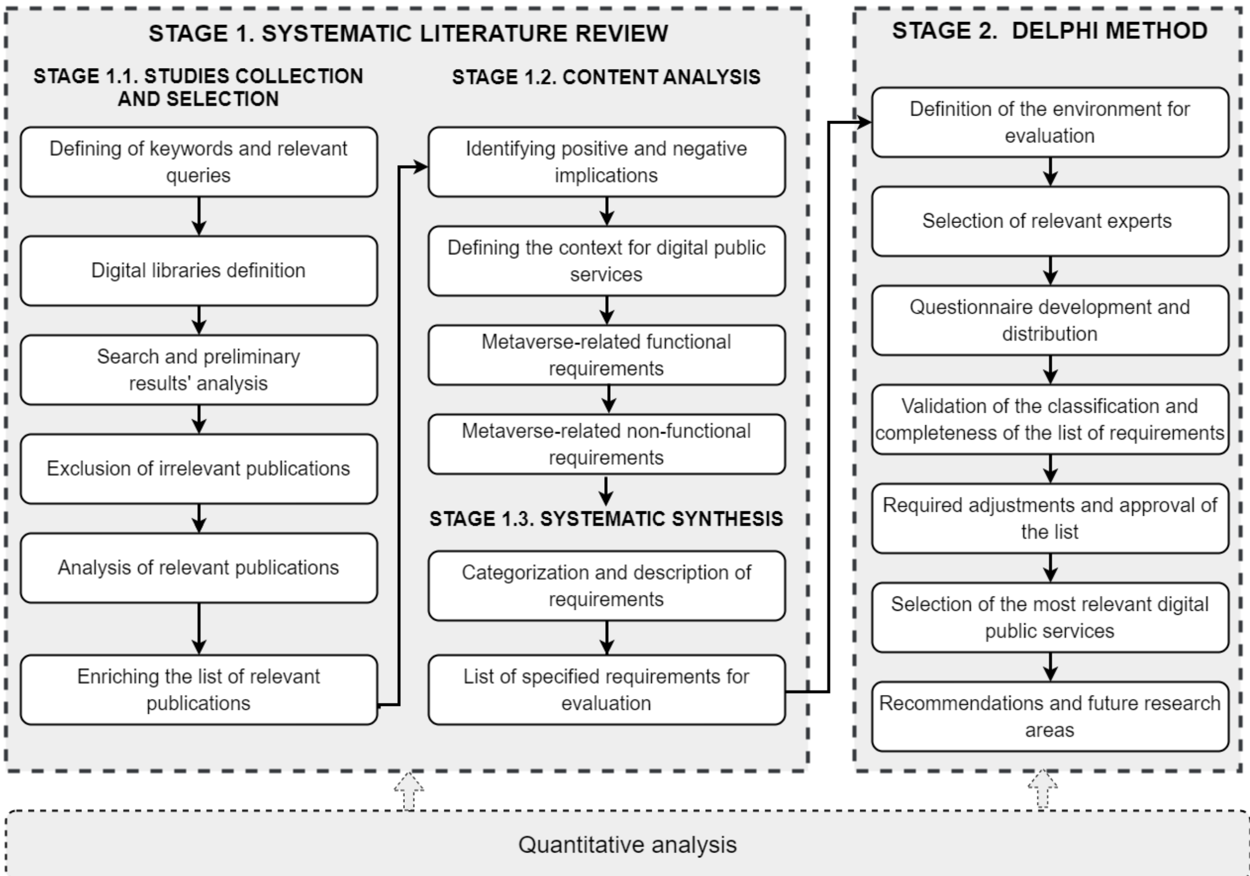

Figure 2. Overview of steps of the research methodology (source: own elaboration)

In *Stage 1.1,* the systematic literature search and collection were performed to build the final dataset for further analysis. For this, three sets of complex search queries of criteria were used to build the database of extant literature. The first set of keywords characterizes selected terms and definitions of digital public services in the metaverse context, such as *metaverse AND e-government / electronic government / e-governance / electronic governance / public sector / public administration / public services / digital public services / online services*. The second set of keywords characterizes the implications of the metaverse for the public sector, namely: *metaverse AND positive sentiment keywords = benefit(s) OR advantage(s) OR contribution(s) OR opportunitie(s), metaverse AND negative sentiment keywords = issue(s) OR risk(s) OR barrier(s) OR problem(s) OR obstacle(s) OR challenge(s)*. Finally, to determine concrete requirements and to be able to set them up for the digital public services and e-government context, we used the following query: *metaverse AND architecture OR framework OR requirement OR characteristic OR component.* When collecting input publications, the search was carried out in (1) digital libraries: ACM Digital Library, ScienceDirect, Web of Science, IEEE Explore, and Scopus, and (2) grey literature, such as non-academic surveys, government reports, news, article summaries, discussions. We considered the publications with title, abstract, and keywords in English. A total of 2187 articles and proceedings/chapters were collected. The summaries of the search results are presented in Appendix 1.

Then, for study selection, based on defined inclusion and exclusion criteria (see Appendix 2), we first removed duplicates and non-English studies. As a result, 902 articles were excluded. Then we identified eligible publications through a screening process involving the evaluation of their titles and abstracts, where we evaluated both their relevance and quality of the study. For this, relevance and quality assessment criteria were developed (see Appendix 2) (Bassey et al., 2022; Zuiderwijk et al., 2021). Three independent experts, i.e., academics with experience in participating in research and consulting projects on digital transformation and e-government, were involved in the evaluation process. At least two experts independently examined every title and abstract to comply with the inclusion and exclusion criteria. Minor differences of opinion were discussed and resolved in a meeting during which an agreement and significant inter-coder reliability were reached. Finally, 157 full-text publications were included in the eligibility assessment step. In the analysis of their full texts, we simultaneously detected forward and back citations to enhance search results (Webster and Watson, 2002). As a result of second-round evaluations conducted by independent experts, which assessed the selected full-text publications' quality and relevance, 21 publications were included in the quantitative synthesis. Then, grey literature was added to the list of publications to understand global trends. Finally, we arrived at a sample of 27 full-text publications' sources.

In *Stage 1.2* the systematic content analysis of the final full-text publications' dataset was conducted (i) to identify the positive and negative implications of the metaverse for the public sector and its digital public services and e-government context and (ii) to extract and collect the metaverse-related functional and non-functional requirements. In *Stage 1.3* Thereafter, the systematic synthesis was performed to classify the results obtained in the previous stage into the architecture requirements of the metaverse for digital public services provisioning. The results of the systematic content analysis and systematic synthesis are presented in the metaverse-related architecture requirements and classification section.

3.3 Evaluation process of the metaverse-related architecture requirements and digital public services

Stage 2 of our methodology aims to perform the *experts' assessment* of metaverse-related architecture requirements and digital public service using the *Delphi method* and includes (i) a definition of the environment, (ii) selection of relevant experts to build the expert panel, (iii) questionnaire development, (iv) application of the Delphi method, and (v) quantitative analysis to process and summarize the results.

3.3.1 The study's environment and resources

The EU was chosen as the environment in which we assessed the provision of digital public services. This choice was justified by the availability of many official government documents and reports related to the implementation of ICT in digital public services and e-government, which enable us to describe the metaverse-related environment, considering the comprehensive strategy and experience of the most mature EU countries. The main source is a series of e-government benchmark reports (European Commission, 2022). Other resources, such as Europe's digital decade or European data strategy, also support our efforts to explore the topic of digital public services provisioning in the metaverse.

The *environment* of our study is determined by the EU's priorities and policies on digital society and advanced digital technologies (European Commission, 2021) and by the document prepared by Madiega et al. (2022) for the Members and staff of the European Parliament. It emphasizes new challenges that the VR environment poses and calls for setting up the conditions that will enable the EU to benefit from the opportunities the metaverse provides. We expect that the EU will be an owner of the metaverse platform, which is expected to be a sub-system of the e-government system and should provide digital public services for the Member States.

To select the most relevant *digital public services* that could be provisioned in the EU's metaverse platform, among the first we used the list of digital public services for citizens and businesses that are defined and measured regularly by the EU in the e-government benchmark reports. There are seven categories of services for citizens and two categories of services for businesses (European Commission, 2022).

3.3.2 Experts' selection

The choice of environment also determined the methodology for building an *expert panel* for the assessment of the metaverse-related architecture requirements and digital public services from carefully selected experts representing the EU countries. The experts first validated the classification of requirements, i.e., to what extent they agree with the classification and completeness of functional requirements and non-functional requirements. Second, after the required adjustments, the experts approved the list of requirements. Finally, the experts were asked to select the most relevant digital public services that should be provisioned in the defined environment.

Experts' qualifications are summarized in Appendix 3, including a country, job position, years of experience, and professional expertise. We used purposive sampling to recruit two key groups of EU countries' experts: (1) government employees and consultants (20%) and (2) academics and researchers involved in a range of research projects on digital transformation and e-government (80%). The choice of these groups was driven by the desire to maximize the coverage of the knowledge and practical experience of (i) the context of the study (digital transformation, e-government, digital public service provision), (ii) the subject (metaverse), and (iii) the specific object of the research (metaverse-related architecture requirements). The collection of data was carried out between December 2022 and March 2023. Each expert consented to take part in each round of the Delphi process and confirmed familiarity with the research problem proposed for the assessment and the steps in the Delphi method. Motivation of experts together with clear and concise instructions, ensure that the dropout rate of experts will be low and findings will be representative (Grisham, 2009; Okoli and Pawlowski, 2004). The external validity of the results is established by ensuring that the process is reliable, consistent, and transparent and that it fulfills the quality requirements derived from prior applications of the Delphi method (Grisham, 2009).

3.3.3 Questionnaire development

We opted for an online expert questionnaire as our chosen method of inquiry to gather data directly from ten experts selected for our expert panel. The questionnaire developed for this study consisted of two main sections: (1) *introductory* section, including a definition of the metaverse, definition of the environment, examples of the provision of digital public services, and aims and instructions, and (2) *evaluation* section, offering experts to directly (i) assess the importance of the functional and non-functional requirements that the metaverse platform should meet and how the system should behave and operate in conjunction with users and (ii) select digital services that have the most potential to attract users and thus should be provisioned in the EU's metaverse platform among the first ones.

In the *introductory* section, the metaverse was presented as a novel concept worth investigating in terms of public services provision under the digital transformation process. As an example of the application of the metaverse into the public service provision, we suggested imagining the *business creation service/process*. More specifically, for businesses needing onsite checks from different public authorities. Transferring the auditors to the actual place remotely provides the opportunity to make calculations of the building and the necessary equipment as well as to check the validity of building plans meeting necessary conditions as well as the necessary documents. This may be applied to doctor offices, restaurants, classrooms etc. or even to the provision of the building permit service. This will embed VR and AR to maximize user experience in terms of understanding. Non-Fungible Token (NFT) technologies potentially ensure authentication and security of operations towards the realization of the services into the metaverse environment (meta-worlds). We also suggested the concepts regarding how the *building permit* could look in the metaverse. There will be 3D modeling visualizations (understanding the design) as well as connections to the real-world area for checking (spatial representation of the building and the area). All necessary public organizations will have access to this environment with specific rights to check, approve, or reject. The designs will bring the NFTs of the designer and manufacturer, ensuring authentication and security of operations, so nothing will be reused wrongly in the process with the right to check and revoke any false use of the NFT. The outcome would be the improvement of the process efficiency. Finally, creating the EU's metaverse environment to support such a service (building permit) will reform the real estate sector.

The evaluation section distributed the questionnaire, including instructions, questions, and response scales, to all experts. First, for the lists of 50 functional (presented in three categories) and 16 non-functional requirements, the experts were asked about the importance of each requirement for the metaverse platform, determined as an environment for a digital public service provision in the EU's e-government system. A four-point Likert scale (high, moderate, low, none) was applied for this purpose. Second, for each list of functional and non-functional requirements, the experts were then asked to what extent they agreed with the classification of requirements. We were able to include both degrees of (dis)agreement – strong, usual, and indifferent view – by using a six-point Likert measure. Third, we provided two open questions for each list of requirements, i.e., (1) would you remove any category or item(s) in the list of requirements and (2) do you see any missing requirements? Fourth, the questionnaire proposed the list of 93 digital public services presented in 7 categories (see Appendix 4) and the experts were asked to select the services that have the most potential to attract users and thus should be provisioned in the EU's metaverse platform among the first ones. A four-point Likert scale (high, moderate, low, none) was applied for this purpose. At the end of the questionnaire, ideas, and opinions of experts about their recommendations, further steps, and future research areas were collected. To process and summarize the results, received from the expert panel, the statistical analysis was performed. The Cronbach's alpha coefficient was presented as an indicator to assess the reliability of the results for the questionnaire used in the study. The results of this stage are provided in the section dealing with experts' assessment results.

4 Results

4.1 The metaverse architecture requirements and classification

Metaverse architecture requires that the system's significant requirements be first obtained from stakeholders with respective expertise viewing requirements from different perspectives based on the boundaries of the environment in which the architecture is considered (Beinke et al., 2019). The classification then serves as a basis for the evaluation of these requirements.

In our study, to answer RQ1: *What metaverse architecture functional and non-functional requirements can be found in related literature? And how can they be classified?*, the metaverse architecture is formed by the sets of functional and non-functional requirements that resulted from the SLR focused on the applications and implications of the metaverse and related architectures for digital public services. We identified three main categories of *functional* requirements (hardware and resources, software and technologies, and content and data), including 50 *functional* requirements and 16 *non-functional* requirements. At the same time, the *hardware and resources* functional category is represented by 15 specific requirements grouped into three subcategories – (1) data infrastructures (4 requirements); (2) networks and communication (5 requirements), and (3) physical devices, sensors, and controllers (6 requirements); the *software and technologies* category is represented by 23 specific requirements grouped into three subcategories – (1) technologies and concepts (10 requirements); (2) recognition, rendering, and modeling environments (8 requirements), and (3) management, maintenance and service (5 requirements); *content and data* category is represented by 12 specific requirements grouped into two subcategories – (1) content management (6 requirements) and (2) user interactions' data (6 requirements). A *complete initial list of* collected and preliminary classified requirements with their description and references is presented in Appendix 5.

According to Park and Kim (2022), the progress of metaverse requirements through the years is associated with the growing proportion of social activities and content. Thus, it is expected that content and data is the category that will grow the most. Moreover, Giang Barrera and Shah (2023) highlighted the importance of considering technological blocks, i.e., the technologies and concepts category provides key concepts to interrelate them.

4.2 Experts' assessment results

The results of the experts' assessment of the collected and preliminary classified metaverse-related architecture requirements (see Appendix 5) and digital public services (see Appendix 4) were processed and analyzed in two rounds. In the first round, the results of the experts' evaluation of the degree of importance of each requirement that the metaverse platform should meet to provide digital public service were analyzed. All answers, given on a four-point ordinal Likert scale, were transformed into scores as follows: rank 3 indicates "High importance", rank 2 – "Moderate importance", rank 1 – "Low importance", and rank 0 – "None importance". To check the significance of our results, the following statistics for the experts' assessment sample were analyzed. The experts agreed on the classification as it was done at the level of synthesis of the SLR results. Through the provision of their assessments, they allowed us to identify the most important functional and non-functional requirements as well as to revise the list of requirements, dropping some of them as non-important ones. They did not provide any further comments on the classification of the requirements.

For the identified *non-functional requirements*, (1) the Average Normalized Standard Deviation (ANSD) for the entire sample is 0.24; (2) the range of ANSD for each of the requirements is [0.10; 0.49]; and (3) the Cronbach alpha reliability coefficient is 0.73 (acceptable internal consistency). These statistics confirmed the reliability of the results and validity of the survey instrument for non-functional requirements. So, the list of non-functional requirements stays as it was created from the SLR. For *functional requirements* (1) the ANSD for the entire sample is 0.32; (2) the range of ANSD for each of the requirements is [0.10; 0.84]; and (3) the Cronbach alpha reliability coefficient is 0.55 (poor internal consistency). These statistics did not confirm the reliability of the results and validity of the survey instrument for functional requirements. In this regard, we planned to provide for the second round of the experts' assessment applying the selection criteria for the functional requirements included in the questionnaire.

In the second round, given the poor level of Cronbach alpha reliability among experts regarding the level of importance of functional requirements, we conducted the second round of the assessment, in which only that met the agreed selection criteria were presented: (1) the mean and median values of the requirements importance scores should be above the average scores for those indicators for the entire sample and (2) the ANSD values should be below the average score for the entire sample (the full descriptive statistics are presented in Appendix 6). As a result, after the required adjustments, the experts approved the list of 15 most important functional requirements in the metaverse architecture in terms of relevance for digital public services provisioning in the EU's environment. This round also raised the level of Cronbach's alpha reliability coefficient to 0.76 (acceptable internal consistency). So, we revised the final list of functional requirements, which were subsequently employed in the subsequent data analysis steps, as presented in Table 1.

4.3 Essential requirements

To answer RQ2: *What are the most important functional and non-functional requirements for a metaverse architecture in terms of relevance for digital public services provisioning in the EU's environment?,* the top-5 most important functional requirements are identified as follows: (1) computation, including loud-edge-end computing paradigm, efficient AR/VR cloud-edge-end rendering, scalable AI model training, quantum computing; (2) digital twin and 3D modeling technologies; (3) Web and other related standards and tools; (4) scene and object recognition and understanding tools; and (5) scene and object generation tools – 3D reconstruction. The most important category is software and technologies (mean=2.75) (see Figure 3). The most representative functional requirements category is hardware and resources, which includes three sub-categories of functional requirements. At the same time, the average importance of this category (mean=2.63) is somewhat inferior to the category content and data (mean=2.65). These results are connected to the already provided and envisaged services that could be built or meant to be developed in the metaverse as presented in the research background section as well as in the scenarios of the questionnaire of the current study.

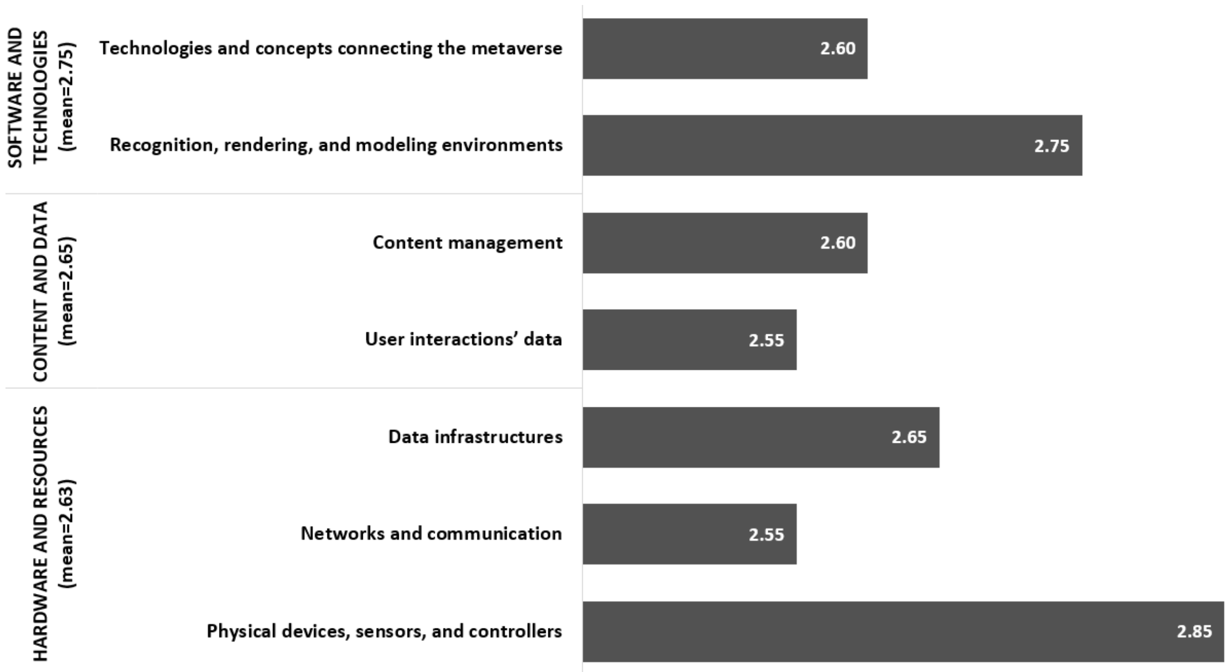

Figure 3. The average importance of functional requirements categories in the metaverse architecture

The most important non-functional requirements have been identified according to the selection criteria introduced in the previous section (the full descriptive statistics are presented in Appendix 7). As a result, the top-6 most important non-functional requirements are presented as follows (Table 1): (1) accessibility to digital public services without restrictions, convert public events to virtual worlds, support of digital literacy and education to reduce; (2) consistency of data and information, transmission, processing, storage though the metaverse, between the physical and digital worlds; (3) privacy to ensure the prevention of privacy leakage, threats to customized privacy, threats to digital footprints, and cluster users into social groups for trustworthiness characterization, data ownership and integrity; (4) security and cybersecurity to ensure safety in the physical vs. the digital world, and employ security standard; (5) policy and governance to ensure that the legal framework must be in place, consider legal aspects, meet general standards of governance, new laws and regulations for virtual crimes; and (6) quality of service to ensure measuring of factors (human, system, or context) that may affect the user experience, network- and application-level metrics. Moreover, the first four requirements showed the same high importance scores (mean=2.90) and experts' opinion consistency (ANSD=0.10).

Table 1. The most important functional and non-functional requirements

Requirements	Description	Average importance
Functional - Hardware and Resources		

Requirements	Description	Average importance
Data infrastructures should include…	Computation - the cloud-edge-end computing paradigm, efficient AR/VR cloud-edge-end rendering, scalable AI model training, quantum computing - programs, instructions, algorithms	**2.90**
	Storage - local caching, edge caching, cloud caching, decentralized edge data storage and sharing, cloud computing, local storage, long-term storage	**2.60**
Networks and communication should include…	Physical and virtual service providers - real-time physical-virtual synchronization, communication services	**2.60**
	Wireless 5G/6G networks, tactile internet	**2.60**
Physical devices, sensors, and controllers should include…	Users' devices and equipment - general (text, audio, video) devices	**2.50**
	Head-mounted displays (equipment) and controllers - AR/VR smart glasses	**2.60**
Functional - Software and Technologies		
Technologies and concepts connecting the metaverse should include…	Digital twin and 3D modeling technologies - 3D simulation, 3D reconstruction, data fusion	**2.90**
	Web and other related standards and tools such as authentication, interoperability, accessibility etc.	**2.80**
Recognition, rendering, and modeling environments should include…	Scene and object recognition and understanding tools	**2.80**
	Scene and object generation tools - 3D reconstruction	**2.70**
	Translation, recommendation, and testing tools - enable correct settings for users	**2.60**
	Identity modeling - authentication, resolution tools	**2.50**
Functional - Content and Data		
Content management should include…	Content creation - authoring, creator culture	**2.70**
User interactions'	Agent persona (virtual entity) modeling	**2.60**

Requirements	**Description**	**Average importance**
data should include…	Social computing - social networks, swarm intelligence	**2.60**
Non-functional		
Accessibility	Should ensure access through all existing digital devices, to all people without restrictions, convert public events to virtual worlds, support digital literacy and education to reduce challenges.	**2.90**
Consistency	Should ensure data and information, transmission, processing, storage etc. though the metaverse, between the physical and digital worlds.	**2.90**
Privacy	Should ensure prevention of privacy leakage in data transmission, processing, storage etc., threats to customized privacy, threats to digital footprints, cluster users into social groups for trustworthiness characterization, data ownership and integrity.	**2.90**
Security and *cybersecurity*	Should ensure safety in physical vs. digital world, ensure hardware (device), software, data/information, content, and network security, employ security standards, authentication and access control, federated learning, adverse machine learning, digital proxemics.	**2.90**
Policy and *governance*	Should ensure that the legal framework must be in place, consider legal aspects, meet general standards of governance, new laws and regulations for virtual crimes.	**2.80**
Quality of *service*	Should ensure measuring of factors (human, system, or context) that may affect the user experience, network- and application-level metrics.	**2.80**

4.4 Selection of digital public services in the metaverse

To answer RQ3: *What digital public services have the most potential to attract users and thus should be provisioned in the EU's metaverse platform among the first ones?*, 21 the most relevant digital public services have been identified according to the selection criteria introduced in section 4.2 (the full descriptive statistics are presented in the Appendix 8). For digital public services: (1) the ANSD for the entire sample is 0.49, (2) the range of ANSD for each of the requirements is [0.18; 0.54], and (3) the Cronbach alpha reliability coefficient is 0.81 (good internal consistency). These statistics confirmed the reliability of the results and validity of the survey instrument for the identification of relevant digital public services. The top-10 most relevant services are presented in Table 2. As we can see, most services focus on guidance and e-consultation features that should empower the citizens and help them develop. So, they are focusing on services that require communication between individuals which is a strong characteristic of the metaverse. These services can help citizens with employment and career issues, health consultations on simple issues, studying abroad, debt management, and housing benefits. Another important feature is the actual monitoring of facilities, which is also one of the most prominent characteristics of the metaverse.

Table 2. A list of the 10 most relevant digital public services

Category	**Digital public service**	**Average relevance**
Citizens – Career	Get guidance with how to arrange help during invalidity, sickness and employment injuries	**2.60**
Citizens – Studying	Get guidance with how to arrange internships and starting your career	**2.60**
Citizens – Health	Apply for e-consults with a hospital doctor (teleconsultation)	**2.60**
Citizens – Studying	Get guidance with how to arrange studying abroad (international office)	**2.50**
Citizens – Health	Get guidance and information about where you can get healthcare	**2.50**
Citizens – Moving	Monitor the availability of local facilities (e.g., schools, health facilities, sport facilities)	**2.50**
Citizens – Career	Get guidance with how to arrange housing benefits	**2.40**
Citizens – Career	Get guidance with how to arrange debt counselling	**2.40**
Citizens – Career	Get guidance with how to arrange health promotion programs	**2.40**
Citizens – Career	Get guidance with how to find a job	**2.40**

Furthermore, it is worth mentioning that out of 93 services, only 22.58% are considered important to be offered through the metaverse. Casual services like VAT and other declarations and refunds, obtaining different kinds of permits, and any kind of registration services are lagging in terms of their importance to be offered through the metaverse. This result means that these services are considered trivial and have no value to be offered through a next-generation platform or that they are already well offered through the current e-government systems. Also, the European Commission has a very specific concept on the high-level services provision that is connected to real life and business events and that these kinds of services are important, but they need to be offered in the background as supportive ones. Thus, it could be deduced that the metaverse will be closely related to the provision of services of actual value to the citizens and businesses.

The three most representative categories out of 21 most relevant services are: (1) career, which includes 7 public services, (2) business start-up (5 public services), and (3) studying (4 public services) (Appendix 8). The selection was made in accordance with the criterion that (1) the mean and median values of the services relevance scores should be above the average scores for those indicators for the entire sample and (2) the ANSD values should be below the average score for the entire sample. Finally, this study identifies the categories with the highest average score of potential to attract users that should be provided on the EU's metaverse platform. Health, moving, and transport are placed first. This is reasonable regarding the new functionality and opportunities the metaverse could deliver through its architecture. Easy communication with enhanced background information and checks of the surroundings using VR and AR technologies would allow a new era of services to be provided virtually. The next three categories deal with e-consultation services as well as virtual participation in real processes. These categories include studying, career development and start-ups as well as justice services. The average relevance level of these categories displayed in Figure 4 represents the most suitable services to be offered through the metaverse against traditional digital means.

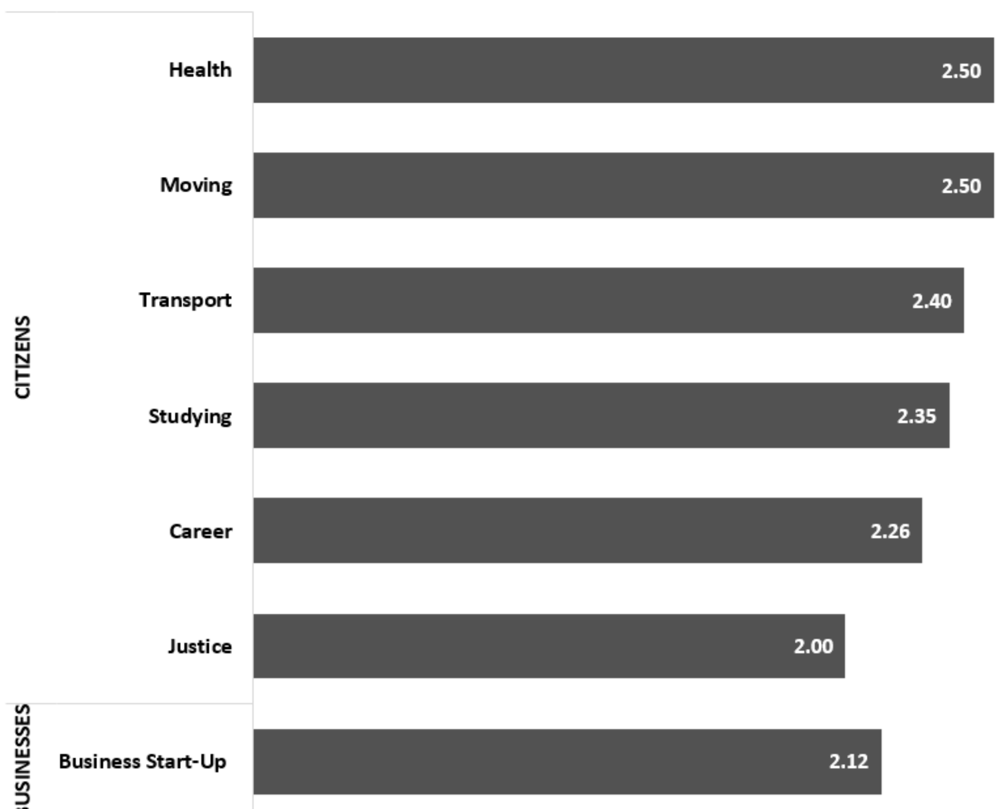

Figure 4. The average relevance level of digital public services' categories in the metaverse architecture

5 Discussion and limitations

The metaverse can potentially transform the delivery of digital public services by providing immersive and interactive experiences beyond traditional websites, web portals, and mobile applications. By leveraging the power of VR, the metaverse can offer more personalized and tailored public services that consider the unique needs and preferences of individual citizens. By offering immersive and interactive experiences, the metaverse can help to foster a sense of community and encourage citizens to engage with public services in new and meaningful ways. In this direction, the metaverse can also provide a platform for co-creation and collaboration, allowing citizens to work alongside public service providers to develop and improve services. Overall, the use of the metaverse for digital public services provisioning presents both opportunities and challenges and requires careful consideration and planning to realize its full potential as a tool for improving digital public services delivery.

In terms of *functional* requirements, our research confirmed that first, *hardware* and *resource* requirements for implementing digital public services in the metaverse are important considerations. Hardware infrastructure and resources for the metaverse must be prepared for data-intensive applications and high-performance computing (Wang et al., 2021). Existing cloud computing infrastructures can play an important role (Lee et al., 2021). Moreover, the metaverse relies on a high-speed internet connection for smooth and seamless interactions between users and digital objects (Wang et al., 2022; Xu et al., 2023). However, it can be a challenge for public service providers operating in areas with limited or unreliable internet connectivity. The use of advanced graphics and rendering technology can help enhance user engagement, promote a sense of presence and immersion, and help create visual and interactive environments that enable citizens to better understand complex information and data (Lee et al., 2021). Public service providers must ensure that they can meet all the requirements of the significant hardware and resource requirements needed to render these environments in real-time (Koohang et al., 2023).

Secondly, *software* and *technologies'* requirements are essential for the effective implementation of digital public services in the metaverse (Choi et al., 2022). The metaverse requires specialized software and technologies to create, render and manage the 3D environments and objects. Digital twin and 3D modeling technologies can help to create realistic and immersive environments that enable citizens to interact with public services more engagingly and intuitively (Lv et al., 2022). Scene and object recognition technologies can help to identify and track objects in the metaverse, enabling the creation of more personalized digital public services (Zhao et al., 2022), but also can help to ensure that citizens' data and privacy are protected, while also enabling secure and transparent transactions (Lee et al., 2021). Furthermore, translation, recommendation, and testing tools can help ensure that digital public services are accessible to citizens of different languages and abilities while also ensuring that these services are optimized for performance and usability (Smith, 2022). The psychological mechanisms underpinning users' experiences with these realities-enhancing technologies should also be considered because they can create and destroy the value for citizens and businesses (Hilken et al., 2022).

However, the cost of purchasing, maintaining, and updating these technologies can be a significant challenge for public service providers, particularly for those with limited budgets (Mystakidis, 2022). The high cost of these technologies can create equity concerns, as it may limit the ability of certain public service providers to effectively compete with others who can afford to invest in more advanced technologies. The funding and resource requirements associated with software and technologies can also be limiting factors in terms of the speed and scale of implementation. Additionally, the complexity of these technologies may require specialized knowledge and skills, which may be a challenge for public service providers who do not have access to these resources (Park and Kim, 2022). Thus, open-source platforms, tools, and services can offer a cost-effective solution for public service providers to access and utilize these technologies. Additionally, outsourcing to the private sector may also be a viable option for public service providers, enabling them to leverage the expertise and resources of specialized technology firms.

Thirdly, as our study proved, *content* and *data* are essential requirements for the development of digital public services in the metaverse. They provide citizens with access to information, resources, and services that can enhance their quality of life (Pamungkas, 2022). Social computing technologies, such as social networks and swarm intelligence, can enable citizens to connect and collaborate, sharing information and knowledge to solve complex problems (Rathore, 2023). The agent personas or virtual entities can provide a more intuitive and natural way for citizens to interact with digital public services (Park and Kim, 2022). On the other hand, by leveraging data analytics and AI, public service providers can gain insights into citizens' preferences and behaviors, enabling them to deliver more customized and relevant digital public services (Watson, 2022). However, ensuring the accuracy, reliability, and security of data, privacy and data protection concerns can create barriers to the sharing and use of citizen data for the development of digital public services (Choi et al., 2022). Furthermore, using AI and data analytics can also raise ethical concerns around bias and discrimination, as well as the potential for algorithmic decision-making to replace human judgment and decision-making (Anshari et al., 2023). To address these challenges, it is essential to develop social norms and cultural values that can guide the development and use of content and data for digital public services in the metaverse (Sriram, 2022).

In terms of *non-functional* requirements, first, the metaverse aims to provide a unique opportunity to build digital services that are more accessible to citizens. The use of virtual environments in the metaverse can allow citizens with physical disabilities to access public services that may not have previously been available in the physical world (Yfantis and Ntalianis, 2022). However, the use of certain technologies, such as VR headsets, may create challenges for citizens with visual, vestibular, or cognitive disabilities who may need additional support to navigate and interact with digital government services (Seigneur and Choukou, 2022). Digital literacy remains a major barrier for many citizens, especially those living in underserved communities or with limited access to technology (Kemec, 2022). Public service providers must be mindful of these issues and work to ensure that their digital services are accessible and inclusive for all citizens. This can be achieved through targeted outreach and education initiatives (Zallio and Clarkson, 2022), as well as through the development of more user-friendly and accessible digital interfaces (Koohang et al., 2023).

Ensuring consistency between the physical and digital worlds is also one of the most important requirements for the provision of digital public services (Mozumder et al., 2022). One of the major challenges is managing data across multiple servers and platforms, which can lead to inconsistencies in data transfer and processing (Xu et al., 2023). Integrating data from different sources can also create data quality and accuracy issues, as different sources may have different levels of reliability or consistency (Nica et al., 2022). To address this issue, public service providers may need to adopt standard protocols and formats for transmitting and processing data to ensure consistency across different servers and platforms (Hollensen et al., 2023). Ensuring the integrity and confidentiality of citizens' data as they are exchanged between the physical and digital worlds is critical (Zallio and Clarkson, 2022).

Security and cybersecurity requirements have become increasingly important for ensuring the safety of citizens and their data (Choi et al., 2022). Unlike the physical world, where security measures are often more tangible and easier to implement, the metaverse presents unique challenges for security and cybersecurity (Dwivedi et al., 2022). For example, the decentralized nature of the metaverse can make it more difficult to regulate and monitor access and activity, leading to potential security breaches and cyber-attacks (Chen et al., 2022). Additionally, using immersive and interactive technologies in the metaverse can create new opportunities for social engineering and phishing attacks, which can be challenging to detect and prevent (Qamar et al., 2023). The collection, storage, and processing of citizens' personal data in the metaverse can create vulnerabilities that can be exploited by malicious actors (Huang et al., 2023). Additionally, using AI and machine learning in digital public services can create ethical and legal challenges around data use and privacy (Yang et al., 2022). As such, public service providers need to prioritize security and cybersecurity in developing and implementing digital public services in the metaverse, while ensuring that citizens' data privacy and protection are upheld (Park and Kim, 2022). This can be achieved using encryption, multi-factor authentication, and other security measures that can help to mitigate the risks associated with the metaverse (Choi et al., 2022).

The next requirement for regulating the metaverse is the lack of a clear policy and governance framework (Dwivedi et al., 2022). The metaverse exists in a complex legal landscape that encompasses different jurisdictions, legal systems, and cultural norms (Kalyvaki, 2023). Policymakers must work to clarify the legal status of virtual assets and transactions, establish clear rules for virtual property ownership and transfer, and define the boundaries of acceptable behavior in virtual spaces (Macedo, 2022). They must also ensure that law enforcement agencies have the resources and expertise to investigate and prosecute virtual crimes such as theft, fraud, and harassment (Katterbauer et al., 2022). To combat virtual crime in the metaverse, policymakers must adopt a comprehensive approach that includes legal frameworks, law enforcement capabilities, and user education. Governments must engage with users and educate them about the risks of virtual crime and the measures they can take to protect themselves (Sia, 2023).

User experience in this virtual world relies heavily on the service quality provided by the network and applications (Choi et al., 2022). Network-level metrics such as latency, throughput, and packet loss can impact user experience in the metaverse. Similarly, application-level metrics such as frame rate, rendering time, and overall system performance can also influence user experience (Cheng et al., 2022). Similarly, device capabilities such as graphics processing power can affect the rendering time and frame rate, which can impact the overall user experience (Duan et al., 2021). Therefore, quality of service requirements should consider these factors and ensure that measuring these metrics is conducted to maintain a consistent and high-quality user experience in the metaverse (Du et al., 2023). At the general level, as the metaverse is still in its infancy, there are no established standards or best practices for metaverse development (Wang et al., 2021). This lack of standardization may create compatibility issues with existing e-government systems, hindering the integration of metaverse technology into existing systems (Lv, 2023). The challenges with interoperability can also lead to a fragmented user experience, resulting in citizens having to navigate through different metaverse platforms to access different public services (Mourtzis et al., 2022). This may discourage citizens from using metaverse technology for digital public services.

In the EU, achieving an agreement on laws and legislation regarding the metaverse could prove to be difficult due to the complex nature of this virtual world. One of the main challenges in the governance of the metaverse is the issue of data privacy. The EU has strict regulations regarding the handling of personal data, such as the General Data Protection Regulation (GDPR)[1]. The metaverse introduces new challenges for data privacy (Canbay et al., 2022). For example, the Open Data Directive[2], which aims to make public data more accessible and usable, presents challenges in the metaverse as personal data can easily be exposed. Another challenge in the governance of the metaverse is the issue of intellectual property rights (Kalyvaki, 2023). The EU needs to work towards a harmonized regulatory framework that considers the unique nature of the metaverse. This will require collaboration between Member States and businesses and a willingness to adapt to new technologies and ways of doing things. At the same time, it should also be noted that the funding will be required to develop the EU's metaverse platform and promote the benefits of metaverse towards citizens and society.

5.1 Theoretical implications

Our findings contribute to the literature in the field of information systems, information technology, and architecture requirements, summarizing, structuring, and conceptualizing current research in the area of the digital government and digital public services in the metaverse. First, we extend the knowledge on the metaverse-related architecture requirements and how they can be classified. We found that both categories of requirements, i.e., functional and non-functional, have their specifics that must be met and considered when providing services to the metaverse in the e-government system. The *functional* requirements are characterized by data-intensive infrastructures and networks that must be designed to meet flows of large amounts of data coming

[1] https://gdpr.eu/

[2] https://data.gov.ie/pages/open-data-directive

from different physical devices, sensors, and controllers. The *non-functional* requirements then focus primarily on accessibility of digital public services and consistency of data and information transmission, processing, and storage through the metaverse. Second, we contribute to the literature in terms of summarization of *functional* requirements on software and technologies-related concepts, environments, and platforms as well as types of content and data created in the metaverse. The *non-functional* requirements then provide insights for the literature on quality of information systems and architectures.

Theoretical implications of our findings are especially important for researchers exploring and modeling different aspects of information systems architectures. These should be linked with other areas such as big data, AI, and machine learning to understand the issues better. Also, this study contributes to the literature on the positive and negative aspects of government in the metaverse and its suitability for providing digital public services.

In essence, our study enhances the *theoretical foundation* of the metaverse, with a specific focus on its implications for the public sector and service delivery. Rooted in William Gibson's "cyberspace" concept and incorporating elements of VR and AR (Park, 2022), in our study, the metaverse as a theory emphasizes its role as a *service*- and *context*-centric, socially relevant platform that does not rely exclusively on immersive technologies. Looking ahead, the metaverse may evolve into the next iteration of VR and AR or even emerge as an all-inclusive package for the next generation of the Internet. While speculative, further exploration through research, case studies, and analysis is essential to unravel the full potential of this emerging field.

5.2 Practical and policy implications

There are three categories of key stakeholders who should consider transforming the research findings of our study for use in practice, namely (1) public officials responsible for legislative procedures in the EU, (2) national governments, and (3) regional and city-level public officials. Although our study is set up in the environment represented by the EU's metaverse platform, using a bottom-up approach can help turn recommendations into actions on the EU level. In addition, other stakeholders, such as citizens, businesses, and non-governmental organizations, are important partners in developing such solutions in practice.

First, we provided the list of core *functional and non-functional requirements* in the metaverse architecture for the defined environment. Additionally, we introduced a classification system that offers valuable direction on categorizing and structuring these requirements. These results could serve as actionable guidelines, assisting government officials in prioritizing critical requirements for provisioning metaverse services within the e-government system. Second, the insights gained from experts' assessments provide *practical guidance* on selecting digital public services with the highest potential to attract users for inclusion in the EU's metaverse platform. These recommendations offer tangible steps for designing the architecture and provisioning of government digital services within the metaverse. Third, this study includes experts' recommendations on *future actions* in this area, focusing on analyzing the current state and preparedness of governments to implement digital public services in the metaverse platform. We encourage key stakeholders to focus on other issues, such as security and privacy.

To sum up, we can define the following actionable recommendations:

- Actively involve stakeholders with diverse expertise in defining metaverse architecture requirements. Regular consultations should be conducted to adapt to evolving perspectives and needs.
- Implement an iterative classification process for metaverse-related architecture requirements. Regularly update the classification based on emerging technologies and evolving stakeholder needs.
- Prioritize resources for the development of content and data-related architecture components. Regularly monitor social activity and content trends to align with the evolving landscape.
- Allocate resources based on the top-5 most important functional requirements, giving priority to computation, digital twin, 3D modeling technologies, web standards, and scene/object tools.
- Integrate the top-6 non-functional requirements, emphasizing accessibility, data consistency, privacy, security, policy and governance, and service quality, into the metaverse architecture.
- Prioritize the provision of user-centric digital public services, particularly focusing on the top-10 most relevant services related to guidance, e-consultation, career development, business start-up, studying, health, moving, and transport.
- Establish a continuous monitoring mechanism for service relevance. Regularly update the service portfolio based on user feedback and emerging trends.
- Involve users in the design and development of metaverse-based services. Understand user preferences and expectations to enhance the user experience and adoption of digital public services.
- Promote collaboration and standardization efforts across sectors to ensure interoperability and seamless integration of digital public services in the metaverse.

5.3 Limitations

This research has several limitations that need to be acknowledged. *First*, it is focused on the metaverse within the context of the EU's e-government system. This may limit the generalizability of findings to other regions or global contexts. The metaverse landscape may differ significantly in other geographical areas with distinct cultural, political, or technological environments. *Second*, the topic of the metaverse is very current and various studies, as well as government strategies, are increasing very quickly. In addition, the data collection span from December 2022 to March 2023 might not fully capture the dynamic nature of the metaverse landscape. Therefore, our findings regarding the most important metaverse architecture requirements may not stand up to the latest studies and practices. *Third*, the classification of metaverse-related architecture requirements may involve subjective judgments during the systematic content analysis and synthesis stages. The interpretation of positive and negative implications of the metaverse for the public sector may vary, potentially influencing the final classification. *Fourth*, the assumption that the EU will be the owner of the metaverse platform might not align with future developments in the metaverse ecosystem. Ownership and governance structures could evolve, impacting the study's applicability and recommendations. Fifth, the study focuses on seven categories of digital public services for citizens and two categories for businesses based on EU e-government benchmark reports. This may not fully represent the diverse spectrum of potential digital services that could emerge in the metaverse.

Finally, the use of the Delphi method also has several limitations. The method's effectiveness relies on the assumption that repeated rounds of feedback lead to convergence, but divergent views may be suppressed. The selection of experts using purposive sampling, while providing in-depth insights, may introduce bias. The chosen experts may have specific perspectives or biases that influence the assessment outcomes. Additionally, due to the limited number of experts involved, we may not be able to capture the full range of perspectives and ideas on this topic. However, our findings focused on the opinions of experts with the maximum degree of consistency, provide valuable guidance to policymakers regarding the strategy and requirements for deploying public services to the metaverse platform.

5.4 Future research areas

Our study suggests several directions for potential future research pathways that could benefit academics and the wider scientific community exploring themes linked to areas of the digital government and digital public services provision in the metaverse.

Avenue for future research 1: Focus on validations and improvements of developed classification and list of functional and non-functional requirements in practice. All of these are needed to be confronted with understanding, expectations, needs, and preferences among the key stakeholders relevant to the defined environment (Chen et al., 2023; Dwivedi et al., 2022; Mourtzis et al., 2022). Their involvement is important for the specification of concrete metaverse domains in which digital public services will be provided. Because as argued by one of the experts "*the metaverse platform cannot meet so many requirements and ensure their support if we don't know exactly what users will want and actually use in the virtual environment*". In this regard, the key areas are represented by software and technologies and content and data, which are most affected by users' expectations and preferences.

Avenue for future research 2: Accessibility, compatibility, interoperability, and usability of interfaces through which digital public services will be provided is also an important topic because of the solutions and tools used by citizens and businesses (Abilkaiyrkyzy et al., 2023; Al-Ghaili et al., 2022; Wang et al., 2021). More precisely, compatibility of existing architecture solutions as well as portability and connectivity to existing personas of users in other architectures, is another area that deserves further research.

Avenue for future research 3: Investigate the possibility of differentiating between requirements on governments and requirements on citizens and businesses. Some of the requirements are and should be supported and provided by governments, such as infrastructures, networks, virtual environments, and content, while the other requirements are relevant for the private sector that ensures the availability of VR/AR devices for citizens and businesses, software and technologies and platforms that could be used by governments etc. In this regard, the requirements should be gained from all these stakeholders, and they should prioritize them as well (Abilkaiyrkyzy et al., 2023; Dwivedi et al., 2022; Xu et al., 2023). Therefore, future research on metaverse-related architecture frameworks should help to overcome these issues and enable clarification of the requirements and formalizing the architectural components and relationships in terms of the key stakeholders.

Avenue for future research 4: Consider the deeper analysis of the current state and preparedness of governments to implement digital public services in the metaverse platform. As argued by one of the experts, future research should be focused on exploring the linking and integration tools to existing e-government services. These should result in requirements dealing with data-intensive transfers because most of the outputs of metaverse activities realized by citizens and businesses must be transferred to public sector information systems or base registries in which these changes must be recorded and verified (Cai et al., 2022; Lee et al., 2021; Zhang et al., 2023). In this regard, the preparedness analysis should focus on the concrete environment and its settings considering available computing, financial, and human resources to get a clear view on these resources and existing systems and their architectures. Because as noted by one of the experts, "*it can be easier to start with standalone environments, e.g., on the level of cities, because integration of metaverse services with existing systems will be a very challenging task*".

6 Conclusions

The concept of the metaverse has gained increasing attention and interest in recent years. The metaverse is a virtual space that is interconnected with the real world and allows for immersive and interactive experiences. This study *aimed* to extend the theoretical grounding of the metaverse, deepening the understanding of the metaverse-related architecture requirements and their relevance for digital public services provisioning in the EU's environment. Our results identified the most important technologies to support the functional requirements, including high-end computation methods and AI, 3D modeling technologies, object recognition, understanding and reconstruction. Our research expands the understanding and extends the theoretical grounding of the metaverse, especially in the context of the public sector and public services provision. As a theory, metaverse, on the one hand, draws inspiration from William Gibson's "cyberspace" concept and VR and AR; aiming for seamless integration of the digital and physical worlds; addresses the evolving landscape of digital spaces, providing a solution for meaningful virtual interactions and representing a progression beyond the mobile internet; on the other hand - stands out as a service-oriented, socially meaningful platform; may not exclusively rely on AR and VR technologies, emphasizing sustainability and social relevance; and its scalability, accommodating a large user base, is crucial for reinforcing social significance. In the future, the concept of metaverse can be viewed as the next generation of VR and AR, or even as an all-inclusive package for the next internet generation. While this is also an assumption, further exploratory research, case studies, and analysis are needed to delve into this emerging field and unravel its potential.

Our findings identified the most suitable services to be offered through the metaverse against the traditional digital means. These categories of services include career, business start-up, and studying-related public services. This also shows that among the digital public services that have the potential to attract new users and should be deployed in the metaverse platform, among the first ones are services that provide guidance for citizens and businesses in life events. In the metaverse, the visualization of information is crucial for creating engaging and interactive experiences. With the help of advanced graphics and visualization technologies, data can be presented more intuitively and immersively, allowing users to explore and interact with information in a more natural and intuitive way. For a metaverse to succeed, it will need to be accessible and inclusive to a diverse range of users and will require collaboration and standardization across different platforms and technologies.

The development of a metaverse is a complex and ongoing process, and how it will evolve and impact society in the future remains to be seen. However, there are also concerns about privacy, security, and potential negative impacts on mental health and social relationships. Our findings may serve as the foundation for the strategy for the design of the research as well as provide guidance for the fieldwork. Overall, the requirements of the metaverse are complex and multifaceted, requiring a collaborative effort by stakeholders from different sectors to ensure the development of a safe, secure, and inclusive virtual environment. In addition, the developed classification can be used as an effective guide for categorizing and organizing the requirements for creating a metaverse in relation to other environments. The results of our study provide further research directions, as well as theoretical and practical implications for governments as they narrow their focus on services that have the greatest potential to attract users and can be recommended to be among the first to be presented on the EU's metaverse platform.

Considering the challenge of rapid technological progress in the metaverse and the increasing interest among scientists, our study acknowledges as a critical consideration the need to ensure the ongoing relevance of our resulting classification of functional and non-functional requirements for metaverse architecture by its continuous improvement and validation. To overcome this aspect, we propose to conduct systematic quarterly reviews that involve evaluations and comprehensive documentation of the current state of the literature. These reviews will aim to validate our research findings and pinpoint emerging trends in immersive technology and metaverse architectural requirements. A crucial component of these reviews is to collect and analyze the successful case studies and best practices of provisioning digital public services in the metaverse by governments. A complete revision of our catalogue of functional and non-functional requirements can be anticipated in at least a year. Following our methodology, this review is reasonable to complement by new rounds of expert evaluation, aiming to refine and validate the digital service metrics with the greatest potential to attract users. We expect that this plan's iterative revision process will be able to ensure that our research remains adaptive and maintains its relevance in the ever-evolving landscape of the metaverse.

In line with the recommendations provided by the experts, we will devote our future research steps to advance the understanding of these requirements among the key stakeholders as well as analyzing the current state and preparedness of governments to implement digital public services in the metaverse platform.

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APPENDICES

Appendix 1. Results of the systematic search

Digital Library	**Web of Science**		**Scopus**		**ACM Digital Library**		**Science Direct**	**IEEE**	
Key words combinations	Proceedings/Chapters	Journals	Proceedings/Chapters	Journals	Proceedings/Chapters	Journals	Journals	Proceedings	Journals
Digital public services in the metaverse context									
metaverse AND e-government	0	1	0	1	2	0	0	0	0
metaverse AND electronic government	0	0	0	0	2	0	8	0	2
metaverse AND e-governance	0	0	0	0	4	0	6	0	0
metaverse AND electronic governance	0	0	1	0	2	0	10	0	0
metaverse AND public sector	0	0	3	2	2	0	13	1	0
metaverse AND public administration	0	0	0	0	2	0	4	1	0
metaverse AND public services	0	1	3	8	6	0	7	2	2
metaverse AND digital public services	0	0	2	3	24	0	14	0	0

Digital Library	Web of Science		Scopus		ACM Digital Library		Science Direct	IEEE	
metaverse AND online services	0	0	11	16	17	0	25	11	4
Implications of the metaverse for the public sector									
metaverse AND benefit	3	8	24	31	5	1	8	9	7
metaverse AND advantage	2	13	28	23	3	0	7	13	6
metaverse AND contribution	3	14	15	12	5	0	6	3	9
metaverse AND opportunity	2	10	40	51	4	0	17	17	8
metaverse AND issue	2	23	47	46	5	0	9	20	26
metaverse AND risk	3	12	19	12	3	0	3	8	0
metaverse AND barrier	1	3	9	6	4	0	4	1	1
metaverse AND problem	18	27	53	41	6	0	10	30	13
metaverse AND obstacle	0	1	7	2	1	0	1	5	2
metaverse AND challenge	6	12	80	71	16	0	22	52	23
Requirements for the digital public services and e-government context									
metaverse AND architecture	22	44	52	37	5	0	2	33	17
metaverse AND framework	24	65	62	57	10	0	14	36	23

Digital Library	Web of Science		Scopus		ACM Digital Library		Science Direct	IEEE	
metaverse AND requirement	1	6	26	25	11	0	3	16	10
metaverse AND characteristic	0	4	27	39	9	0	6	12	7
metaverse AND component	5	6	22	20	2	1	5	20	5

Appendix 2: Study selection and evaluation criteria – adapted from Bassey et al. (2022) and Zuiderwijk et al. (2021)

Inclusion criteria	- studies written in English - academic or commercial studies
Exclusion criteria	- theoretical speculations - work-in-progress papers - duplicates, i.e., studies of the same author on the same topic (only the most relevant ones are selected) - extended abstracts
Study relevance	- Metaverse in the context of digital public services or online services should play a substantial or major role in the study (its RQs, objective, etc.). Studies in which the focus on metaverse use in private sector was minor or secondary were excluded in this phase - the implications of the use of metaverse in digital services in public sector context should be central to the study. If the study did not (at least partly) address metaverse implications in the context of the public sector it was excluded in this phase. - the requirements for the digital public services and e-government context should be as a one of the central research focus - focus only on theoretical aspects - that the research output is accessible to the researcher for evaluation
Quality assessment	- The study's objective is explicitly outlined, and there is a comprehensive explanation of the methods used for data collection. Important claims in the paper are substantiated by relevant references. - The study's design aligns well with its research objective. It successfully addresses the RQs. - The study's chosen research methodology is sufficiently elucidated, providing adequate details for comprehension.

Appendix 3. List of experts and their profiles

No.	Country	Job position	Years of expertise	Professional expertise
1.	Czech Republic	Assistant professor, e-government consultant	12	The respondent has over 10 years of experience in e-government, open government, big and open linked data, and impacts of modern technologies in the public sector
2.	Estonia	Assistant professor	8	Information Systems, Software Engineering, Data management, focusing on data quality and data integration issues, open data and open government data (OGD) related subtopics, covering both technological and societal aspects of OGD
3.	Germany	Government employee (under the State)	10	PhD in Computer Science, employed at a university for 4 years as a researcher – research on information systems, 6 years experience as a system analyst and designer in the public sector
3.	Germany	University professor	35	12 years of experience in Business Modeling and Knowledge Engineering, Semantic Web and public sector digitization
5.	Greece	Senior researcher	12	Computer science
6.	Italy	Researcher/ developer	8	Software development; scalable web applications development; PhD in recommender systems
7.	Netherlands	Researcher	8	Open data, back-end developer
8.	Poland	Assistant professor	17	The respondent has over 15 years of experience in computational linguistics, AI, and machine learning and their application for business processes and service improvement in the public sector
9.	Poland	Assistant professor	12	Co-creation, service design, project management, e-government
10.	Spain	Researcher	7	Researcher in the domain of computer science and e-government.

Appendix 4. List of digital public services whose delivery is compared by the series of e-government benchmark reports by the EU

For citizens (7 categories):

Career - 1.1 Registering as unemployed, 1.2 Calculate unemployment benefits (duration and height), 1.3 Apply for unemployment benefits, 1.4 Appeal against decision when unemployment benefits are not granted, 2.1 Check eligibility for additional unemployment benefits, 2.2 Get guidance with how to arrange housing benefits, 2.3 Get guidance with how to arrange debt counselling, 2.4 Get guidance with how to arrange health promotion programs, 2.5 Get guidance with how to arrange help during invalidity, sickness and employment injuries, 2.6 Apply for a tax refund or other allowances affected by unemployment, 3.1 Check obligations for keeping unemployment benefits, 3.2 Submit evidence that proves you are looking for work, 3.3 Register circumstances that impede you from looking for work, 4.1 Get guidance with how to find a job, 4.2 Register employment to stop unemployment benefits, 4.3 Declare personal income taxes, 5.1 Calculate future pensions, 5.2 Apply for state pension, 5.3 Check entitlement for pension when moving abroad or returning from another country.

Family - 1.1 Check conditions for parental leave, 1.2 Register child with competent authority, 1.3 Register parental authority (e.g. with court in case not married), 1.4 Apply for child allowance, 2.1 Register with civil/local registry in order to get married or to close a civil partnership, 2.2 Register divorce with civil/local registry in order to end marriage or a civil partnership, 3.1 Obtain passport, 3.2 Obtain birth certificate, 3.3 Obtain for a European Health Insurance Card, 4.1 Check requirements for registering the death of a relative.

Studying - 1.1 Monitor study programs provided by universities, 1.2 Check admission requirements for enrolling in higher education, 2.2 Register in higher education, 2.3 Apply for student grants, 2.4 Calculate additional financial possibilities, 2.5 Apply for additional social benefits, 3.1 Apply for portability of student grant (abroad), 3.2 Monitor grades and personal data, 3.3 Get guidance with how to arrange studying abroad (international office), 3.4 Get guidance with how to arrange internships and starting your career.

Health - 1.1 Get guidance and information about where you can get healthcare, 1.2 Monitor online information on doctor's registration, specialty and necessary licenses etc., 1.3 Obtain a European Health Insurance Card, 2.1 Register and (re)schedule appointment at the hospital, 2.2 Apply for e-consults with a hospital doctor (tele-consultation), 2.3 Obtain e-prescription from a hospital doctor, 2.4 Apply for electronic health records.

Justice - 1.1 Check procedural steps for starting a small claims procedure, 1.2 Check relevant legislation and rights for defending your case, 2.1 Submit small claims procedure (issue the claim to court), 2.2 Submit evidence/supporting documents, 3.1 Monitor status of case, 3.2 Appeal against court decision.

Moving - 1.1 Monitor the availability of local facilities (e.g. schools, health facilities, sport facilities), 1.2 Register new address in municipality register, 1.3 Register new address with additional organizations, 1.4 Obtain proof of residence, 1.5 Register you signing out from old municipality, 1.6 Apply for disabled facilities grant or similar benefit to cover for costs for making changes to a house in order to allow to continue living at one's property independently.

Transport - 1.1 Register a second-hand car, 1.2 Apply for government support for alternative fueled car, 2.1 Obtain a parking permit, 2.2 Declare vehicle/road tax, 2.3 Obtain permit for toll roads or vignettes, 2.4 Obtain emission stickers, 3.1 Check information and plan a journey (involving multiple types of public transport), 3.2 Obtain public transport tickets (standard tariff), 3.3 Appeal and claim a ticket refund.

For businesses (2 categories):

Business Start-Up - 1.1 Check requirements for starting a business, 1.2 Get guidance with how to write a business plan, 1.3 Get guidance with how to explore financial possibilities, 2.1 Obtain certificate of no outstanding charges, 3.1 Register company for the first time, 4.1 Obtain tax identification card/number, 4.2 Obtain VAT collector number, 5.1 Register with Social Security Office, 5.2 Get guidance with how to arrange (mandatory) pension insurance, 5.3 Get guidance with how to arrange (compulsory) healthcare insurance, 6.1 Register your company as an employer, 6.2 Register employee before first workday, 6.3 Check contractual obligations for hiring employees, 6.4 Check working conditions for employing employees, 7.1 Check conditions for environmental permits, 7.2 Obtain pollution/environmental permit.

Economic - 1.1 Declare corporate tax, 1.2 Declare social contributions, 1.3 Submit financial reports to business registration office, 1.4 Submit company data to statistical offices, 2.1 Declare VAT, 2.2 Apply for a refund of VAT, 2.3 Appeal against VAT decision, 3.1 Register illness of employee with competent administration, 3.2 Register the end of a contract of an employee with competent authority, 3.3 Register new address with competent authority.

Appendix 5. List of functional and non-functional requirements of the metaverse architecture

Requirements - functional	**Description**	**References**
HARDWARE AND RESOURCES		
Data infrastructures should include…	Computation - the cloud-edge-end computing paradigm, efficient AR/VR cloud-edge-end rendering, scalable AI model training, quantum computing - programs, instructions, algorithms	Choi et al. (2022); Duan et al. (2021); Giang Barrera and Shah (2023); Hollensen et al. (2023); Huynh-The et al. (2023); Lee et al. (2021); Mozumder et al. (2022); Ning et al. (2021); Schmitt (2022); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023)
	Storage - local caching, edge caching, cloud caching, decentralized edge data storage and sharing, cloud computing, local storage, long-term storage	Choi et al. (2022); Duan et al. (2021); Huynh-The et al. (2023); Lee et al. (2021); Ning et al. (2021); Wang et al. (2023); Zhao et al. (2022)
	Blockchain - the blockchain-based metaverse system, blockchain scalability and interoperability, blockchain in edge resource management, secure and persistent data transfers and storage	Duan et al. (2021); Dwivedi et al. (2022); Giang Barrera and Shah (2023); Huynh-The et al. (2023); Ning et al. (2021); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023)
	Other hardware and general infrastructure equipments to support data lifecycle and data intensive design	Choi et al. (2022); Hollensen et al. (2023); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023)
Networks and communication should include…	Physical and virtual service providers - real-time physical-virtual synchronization, communication services	Alpala et al. (2022); Duan et al. (2021); Mozumder et al. (2022); Ning et al. (2021); Wang et al. (2021); Xu et al. (2023)
	Wireless 5G/6G networks, tactile	Jung and Jeon (2022); Hollensen et al.

	internet	(2023); Huynh-The et al. (2023); Lee et al. (2021); Mozumder et al. (2022); Ning et al. (2021); Park and Kim (2022); Wang et al. (2021); Xu et al. (2023)
	Optical and wired networks	Jung and Jeon (2022); Park and Kim (2022); Wang et al. (2021)
	IoT and sensor networks of intelligent objects	Al-Ghaili et al. (2022); Giang Barrera and Shah (2023); Jung and Jeon (2022); Lee et al. (2021); Mozumder et al. (2022); Ning et al. (2021); Wang et al. (2021); Xu et al. (2023)
	Network services and resources management - slicing, orchestration, integration	Ning et al. (2021); Wang et al. (2021); Xu et al. (2023)
Physical devices, sensors, and controllers should include…	Users' devices and equipment - general (text, audio, video) devices	Dwivedi et al. (2022); Giang Barrera and Shah (2023); Wang et al. (2021); Xu et al. (2023)
	Head-mounted displays (equipment) and controllers - AR/VR smart glasses	Alpala et al. (2022); Giang Barrera and Shah (2023); Jung and Jeon (2022); Lee et al. (2021); Mozumder et al. (2022); Park and Kim (2022); Wang et al. (2021); Wang et al. (2023)
	Hand-based input devices and controllers - VR gloves, wristband, smart ring, haptic gloves	Alpala et al. (2022); Giang Barrera and Shah (2023); Jung and Jeon (2022); Lee et al. (2021); Mozumder et al. (2022); Park and Kim (2022); Wang et al. (2021); Wang et al. (2023)
	Non-hand-based input devices and controllers - haptic suit	Alpala et al. (2022); Jung and Jeon (2022); Lee et al. (2021); Mozumder et al. (2022); Park and Kim (2022); Wang et al. (2021); Wang et al. (2023)
	Motion input devices and eye tracking devices and controllers	Alpala et al. (2022); Park and Kim (2022); Wang et al. (2021)
	Robotics - connected vehicles, drones, human-robot interaction	Dwivedi et al. (2022); Lee et al. (2021)
SOFTWARE AND TECHNOLOGIES		
Technologies and concepts connecting the metaverse should	Big data, data analytics, data lifecycle management	Dwivedi et al. (2022); Lee et al. (2021); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023); Zhao et al. (2022); Zhang et al. (2023)

include…		
	Cloud, edge, quantum computing	Al-Ghaili et al. (2022); Choi et al. (2022); Duan et al. (2021); Dwivedi et al. (2022); Lee et al. (2021); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023)
	XR (AR, VR, MR), brain-computer interface (BCI) and interactive and immersive technologies	Al-Ghaili et al. (2022); Alpala et al. (2022); Giang Barrera and Shah (2023); Huynh-The et al. (2023); Lee et al. (2021); Ning et al. (2021); Mozumder et al. (2022); Rosenberg (2023); Schmitt (2022); Wang et al. (2023); Xu et al. (2023)
	Digital twin and 3D modeling technologies - 3D simulation, 3D reconstruction, data fusion	Duan et al. (2021); Giang Barrera and Shah (2023); Huynh-The et al. (2023); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023)
	AI - machine learning and deep learning technologies	Al-Ghaili et al. (2022); Duan et al. (2021); Giang Barrera and Shah (2023); Huynh-The et al. (2023); Lee et al. (2021); Mozumder et al. (2022); Ning et al. (2021); Schmitt (2022); Wang et al. (2021); Xu et al. (2023)
	Virtual economy - markets and mechanisms, marketing, payments	Duan et al. (2021); Dwivedi et al. (2022); Hollensen et al. (2023); Lee et al. (2021); Schmitt (2022); Wang et al. (2021); Xu et al. (2023)
	Blockchain - consensus mechanisms, smart contracts, NFTs, decentralized finance	Al-Ghaili et al. (2022); Duan et al. (2021); Dwivedi et al. (2022); Giang Barrera and Shah (2023); Huynh-The et al. (2023); Lee et al. (2021); Ning et al. (2021); Mozumder et al. (2022); Schmitt (2022); Wang et al. (2021); Wang et al. (2023)
	Biometrics and bioinformatics - human-in-the-loop communication	Dwivedi et al. (2022); Wang et al. (2023); Xu et al. (2023)
	Nanotechnology - battery life, display resolution and viewing angles	Mozumder et al. (2022); Ning et al. (2021)
	Web and other related standards and tools such as authentication, interoperability, accessibility etc.	Choi et al. (2022); Hollensen et al. (2023); Ning et al. (2021); Wang et al. (2023); Xu et al. (2023); Zhao et al. (2022)
Recognition, rendering, and modeling environments	Scene and object recognition and understanding tools	Choi et al. (2022); Duan et al. (2021); Huynh-The et al. (2023); Park and Kim (2022); Lee et al. (2021); Wang et al. (2023); Zhao et al. (2022)

should include…		
	Scene and object generation tools - 3D reconstruction	Al-Ghaili et al. (2022); Park and Kim (2022); Wang et al. (2023); Zhao et al. (2022)
	Sound and speech recognition tools - pose estimation, action recognition	Duan et al. (2021); Huynh-The et al. (2023); Park and Kim (2022); Zhao et al. (2022)
	Sound and speech synthesis tools	Huynh-The et al. (2023); Park and Kim (2022); Zhao et al. (2022)
	Motion rendering and image processing tools (restoration and enhancement)	Choi et al. (2022); Duan et al. (2021); Huynh-The et al. (2023); Lee et al. (2021); Park and Kim (2022); Wang et al. (2023); Zhao et al. (2022)
	Translation, recommendation, and testing tools - enable correct settings for users	Alpala et al. (2022); Wang et al. (2023); Zhao et al. (2022)
	Identity modeling - authentication, resolution tools	Huynh-The et al. (2023); Mozumder et al. (2022); Ning et al. (2021)
	Computer vision - localization and mapping, body and gaze tracking tools	Lee et al. (2021)
Management, maintenance and service platforms should include…	Metaverse production and implementation platforms	Choi et al. (2022); Lee et al. (2021); Jung and Jeon (2022); Wang et al. (2021); Zhao et al. (2022)
	Metaverse maintenance and service platforms	Choi et al. (2022); Lee et al. (2021); Jung and Jeon (2022); Wang et al. (2021); Zhao et al. (2022)
	Energy management - equipment/network/service energy consumption	Ning et al. (2021)
	Resource management - discovery, addressing, allocation	Ning et al. (2021)
	Session management - single/multi-session management	Ning et al. (2021)
CONTENT AND DATA		
Content management	Content creation - authoring, creator culture	Choi et al. (2022); Duan et al. (2021); Hollensen et al. (2023); Lee et al. (2021);

should include…		Schmitt (2022); Wang et al. (2021); Zhao et al. (2022)
	Scenario generation and evaluation	Park and Kim (2022); Zhao et al. (2022)
	Content editing and upload - multi-user collaboration	Choi et al. (2022); Duan et al. (2021); Hollensen et al. (2023); Lee et al. (2021); Schmitt (2022); Wang et al. (2021); Zhao et al. (2022)
	Content audit and supervision - licenses, censorship	Duan et al. (2021); Lee et al. (2021); Wang et al. (2021); Zhao et al. (2022)
	Conversion and transfer of contents - 3D converter	Choi et al. (2022)
	Widgets - visual parts of the applications (customization adapted)	Alpala et al. (2022)
User interactions' data should include…	Agent persona (virtual entity) modeling	Dwivedi et al. (2022); Lee et al. (2021); Wang et al. (2021); Park and Kim (2022); Schmitt (2022); Zhao et al. (2022)
	Multimodal content representation (interaction)	Duan et al. (2021); Dwivedi et al. (2022); Lee et al. (2021); Park and Kim (2022); Zhao et al. (2022)
	Multimodal entity linking and expansion	Park and Kim (2022); Zhao et al. (2022)
	Multi-task interaction	Dwivedi et al. (2022); Park and Kim (2022); Zhao et al. (2022)
	Embodied interaction	Dwivedi et al. (2022); Park and Kim (2022); Zhao et al. (2022)
	Social computing - social networks, swarm intelligence	Mozumder et al. (2022); Ning et al. (2021); Rosenberg (2023)
Requirements - non-functional	**Description**	**References**
Accessibility	Should ensure access through all existing digital devices, to all people without restrictions, convert public events to virtual worlds, support digital literacy and education to reduce challenges.	Alpala et al. (2022); Choi et al. (2022); Dionisio et al. (2013); Duan et al. (2021); Zallio and Clarkson (2022)
Consistency	Should ensure data and information, transmission,	Mozumder et al. (2022); Ning et al. (2021)

	processing, storage etc. though the metaverse, between the physical and digital worlds.	
Ethics and *behavior*	Should ensure ethical consciousness in which various avatars can live, ethical behavior, guidelines and rules of users' groups, psychological safety and people behavior.	Falchuk et al. (2018); Hollensen et al. (2023); Lee et al. (2021); Ning et al. (2021); Park and Kim (2022); Schmitt (2022); Wang et al. (2021); Zallio and Clarkson (2022)
Heterogeneity and *diversity*	Should ensure and guarantee users' equity, diversity, fairness, cultural diversity, prevent users' addiction and cyberbullying, foster a positive sense of diverse communities, heterogeneous virtual spaces, devices, and data types.	Duan et al. (2021); Dwivedi et al. (2022); Lee et al. (2021); Ning et al. (2021); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023); Zallio and Clarkson (2022)
Hyper spatiotemporality	Should ensure a virtual world parallel to the real world and how, where, and why people locate and move across various worlds with different spatiotemporal dimensions.	Mozumder et al. (2022); Ning et al. (2021); Wang et al. (2023)
Immersiveness	Should ensure that the computer-generated virtual space is realistic to allow users to feel psychologically and emotionally immersed in the experience. Technology-related factors may manipulate the degree (i.e., low to high) of telepresence.	Al-Ghaili et al. (2022); Choi et al. (2022); Dionisio et al. (2013); Duan et al. (2021); Dwivedi et al. (2022); Giang Barrera and Shah (2023); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023); Zhao et al. (2022)
Interoperability	Should ensure a multi-technological environment, employ existing standards, users can seamlessly move across virtual worlds, virtual worlds are interchangeable across distinct platforms, data exchange.	Abbate et al. (2022); Al-Ghaili et al. (2022); Choi et al. (2022); Dionisio et al. (2013); Lee et al. (2021); Ning et al. (2021); Wang et al. (2023); Xu et al. (2023); Zhao et al. (2022)
Policy and *governance*	Should ensure that the legal framework must be in place, consider legal aspects, meet general standards of governance, new laws and regulations for virtual crimes.	Dwivedi et al. (2022); Giang Barrera and Shah (2023); Lee et al. (2021); Rosenberg (2023); Schmitt (2022); Wang et al. (2021); Kalyvaki, M. (2023)

Privacy	Should ensure preventing privacy leakage in data transmission, processing, storage etc., threats to customized privacy, threats to digital footprints, cluster users into social groups for trustworthiness characterization, data ownership and integrity.	Al-Ghaili et al. (2022); Choi et al. (2022); Di Pietro and Cresci (2021); Dwivedi et al. (2022); Falchuk et al. (2018); Huynh-The et al. (2023); Lee et al. (2021); Mozumder et al. (2022); Ning et al. (2021); Park and Kim (2022); Schmitt (2022); Wang et al. (2023); Xu et al. (2023); Zallio and Clarkson (2022)
Quality of *service*	Should ensure measuring of factors (human, system, or context) that may affect the user experience, network- and application-level metrics.	Choi et al. (2022); Du et al. (2023); Dwivedi et al. (2022); Hollensen et al. (2023); Lee et al. (2021)
Scalability	Should ensure the capacity of metaverse to remain efficient with the number of concurrent users/avatars, the level of scene complexity, and the mode of user/avatar interactions.	Al-Ghaili et al. (2022); Dionisio et al. (2013); Wang et al. (2023); Xu et al. (2023)
Security and *cybersecurity*	Should ensure safety in physical vs. digital world, ensure hardware (device), software, data/information, content, and network security, employ security standards, authentication and access control, federated learning, adverse machine learning, digital proxemics.	Abbate et al. (2022); Al-Ghaili et al. (2022); Choi et al. (2022); Di Pietro and Cresci (2021); Dwivedi et al. (2022); Huynh-The et al. (2023); Lee et al. (2021); Mozumder et al. (2022); Ning et al. (2021); Park and Kim (2022); Schmitt (2022); Wang et al. (2021); Wang et al. (2023); Xu et al. (2023); Zallio and Clarkson (2022)
Sociability	Should ensure interactions among users, i.e., sharing, collaborating, and co-creating contents, experiences, and objects, personalized experience, and shareable stories.	Al-Ghaili et al. (2022); Giang Barrera and Shah (2023); Huynh-The et al. (2023); Lee et al. (2021); Xu et al. (2023); Zallio and Clarkson (2022); Zhao et al. (2022)
Sustainability	Should ensure that the metaverse maintains a closed economic loop and a consistent value system with a high level of independence. Prevent from being controlled by a few powerful entities.	Choi et al. (2022); Dwivedi et al. (2022); Giang Barrera and Shah (2023); Park and Kim (2022); Wang et al. (2021); Wang et al. (2021); Wang et al. (2023)
Trust and *accountability*	Should ensure fairness, power and control, auditing, trusted execution environments, people are comfortable with and embrace the technologies.	Al-Ghaili et al. (2022); Choi et al. (2022); Dwivedi et al. (2022); Lee et al. (2021)

Appendix 6. The most important functional requirements' statistics

Category	Functional requirements	Mean	Median	ANSD
Data infrastructures	Computation - the cloud-edge-end computing paradigm, efficient AR/VR cloud-edge-end rendering, scalable AI model training, quantum computing - programs, instructions, algorithms	**2.90**	**3.00**	**0.10**
Technologies and concepts	Digital twin and 3D modeling technologies - 3D simulation, 3D reconstruction, data fusion	**2.90**	**3.00**	**0.10**
Technologies and concepts	Web and other related standards and tools such as authentication, interoperability, accessibility etc.	**2.80**	**3.00**	**0.18**
Recognition, rendering, and modeling environments	Scene and object recognition and understanding tools	**2.80**	**3.00**	**0.18**
Recognition, rendering, and modeling environments	Scene and object generation tools - 3D reconstruction	**2.70**	**3.00**	**0.23**
Content management	Content creation - authoring, creator culture	**2.70**	**3.00**	**0.23**
Data infrastructures	Storage - local caching, edge caching, cloud caching, decentralized edge data storage and sharing, cloud computing, local storage, long-term storage	**2.60**	**3.00**	**0.27**
Networks and communication	Physical and virtual service providers - real-time physical-virtual synchronization, communication services	**2.60**	**3.00**	**0.27**
Networks and communication	Wireless 5G/6G networks, tactile internet	**2.60**	**3.00**	**0.27**
Physical devices, sensors, and controllers	Head-mounted displays (equipment) and controllers - AR/VR smart glasses	**2.60**	**3.00**	**0.27**
Recognition, rendering, and modeling environments	Translation, recommendation, and testing tools - enable correct settings for users	**2.60**	**3.00**	**0.27**
User interactions' data	Agent persona (virtual entity) modeling	**2.60**	**3.00**	**0.27**
User interactions' data	Social computing - social networks,	**2.60**	**3.00**	**0.27**

Category	Functional requirements	Mean	Median	ANSD
	swarm intelligence			
Physical devices, sensors, and controllers	Users' devices and equipment - general (text, audio, video) devices	**2.50**	**2.50**	**0.28**
Recognition, rendering, and modeling environments	Identity modeling - authentication, resolution tools	**2.50**	**2.50**	**0.28**

Appendix 7. The most important non-functional requirements' statistics

Non-functional requirements	Mean	Median	ANSD
Accessibility	**2.90**	**3.00**	**0.32**
Consistency	**2.90**	**3.00**	**0.32**
Privacy	**2.90**	**3.00**	**0.32**
Security and cybersecurity	**2.90**	**3.00**	**0.32**
Policy and governance	**2.80**	**3.00**	**0.42**
Quality of service	**2.80**	**3.00**	**0.42**
Scalability	**2.60**	**3.00**	**0.52**
Sociability	**2.60**	**3.00**	**0.70**
Trust and accountability	**2.60**	**3.00**	**0.52**
Ethics and behavior	**2.50**	**2.50**	**0.53**
Heterogeneity and diversity	**2.50**	**2.50**	**0.53**
Interoperability	**2.40**	**2.00**	**0.52**
Sustainability	**2.40**	**2.50**	**0.70**
Immersiveness	**2.30**	**2.00**	**0.67**
Hyper spatiotemporality	**2.10**	**2.00**	**0.32**

Appendix 8. The most relevant digital public services to be provisioned in the EU's metaverse platform

Category	Digital public service	Mean	Median	ANSD

Citizens – Career	2.5 Get guidance with how to arrange help during invalidity, sickness and employment injuries	**2.6**	**3**	**0.27**
Citizens – Studying	3.4 Get guidance with how to arrange internships and starting your career	**2.6**	**3**	**0.49**
Citizens – Studying	3.3 Get guidance with how to arrange studying abroad (international office)	**2.5**	**3**	**0.50**
Citizens – Health	1.1 Get guidance and information about where you can get healthcare	**2.5**	**2.5**	**0.28**
Citizens – Moving	1.1 Monitor the availability of local facilities (e.g., schools, health facilities, sport facilities)	**2.5**	**3**	**0.50**
Citizens – Career	2.2 Get guidance with how to arrange housing benefits	**2.4**	**2**	**0.27**
Citizens – Career	2.3 Get guidance with how to arrange debt counselling	**2.4**	**2**	**0.27**
Citizens – Career	2.4 Get guidance with how to arrange health promotion programs	**2.4**	**2**	**0.27**
Citizens – Career	4.1 Get guidance with how to find a job	**2.4**	**2.5**	**0.49**
Citizens – Studying	1.1 Monitor study programs provided by universities	**2.4**	**2.5**	**0.49**
Citizens – Transport	3.1 Check information and plan a journey (involving multiple types of public transport)	**2.4**	**2.5**	**0.49**
Businesses – Business Start-Up	1.3 Get guidance with how to explore financial possibilities	**2.3**	**2**	**0.46**
Businesses – Business Start-Up	1.2 Get guidance with how to write a business plan	**2.2**	**2**	**0.18**
Businesses – Business Start-Up	5.3 Get guidance with how to arrange (compulsory) healthcare insurance	**2.2**	**2**	**0.18**

Citizens – Justice	1.2 Check relevant legislation and rights for defending your case	**2**	**2**	**0.44**
Businesses – Business Start-Up	5.2 Get guidance with how to arrange (mandatory) pension insurance	**2**	**2**	**0.22**
Citizens – Studying	1.2 Check admission requirements for enrolling in higher education	**1.9**	**2**	**0.54**
Businesses – Business Start-Up	1.1 Check requirements for starting a business	**1.9**	**2**	**0.32**
Citizens – Career	5.1 Calculate future pensions	**1.8**	**2**	**0.40**
Citizens – Career	5.3 Check entitlement for pension when moving abroad or returning from another country	**1.8**	**2**	**0.40**
Citizens – Family	3.1 Obtain passport	**1.8**	**2**	**0.40**