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How can the Communication Sector Adapt to the Metaverse.

Afonso da Costa e Silva Carvalho Alves

Master's Degree in Telecommunications and Computer Engineering

Supervisor:
PhD Rúben Filipe de Sousa Pereira, Assistant Professor, Iscte-IUL

Co-Supervisor:
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TECNOLOGIAS
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Department of Information Science and Technology

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Resumo

O metaverse é um termo utilizado para descrever uma nova geração da Internet, em que os utilizadores podem interagir uns com os outros e com objetos e experiências virtuais em tempo real. Prevê-se que venha a ter um impacto significativo numa vasta gama de sectores.

Esta investigação examina os potenciais impactos do metaverse no sector das comunicações a curto prazo. Começa por definir o metaverse e discutir as principais tecnologias que permitem o seu desenvolvimento. Em seguida, identifica as áreas de negócio com maior probabilidade de serem afetadas pelo metaverse. Este estudo defende que o metaverse terá um impacto significativo no sector das comunicações a curto prazo e conduzirá ao desenvolvimento de novas tecnologias de comunicação, plataformas e modelos de negócio. Também mudará a forma como as pessoas comunicam umas com as outras e consomem informação.

Esta investigação analisa a forma como o sector das comunicações se pode adaptar ao metaverse. Defende que o sector precisa de investir em novas tecnologias e plataformas e desenvolver novos modelos de negócio. Deve também concentrar-se na criação de experiências de utilização envolventes e cativantes que atraiam uma maior adoção do metaverse por dos utilizadores.

Palavras-Chave: metaverse, indústria das comunicações, tecnologia, modelos de negócio, experiência na ótica do utilizador

Abstract

The metaverse is a term used to describe a new generation of the internet, where users can interact with each other and virtual objects and experiences in real-time. It is expected to significantly impact a wide range of industries, including communications, entertainment, and education.

This research examines the potential impacts of the metaverse on the communications industry in the short term. It begins by defining the metaverse and discussing the key technologies enabling its development. It then goes on to identify the business areas that are most likely to be impacted by the metaverse.

This research argues that the metaverse will significantly impact the communications industry in the short term. It will lead to the development of new communication technologies, platforms, and business models. It will also change the way that people communicate with each other and consume information.

This investigation discusses how the communications industry can adapt to the metaverse. It argues that the industry needs to invest in new technologies and platforms and develop new business models. It also needs to focus on creating immersive and engaging user experiences.

Keywords: metaverse, communications industry, technology, business models, user experience

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CHAPTER 1

Introduction

The metaverse is a term used to describe immersive digital environments that allow users to interact with each other and with virtual objects and experiences in real-time [41]. The concept of the metaverse has been around for decades and has been popularized in science fiction literature and movies [1]. However, with the recent advances in virtual and augmented reality technology, the metaverse is becoming more of a reality, as companies and organizations are beginning to build and explore the possibilities of these immersive digital spaces [42]. The metaverse will likely have a significant impact on communication technologies, as it will provide a new platform for people to connect and communicate with each other [21]. Metaverse will also likely lead to the development of new communication technologies and platforms, as companies and organizations seek to build and explore the possibilities of these immersive digital spaces [21]. For example, Meta is currently hiring thousands of engineers in Europe to develop projects associated with the metaverse and to develop new technologies and solutions in this area, bringing the existence of a large-scale, global metaverse ever closer [41].

Concerning accessibility, as the metaverse becomes more prevalent, there will also be a need for governance and regulation to ensure that it is used ethically and responsibly [3]. This could include issues around privacy, security, and the impact on physical communities, as well as other issues that may arise as the metaverse evolves [12]. It will be important for companies, policymakers, and users to work together to develop appropriate governance frameworks [13].

Virtual reality (VR) technology is likely to play a significant role in the development of the metaverse, as it allows users to fully immerse themselves in virtual environments [7]. However, the use of VR technology also raises some ethical and societal considerations, such as the potential for addiction or the impact on physical health [6]. Also, artificial intelligence (AI) is likely to play a significant role in the metaverse, as it can be used to create more realistic and immersive virtual experiences, as well as to facilitate communication and interaction between users [10]. However, the use of AI in the metaverse also raises some ethical and societal considerations, such as the potential for bias or the impact on employment [6]. It will be important to consider these issues as AI technology continues to evolve and become more prevalent in the metaverse [6].

Regarding business opportunities, metaverse means a lot of new opportunities, as companies and organizations seek to build and explore the possibilities of these immersive digital spaces [3]. For example, the limited-edition virtual products launched by the Italian luxury fashion brand Gucci on the Roblox platform proved to be extremely profitable for the brand, while also managing to establish new and innovative ways of interacting with its users in the metaverse [14]. Additionally, the metaverse may provide new platforms for advertising, as companies seek to reach consumers in these immersive digital environments [31]. In education, metaverse provides a new platform for people to learn and develop new skills [9]. For example, users may be able to participate in virtual reality simulations or experiences that help them learn in a more

immersive and interactive way [9]. The metaverse may also provide new opportunities for distance learning and may allow people to access educational resources and experiences that are not available in their physical location [7]. In entertainment, metaverse has a big role transforming this industry, as it provides a new platform for people to engage with and participate in virtual experiences and events [13]. For example, users may be able to attend virtual concerts or sporting events or participate in virtual reality games or experiences [7]. The metaverse may also provide new opportunities for the creation and distribution of entertainment content, such as movies, TV shows, and music.

Overall, the metaverse has the potential to revolutionize communication technologies and the ways in which we connect and communicate with each other. Regarding this context, this research aims to assess what impacts the metaverse and associated technologies will have on the current communications market in the short term, and how this business sector can adapt and use to its advantage this new wave of tools and possibilities, rather than miss out on this huge range of opportunities that will emerge over the next few years. This research aims to understand how the business sector that serves as underlay for everything regarding connectivity: the communications industry, can adapt to serve this new era of global communication, that brings very ambitious and demanding requisites that will test the global communication infrastructure.

To accomplish the purpose of this investigation, it is first needed to understand what metaverse truly is, including the technological ecosystem underneath it, and the business areas where it can bring more changes and benefits. Secondly, it is necessary to comprehend how will metaverse impact the communications industry in the short-term period, to have a proper timeline to understand how this sector can adapt to it before these technologies become dominant in the market. And as last, and with the input of the answers of the two previous problems, this investigation will assess how the communications business should adapt to this new reality, and what action should this companies take to accomplish this adaptation. Therefore, this investigation will focus on the following 5 research questions:

RQ1: What is the metaverse?

RQ2: What technologies work together to form the metaverse?

RQ3: What business areas will benefit more from the metaverse?

RQ4: How will the metaverse impact the communication industry for the next 5 years?

RQ5: How can the communication industry adapt to the metaverse?

The following chapters on this document will be dedicated to the discussion and analysis for finding the answers to the above questions. Chapter 2 walks through the methodology used for this investigation, while chapter 3 have the discussion and analysis of all the collected data, and finally chapter 4 will have the answers obtained for the research question, and general conclusions of this investigation.

CHAPTER 2

Methodology

2.1. Literature Review

The literature review will be conducted to identify and synthesize the existing knowledge on the metaverse and its implications for the communication industry. The literature will be drawn from a variety of sources, including academic journals, industry reports, and news articles. The following keywords will be used to search for relevant literature:

KW1: Metaverse

KW2: Communications

It was opted for a multivocal literature review, given the lack of scientific literature that brings together the topics of the metaverse and the communications business. By also including industry reports and news articles, this literature review ensures a broader comprehension not only for metaverse key technologies and how they interact and depend on each other, but also on the business areas it can have an impact, and what will be the role of communication companies in the adoption of this new wave of technologies.

2.2. Interviews

The interviews will be conducted with a sample of experts in the communication industry, including technical and business professionals. The interviews will be semi-structured, and will focus on the following topics:

- The challenges and opportunities of the metaverse for the communication industry.
- The key trends in the metaverse that will impact the communication industry in the short term.
- The recommendations for the communication industry in adapting to the metaverse.

The interviews will be recorded and transcribed. The transcripts will be analyzed to identify themes and patterns.

The main purpose of these interviews is to bridge the information gaps from the literature review given the lack of documentation. The research questions will be formulated after the literature review, to cover the topics and the research questions that the literature review is not able to fully analyze.

The total number of interviews that will be conducted is not fixed, once it will depend on the saturation rate of the questions. This investigation will conduct interviews until it is detected that for every question, the provided answers are no longer adding substantial new information that will be used to answer to the research questions.

The sample of communication specialists that was interviewed is a mix of personal contacts of the researcher in the communication area, as well as the result of a research in the professional social media platform LinkedIn for professionals that have high responsibility role in prominent communication businesses, or professionals with deep technical knowledge of at least one of metaverses' key technologies.

2.3. Data analysis

The data from the literature review and the interviews will be analyzed using a thematic analysis approach. Thematic analysis is a method for identifying, analyzing, and reporting patterns (themes) within data. The themes will be used to answer the research questions and to develop the conclusions of the study.

On the literature review, this will translate on the identification of the key areas that are present in the scientific community. On the interviews, this method will extract the main patterns in the experts' responses, as well as minoritarian opinions and outliers.

2.4. Challenges of conducting research on the metaverse

There are several challenges associated with conducting research on the metaverse. One challenge is the lack of a clear definition of the metaverse. The term is still evolving, and there is no consensus on what it means. This makes it difficult to identify and synthesize the existing knowledge on the metaverse.

Another challenge is the lack of data on the metaverse. The metaverse is still in its early stages of development, and there is not a lot of data available on its users, usage patterns, and economic impact. This makes it difficult to understand the implications of the metaverse for the communication industry.

Despite these challenges, this study will contribute to the understanding of how the communication industry can adapt to the metaverse. The findings of this study will be valuable to communication industry professionals who are looking to understand the opportunities and challenges of the metaverse.

2.5. Limitations of the study

This study has several limitations. First, the literature review is limited by the availability of literature on the metaverse and its implications for the communication industry. Second, the interviews are limited by the sample of experts who were interviewed. Third, the thematic analysis is limited by the interpretation of the researcher.

CHAPTER 3

Literature Review

For this literature review, the author initially thought to use the keywords "metaverse" and "telecommunications" since they are the two main terms intended to evaluate the level of scientific knowledge production. After some tests, the conclusion was that these two keywords could have brought better results in the primary scientific databases because many of the articles were outside the scope of this research. The author concluded that the keywords "metaverse" and "communication" best fit the intended review. With the previously defined keywords, the author used the following query: ("All Metadata": Metaverse) AND ("All Metadata": Communications), resulting in the results shown in table 1.

Table 1 – Results obtained with the keywords “metaverse” and “communications”.

Scientific Database	# Results	# Selected
IEEE Xplore	71	9
ACM Digital Library	49	2
Springer Link	87	0
Web of Science	62	1
Scopus	1177	15
EBSCO	1746	6

All the results in the "# Selected" column already exclude duplicate articles, totaling 33 articles selected for this literature review. This low value of results is because the term metaverse, although already used for several decades [1], is recent in the technological environment, resulting in the low production of scientific literature regarding this topic. This situation worsens when trying to research literature that intercepts metaverse with communications. Given the low value of results in scientific literature, this investigation decided to do a Multivocal Literature Review (MLR) to obtain more information from the grey literature because this is a recent area of research and because this is a sector of technological innovation, which may be more studied on in the business sector than in the scientific environment.

When searching the grey literature, the same methodology was used as in the scientific databases, looking for any matches containing the exact keywords already mentioned, but this time in the Google search engine. This method led to thirteen selected articles after removing publications that, although from different authors and pages, had the same text content in most or all. This literature review includes 46 documents, 33 scientific articles, and 13 grey literature publications at the end of the research process.

In the analysis of the documents, two main components in which the metaverse and the communications sector intersect stand out, and within each of these components, several themes with different hierarchies of relevance are referred to and developed. The first component is the technical one, which describes the leading technologies involving the metaverse and their role in the future, as well as which technical areas will have to support the implementation of these technologies in the market, such as legislation, for example. The second component is business, which mentions the areas that can benefit most from the arrival of the metaverse and all the technologies that comprise it. Image 1 and show these components and their main topics.

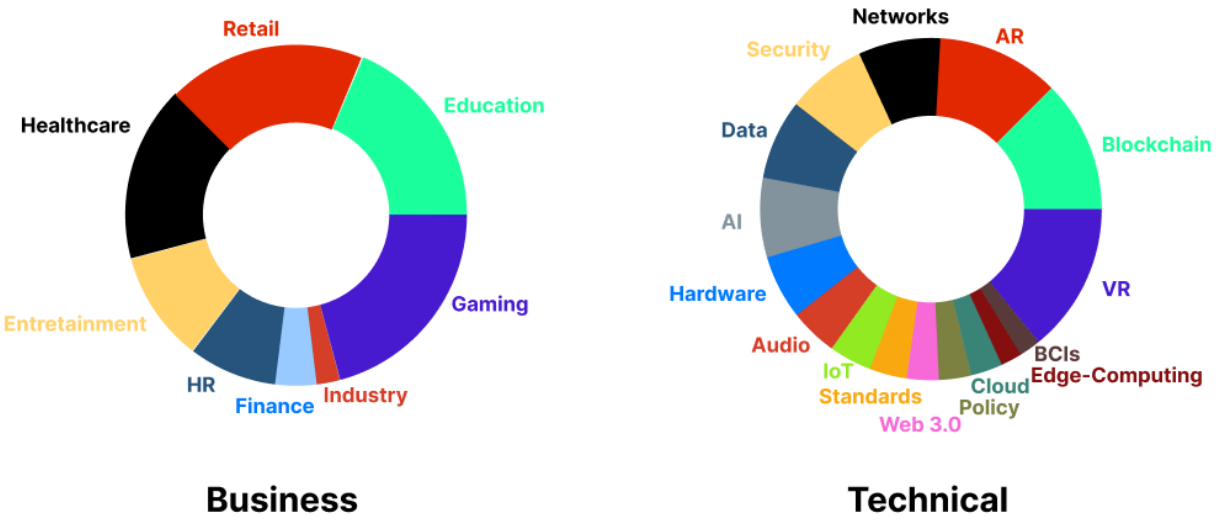

Image 1 – Business and technical components and their main topics

3.1. Definition of Metaverse

Although the concept of metaverse applied to technology and digital transformation is recent, as mentioned before, this term is a few decades old. Its first appearance was in the cyberpunk dystopia novel "Snow Crash" by Neal Stephenson and published in 1992, where the author describes that the main character finds himself "in a computer-generated universe that his computer is drawing onto his goggles and pumping into his earphones. In the lingo, this imaginary place is known as the Metaverse" [1]. Based on this definition, several authors have varied in their descriptions of the metaverse, and there are multiple interpretations of whether the metaverse already exists in the present or if it should occur in the short term [2] or only in several decades [3]. In [4], a compilation of 54 different definitions of metaverse organized in chronological order and their author shows the already high number of attempts to define such a new topic for academic research.

Despite many different descriptions and views of the metaverse and whether it exists in the present, it is necessary to choose a single definition to carry out this research. This investigation chose the more cited article to address this issue. The selected article [5] describes the metaverse as "A collective virtual shared space, created by the convergence of virtually enhanced physical reality and physically persistent virtual space, including the sum of all virtual worlds, augmented reality, and the Internet." It is relevant to point out that this is not the most cited

article of all those considered for this literature review, that being [4]. However, [4] consists of a literature review, considered a secondary source of information, making this investigation choose the definition presented in the second most cited article.

3.2. Technical Component

3.2.1. Virtual Reality

Virtual Reality (VR) is described in [6] as "a simulated experience that imitates the real world, or some aspects of it, using specialized software and hardware." There is also a distinction between Atomistic and holistic VR, the former being described as having a low level of virtual presence, with the users not having the feeling of being present in the virtual world presented to them, and the latter, in contrast, is characterized by high levels of virtual presence supported by high quality multisensory digital content, and great freedom of actions [7]. One of the factors that best distinguish VR from other digital reality technologies, like augmented reality (AR) or mixed reality (XR), is that VR must provide some level of immersion in its use [6].

As seen earlier in this chapter, VR is the most mentioned technology when considering all the technologies expected to influence the metaverse significantly. Readers who have never experienced VR devices are even advised in [3] to experiment. On the one hand, VR will be used to create immersive 3D digital environments [2] (an essential feature for constructing the metaverse as described above). On the other hand, the necessary hardware, such as a headset or haptic gloves, is increasingly affordable [1], which makes this technology one of the most critical for a global metaverse implementation.

The potential of VR is undeniable, yet its widespread adoption as a communication medium could be improved by demanding computing power and bandwidth requirements [8]. Meeting the need for efficient and economical distribution at scale presents significant challenges, as the global network infrastructure currently imposes limits on computational capacity and bandwidth. Additionally, ultra-low latency and ultra-reliable wireless connections are required for VR services delivered via metaverse applications, such as Massive Multiplayer Online Games (MMOG) or virtual concerts [8]. The memory and storage demand of VR are also significant, with an entry-level 360° VR experience requiring approximately ten terabytes (TB) of space for a decompressed video that lasts only 20 minutes [9]. Furthermore, VR technology poses privacy risks as it can monitor and measure user movements in detail and volume, potentially enabling the establishment of movement or neuronal activity patterns [5][7]. The development of industry standards for VR hardware is also lagging, which may impede the widespread adoption of this technology and its solutions [6].

Meta has announced that it is actively developing a high-end VR project named Cambria that promises to offer features currently unavailable in VR devices. The Cambria headset incorporates new sensors that enable the virtual representation of users to maintain eye contact and mimic facial expressions, ultimately replicating the user's face and eye movements in a virtual environment [7]. Alongside this ambitious project, the latest VR advances concentrate on the senses and their corresponding affordances [6].

3.2.2. Blockchain

Blockchain is considered one of the essential components of the metaverse and originated as the foundational technology of bitcoin, the first decentralized digital cryptocurrency introduced by Satoshi Nakamoto [10]. As described in [10], blockchain is a distributed and immutable ledger that enables transparent transactions. Blockchain is a game changer in terms of security and anonymity, functioning as a ledger that records information about transactions, facilitates tracking processes, and protects digital assets in a business network [11]. Furthermore, as stated in [11], blockchain's primary functionalities include storage, sharing, and information interoperability.

Network-integrated blockchain is a crucial element of the new generation of the world wide web, enabling efficient management of the peer-to-peer network at both the physical and virtual levels while achieving integration across multiple intermediaries and platforms [12]. According to [12], the decentralization characteristic of blockchain has enormous potential to satisfy several communication and computation requirements, sustaining the connection, coordination, and control of multiple heterogeneous devices, making it a possible solution for managing various devices from different manufacturers, which will be necessary for the metaverse. Blockchain's native communication approach in the metaverse, as mentioned in [10], can directly integrate multiple platforms into encrypted addresses unique to each user, allowing the elimination of current services that initiate, manage, and terminate sessions in internet access, such as IP and HTTP, for example. Blockchain's consensual mechanism to perform transactions anonymously but accountably is one of its main benefits for the metaverse, as stated in [10].

Blockchain is a critical technology for the metaverse, as it provides a reliable and stable mechanism for authentication [13]. It enables information sovereignty, virtual identity authentication, and biometric data circulation. The importance of blockchain for protecting the digital property of metaverse users is reinforced in [11]. The metaverse ecosystem can ensure its users' integrity, privacy, and reputation by leveraging blockchain technology. As emphasized in [11], blockchain transactions lack intermediaries, which means third parties cannot access confidential information and potentially take advantage of it, helping to prevent theft, extrusion, or other forms of abuse. In a blockchain-based metaverse reality, users are the owners and holders of their data, with the power to decide if and how third parties access their data and under which circumstances.

Using blockchain in the metaverse provides financial benefits, such as cost efficiency due to recording all network events as transactions, eliminating the need for third-party audits [12]. Blockchain's impact on the financial sector goes beyond cost reduction, as financial assets represented as tokens are integrated into the inner functions of most decentralized web activities [14]. The introduction of blockchain technology and the Bitcoin cryptocurrency was a milestone in developing the digital economy [11]. For instance, the Decentraland platform running on the Ethereum blockchain enables the creation, purchase, and sale of virtual land,

properties, and digital goods, illustrating the global adoption of blockchain technology in the metaverse [7].
Although blockchain technology provides various benefits to the metaverse, it poses challenges, as mentioned in [10]. One such challenge is the introduction of overhead in communications due to the computational and communication resources needed to support transactions in this technology. Additionally, [10] raises two pertinent questions related to the metaverse's logistical, financial, and regulatory aspects. These questions pertain to who will pay for the considerable investments needed in computing and communication and which bodies will regulate the activities and services of the metaverse, especially in a fully decentralized system, as presented in [10].

3.2.2.1. Non-Fungible Tokens

NFTs, or Non-Fungible Tokens, are information recorded on a blockchain, as stated in [3]. According to [15], NFTs provide an effective way to prove the originality of user or service-provider-created content, making it distinct from a replica (hence its name). In addition, [15] explains that NFTs enable digital content owners to buy or sell their property through smart contracts based on a blockchain. NFTs also enable private ownership in the metaverse, allowing users to prove that they own items, representations of themselves in the form of avatars, property, and other types of assets, and verify the authentication of virtual assets or identities, as explained in [7]. As for development and implementation, [16] points out that NFTs are created using the same type of programming as cryptocurrencies but with the distinct feature that they are not exchangeable but rather represent digital property records. These tokens are mainly used for creating, buying, or selling digital art and video game skins, sneakers, and other collectibles.

Some platforms that have experienced significant growth in the buying and selling virtual property in the form of NFTs are mentioned in [17], such as Decentraland or The Sandbox. These platforms allow users to purchase virtual land parcels using cryptocurrencies. [10] notes that NFTs are recognized as the most critical technology for virtual property identification, as their operation depends on the inherent properties of the blockchain, namely its ability to store information in a transparent and immutable way.

One possible vision for the evolution of the metaverse, as presented in [2], is that users could own virtual items instead of service platforms. In this vision, the interoperability of the metaverse would allow users to buy any virtual items traded as NFTs through a platform's virtual store and later use them in their avatars in other applications or services of the metaverse.

As mentioned before, this expansion of NFTs is not limited to gaming experiences and virtual products but also to other areas such as fashion, concerts, and virtual performances, as noted in [17]. A blockchain-based metaverse can thus create a marketplace driven by its users, where they can buy and sell such experiences and products, all made possible by NFTs.

3.2.2.2. Cryptocurrencies

Some have considered cryptocurrencies as the foundation of the economy in the metaverse [1] and have the potential to become the primary payment method for buying and selling goods and services in this virtual space. The basis of cryptocurrencies in the blockchain is expected to play a crucial role in the future of applications due to the great need for privacy and individual control that characterizes modern applications [14]. The early stage of the metaverse was marked by the emergence of encrypted addresses following the first cryptocurrency, bitcoin [10]. Cryptocurrencies also serve as an economic bridge between the metaverse and the natural world [4]. The decentralized web operates with a high reliance on the blockchain, and most current metaverse platforms allow using cryptocurrencies as a payment method [19]. However, the volatility and unpredictability of cryptocurrencies can also introduce disadvantages [19].

3.2.3. Augmented Reality

Augmented reality (AR) is a technology that blends the real and virtual worlds [10]. Using computer vision, AR can recognize surfaces and objects in the physical world with object recognition, plane detection, face recognition, and motion tracking [10]. A computer overlays the digitally generated content, such as graphics, sounds and messages, on the previously identified natural surfaces and objects [20]. The digital content generated by an AR application is notably distinct from the physical environment, and in most situations, AR users perceive virtual objects floating in real-world places or things [7]. Unlike other technologies often confused with AR, such as VR, AR does not provide the user with a notion of total immersion. All the content arranged in the user's field of view appears to compose reality [7].

The importance of AR technology is pointed out in [3], where it is mentioned that each user in the metaverse should have and control a representation of himself called an avatar. This importance is reinforced in [8], which notes that VR and AR devices will be users' gateway to the metaverse. Moreover, it is said in [21] that AR devices have been becoming increasingly cheaper, facilitating their massification in accessing the metaverse. In [20], it is even mentioned that AR and other technologies, such as VR and Artificial Intelligence (AI), may create new virtual environments with minimal human intervention.

According to [9], current AR technology relies on computing elements located locally in the headsets, and future developments will require compatibility with distributed computing systems that offer multiple functions for different services to support the metaverse's potential fully. [11] highlights the importance of AR technology reaching a point where virtual objects represented by the AR headset are indistinguishable from actual surroundings, which is seen as a critical aspect of the metaverse's future. Moreover, [11] expects AR and VR technologies to facilitate information exchange, enabling innovative solutions to real-world problems or experiences limited by physical resources. [22] adds that achieving this vision for AR will require high-quality, high-speed, and low-latency processing of digitally created images and audio.

AR, despite its potential benefits, has risks. As noted in [7], certain types of malware can temporarily blind a user when using AR hardware, potentially leading to risky situations. Furthermore, as with VR, [23] highlights the potential privacy concerns of collecting detailed user data through AR use. In addition, [22] notes that any compromise of an AR service or device could create inconsistencies between the virtual and physical worlds, potentially leading to dangerous situations.

3.2.4. Digital Twinning

Digital Twin technology, as defined by [18], enables digitizing physical objects into the virtual world. Through this technology, users can experience the movement and behavior of physical objects in virtual environments. DT maps real and virtual goals in real-time, providing an immersive experience in the metaverse, which [12] expects to be data-driven and sensitive to delays concerning changes in the physical states of the DT. Moreover, virtual representations of real-life-like environments will be supported through DT with graphical representation via AR or VR headsets. DT's evolution currently allows its use in modelling and mirroring information, digital simulations, and 3D printing [12]. The business sector has also recognized its importance, with [24] mentioning that TCTx, a Dubai-based company dedicated to developing metaverse applications, is working on a full-scale DT of the real world.

DT has several applications in the industrial sector. It allows the replication of physical systems properties or the capacity of a VR system to render 3D visual content using images as input [9]. Additionally, mapping the physical world to the metaverse using DT enables combining data from cyber-physical spaces with deep learning and AI-enhanced learning methods for organic growth-oriented content editing [13], creating a rich and plural global digital environment. DT is also being used in the retail industry. For instance, IKEA has launched an AR service that creates a digital replica of a particular product that users can test before buying [7].

According to [12], DT technology creates new possibilities for decentralized computing by enhancing the performance of a physical device beyond its locally available resources through optimization, information processing, and AI algorithms that operate in the DT of the device. Furthermore, the DT may have distributed computing capacity through edge-computing or remote cloud services, opening a world of possibilities.

3.2.5. Networks

To enable the proper functioning of the technologies mentioned above and support the metaverse, a robust network infrastructure is crucial, as noted by [3]. This infrastructure must provide stable, high-bandwidth connections in real-time and be able to transmit data in a decentralized manner. Backbone providers, traffic switching points, and service providers running on top of the physical infrastructure all ensure these characteristics. As noted by [12], the integration between network infrastructure and blockchain is a critical element of the next generation of the World Wide Web (Web 3.0), and universal connectivity will be necessary for the operation of the metaverse. The 3rd Generation Partnership Project (3GPP), established in 2015, has developed the TR 22.891 specification for 5G satellite connectivity, which could solve the connectivity problem. However, as noted by [25], latency in transmissions remains a

significant challenge for metaverse applications, despite the development of many communication techniques.

Network management, interoperability, privacy, and security are among the main challenges that must be overcome to support the metaverse [12]. Standardized network access and robust routing and congestion management protocols will be necessary for the communication and networking technologies supporting the metaverse. However, [12] also points out that there will be a high heterogeneity of devices and manufacturers in the metaverse, requiring the refinement of these protocols in each subsystem. Despite the emergence of cloud computing techniques, distributed computing, and mobile edge computing, modern networks maintain a client-server architecture that does not optimize point-to-point connectivity [9]. In the context of the metaverse, [9] highlights the high requirements for information storage, binary streaming rates, and processing capacity, which will accelerate the fusion between large clouds and the rest of the network, leading to highly distributed and intensive networks in terms of information transmission, stimulating the emergence of third-generation networks that are characterized by their high levels of distribution and caching systems, as well as innovative network management and congestion techniques [9].

3.2.5.1. Wireless

The latest mobile communication technology, 5G, is considered the most suitable means for accessing the metaverse anywhere and anytime [8]. This idea is reinforced by [13], highlighting the importance of 5G in supporting the metaverse due to its high speed, low latency, and large-scale connectivity capabilities. In addition, [4] mentions that 5G remains the preferred technology for coverage over large areas. The recent significant progress made in 5G has accelerated the metaverse development considerably, as stated in [15], emphasizing the critical role of 5G as a communication mechanism. According to [8], the metaverse is the best use case for 5G, given its capacity and speed, which can support large-scale VR and AR applications that other communication technologies may significantly limit.

Although 5G is the latest mobile connectivity technology, it is estimated that the emergence of the metaverse and its technologies is not only the main driver for the emergence of 6G but also the one that will scale the requirements for this new iteration in cellular connectivity [12]. To achieve the ambitious requirements planned for 6G, multiple sensing, communication, and computing techniques must be integrated with the network [12]. This paradigm brings vast challenges for 6G development, namely in terms of ubiquity in connectivity, ultra-low latency, ultra-high capacity and reliability, and strict security standards [12]. Furthermore, to allow users to move in and out of the metaverse anywhere at any time, it is necessary to support concurrent access of users in both space and time, which will substantially increase the requirements for seamless and full-coverage connectivity for 6G [12]. The metaverse relies on many technologies whose proper functioning is dependent on 6G. For example, DTs need great processing speed for AI algorithms, information exchange, and high levels of security to interact with each other and behave similarly to real objects [12]. Currently, 6G is under development, and while there are not many known specifications yet, it is known that it will involve higher frequencies than those currently used and will also include AI [27].

Although 5G and 6G are often discussed concerning communication within the metaverse, wireless communication is also crucial due to the need for cable-free connectivity in devices such as VR or AR headsets. [8] suggests that a wireless edge-empowered metaverse could be possible with ubiquitous wireless connectivity and powerful edge-computing technologies. [9] reinforces the importance of wireless connectivity by stating that third-generation networks will be highly distributed and primarily wireless. Additionally, [10] notes that wireless communication is critical for local metaverse entities, as most users connect via mobile networks using devices such as VR and AR glasses, haptic gloves, or computer hardware. [4] further highlights the importance of wireless connectivity by suggesting that Wi-Fi 6 should continue to be the preferred technology for indoor wireless connectivity due to its low implementation costs.

3.2.6. Security

Ensuring security and privacy in the metaverse is emphasized throughout this research. The vast amount of data generated and collected in the metaverse, stored in data centers and clouds, presents a significant risk of privacy violation [12]. Such a risk arises due to the possibility of compromising a massive amount of information at a single point of failure in case of a security breach. Additionally, collecting large amounts of data raises issues such as information fraud and monopolization [13]. Given the metaverse's capacity to collect user behavior data in much greater detail than the present data collection with the internet, [4] highlights the need for strict security and privacy measures.

As the metaverse presents several challenges to security and privacy [12], blockchain-based solutions are seen as one of the main ways to address these challenges [12]. Access management and identity verification systems can be developed using blockchain, thereby increasing security [12]. The technology is deemed critical in the metaverse due to its potential for interoperability, reliability, privacy, security, and scalability [12]. [10] envisions a metaverse accessible through encrypted addresses and service providers, allowing for maximized privacy, user anonymization, and end-to-end security. Once all entities are identified by their encrypted addresses, [10] argues that communication should be optimized from the root to ensure security and connectivity with minimal third-party involvement. While [11] suggests that the detailed information collected in the metaverse will be essential for creating effective targeting systems for businesses and applications, [4] notes that users' information is protected on the blockchain through an asymmetric key encryption system and hashing algorithms and can only be used for targeting purposes with their consent. However, blockchain-based technologies are not invulnerable to attack, with [7] mentioning the vulnerabilities of NFTs and cryptocurrencies and [23] cautioning against the risk of credential theft, social engineering techniques, or Denial of Service (DoS) attacks. Additionally, advances in deep fake technology make social engineering attacks increasingly challenging to detect [23].

As highlighted by [13], standardization of security requirements in the metaverse is crucial in addressing security challenges. C-Security standards, which include hardware, software, and information security components, can guide the protection requirements of the physical

equipment, software systems, and information in the metaverse. However, as noted by [12], blockchain solutions alone cannot fully address all security challenges in the metaverse, especially in protecting users' privacy. Additionally, as mentioned by [17], the high degree of freedom in the metaverse can increase the risk of privacy violations and cyberbullying. Therefore, while significant investments have been made in developing metaverse technologies, as emphasized by [7], more attention must be given to security and privacy issues to prevent potential problems.

In addition to the "security by design" approach, [7] suggests using multi-factor authentication and encryption techniques to protect sensitive data, along with regular security audits and vulnerability assessments. [13] also suggests the need for continuous monitoring and evaluation of the metaverse's security and the implementation of a security incident response plan in the event of a security breach. [17] adds that education and awareness of users about cybersecurity best practices are also crucial to mitigate security risks and prevent cyberbullying, harassment, and other forms of online abuse in the metaverse. Moreover, [7] also proposes using decentralized storage and communication systems to enhance privacy and security in the metaverse. Decentralized systems can mitigate the risk of single points of failure and reduce the possibility of large-scale data breaches. [12] supports this approach, stating that decentralized systems such as blockchain-based ones can provide high security and privacy for users in the metaverse. Additionally, [10] advocates using encrypted addresses for user identification and communication to ensure end-to-end security and user anonymity.

It is important to note that while AR or VR headsets can provide a more immersive and engaging experience in the metaverse, they also pose potential security risks. As mentioned in [23], attackers can take advantage of the headsets' software or hardware vulnerabilities to gain unauthorized access to the user's personal information, such as biometric data or location data. Additionally, [6] raises concerns about the potential for users to become so immersed in the metaverse that they may become more vulnerable to social engineering attacks, such as phishing scams or identity theft. It is essential to consider these risks and develop security measures that can mitigate them to ensure the safety and privacy of users in the metaverse.

In conclusion, the metaverse is expected to revolutionize how people consume, access services, play media, and interact with other people and businesses [28]. This virtual world is predicted to bring people together in ways that traditional platforms such as Microsoft, Google, Zoom, or Facebook have yet to achieve [28]. However, with this revolutionary change comes the need for metaverse developers to prioritize security and privacy as critical factors, given the potential risks and vulnerabilities associated with the complex technologies that comprise the metaverse [28].

3.2.7. Data

As previously discussed, the importance of data collection and processing is already a prominent theme in current computer systems. This theme is expected to grow in proportion to the expansion of data collection and processing with the arrival of the metaverse, as noted by several sources. The metaverse is expected to depend on big data, among other technologies, to achieve large-scale data acquisition, analysis, and storage, according to [13]. For instance, data acquisition is critical in the metaverse ecosystem, as [11] highlights. For users to make payments, certain sensitive information, such as credit card data, must be acquired. Moreover, sensitive user data, such as biometric and motion data, must be collected to generate virtual representations of users in the metaverse (avatars). Furthermore, as [11] notes, data collection enables the creation of various Machine Learning (ML) and artificial intelligence algorithms that can aid in the development of new products and the improvement of existing products, as well as the design of decision support, recommendation, and marketing systems in the metaverse. [7] even advocates for the idea that the data collected by the metaverse may become so valuable in quality and quantity that it could create a new area of data analysis called "mega data."

The role of data in the metaverse is crucial not only for its operation but also for the privacy and security of its users. While big data is essential for acquiring, analyzing, and storing data in the metaverse, it also presents challenges that must be addressed. [13] emphasizes the importance of establishing standards for big data, covering classification and information management, data analysis, data traceability, and data transmission between locations. From a legal perspective, it is essential to modernize the legal framework for protecting data property [13]. Additionally, the metaverse poses unique challenges as everything that avatars say and do, and even what they look at, is possible information to collect [16]. Therefore, proper data management planning is critical to ensure that third parties do not use or sell the information collected. [4] proposes massive data encryption in both storage and transmission to ensure metaverse information privacy, although this solution introduces considerable computing power problems.

Maintaining the integrity of information is a critical challenge in the metaverse [11]. Any compromise in information integrity may lead to a reduction in investment and confidence of stakeholders, thereby delaying universal implementation. Blockchain's immutability is one of the solutions to this challenge, as it requires a wide range of network members' consent before changing or deleting information from the metaverse. However, cross-referencing data collected from other platforms, such as social networks, is another significant challenge that could create problems in digital surveillance privacy [6]. Additionally, storing the vast amount of sensitive data generated by the metaverse is a primary concern that requires a suitable solution [11][25]. [29] highlights the importance of data in the present and predicts that the metaverse will enable even more significant and better data collection. Therefore, it is necessary to address the challenges of data privacy and security in the metaverse to ensure that the user's information is protected.

3.2.8. Artificial Intelligence

As the metaverse becomes more prevalent with time, artificial intelligence (AI) is emerging as a crucial technology. AI's ability to create realistic digital landscapes and environments by leveraging computer vision and deep learning is discussed in [3]. Additionally, [3] highlights how AI can enhance customer support by suggesting personalized shopping options based on a customer's consumption information. However, AI is not limited to the metaverse's future applications; it is already extensively used in the present generation of the web, web 2.0, as noted by [14]. As the web evolves into web 3.0, AI's role is expected to expand further [14]. The potential of AI in the next generation of mobile communications, 6G, is also recognized in [12], with the technology's capacity to transport information to and from geographically distributed IA algorithms. Improving existing standards is crucial to realizing this vision [13].

The role of artificial intelligence (AI) in the metaverse is crucial, as it promises to automate the metaverse ecosystem and generate 3D procedural content [11][25]. However, while AI has shown the potential to generate virtual humans [20], its autonomy in the metaverse must be appropriately regulated and limited [6]. Notably, the maturity level of AI for large-scale metaverse implementation still needs to be achieved [25], and its absolute control may be required by the digital governments of metaverses [11]. The importance of AI in the metaverse is expected to grow even more, as it is already extensively used in the present generation of the web and is expected to play a critical role in the next generation of mobile communications, 6G [14][12]. Nevertheless, improvements in existing standards are needed for this scenario to become a reality [13].

3.2.9. Hardware

Hardware is a crucial technical component of the metaverse, encompassing all physical devices, from end-user and network devices to large servers and data centers. The category includes handheld devices, tablets, VR devices, and related technical support for all technologies and physical equipment used to access, interact with, or process the metaverse [3]. The metaverse's multimedia content is predominantly in three dimensions, necessitating high-performance hardware requirements [7]. The hardware challenges of VR devices are highlighted in [6], which states the need for manufacturing standards for this type of equipment, which could be an obstacle to the mass adoption of VR technology across different industries. In addition, VR equipment is expected to evolve beyond head-mounted displays to more immersive hardware, such as haptic gloves and scent modules, to provide users with a more realistic and memorable experience.

In the metaverse, hardware is not limited to devices for accessing the virtual world, such as VR or AR glasses. According to [2], sensors used by users will allow their avatars to replicate physical movements in the virtual world and provide data from the real world to enhance the immersive experience. For instance, smart wearables and implanted sensors could collect vital signs and emotional information, including heart rate, breathing rate, skin temperature, and electrocardiogram, as mentioned in [12]. Moreover, [13] describes the necessary general infrastructure equipment for the metaverse, including smart sensors, automatic identification

devices, display equipment, perceptual access equipment, and high-speed chips. Developing technical standards for each equipment type is essential for ensuring technical, security, and signaling requirements.

To support the complex ecosystem of technologies that make up the metaverse, a high set of physical equipment is required, serving as the "bed" of the metaverse, as described by [13]. However, to ensure the proper functioning of the metaverse, it is necessary to standardize the security requirements for the hardware used, as discussed in the dedicated subchapter on security.

3.2.10. Multimedia

As one of the primary forms of communication on the internet today, multimedia content in the metaverse will also be critical for a positive and immersive experience. Several initiatives have been carried out in the scientific community to create audio solutions for the metaverse or equivalent digital environments. One of the earliest examples of such solutions is mentioned in [30], where a scalable three-dimensional spatial audio streaming architecture for virtual network environments is proposed. This proposal from [30] highlights that efforts to create immersive audio systems for digital environments are more than just something of the present, with this solution being over ten years old when the metaverse was far from becoming a possible project.

Rendering audio in the metaverse is a significant challenge, as pointed out by [31]. In the physical world, audio communication is straightforward, requiring only an input and an output, such as a microphone and a speaker. However, this changes in the virtual world of the metaverse. [31] delves into this issue by questioning how one can access a virtual microphone and transmit that information to a virtual speaker. The details of how multimedia is generated, transmitted, and played in the virtual world will vary from application to application, and there is no universal solution to this problem. Despite the challenge, the scientific community has proposed several scalable three-dimensional spatial audio streaming architectures, such as the one presented in [30], to address this issue.

In the metaverse, traditional online communication activities such as chat, voice and video calls are expected to be supported and integrated with existing solutions, according to [2]. This integration allows communication service providers to adapt their services to the metaverse. Additionally, [2] suggests that messaging and video conferencing applications and other metaverse technologies, such as DTs and VR, will enable immersive meetings. Supporting this notion, [32] posits that the metaverse will offer a variety of communication channels, including video, audio, chat, and non-verbal language, through a digital representation of users, reinforcing the enduring importance of current communication methods in the metaverse.

Speech recognition plays a crucial role in communication within the metaverse, as it enables users to understand the virtual environment they are in and communicate with other avatars and NPCs [4]. However, to achieve true immersion and a sense of reality, it is crucial to separate

synthesized ambient sound and the user's voice without noise and ensure that the sound's volume follows the user's distance from the sound source [4]. Furthermore, for a realistic environment, human voice recognition that considers the virtual environment's noise is necessary to adapt the volumes of each sound source and create comfortable acoustics for the user [4]. Despite the importance of sound synthesis in achieving an immersive experience in the metaverse, research and development in this area lags vision solutions such as DTs, VR, and AR, providing an opportunity for communications service providers to integrate into this new technological reality [4]. Concerning telecommuting applications, spatialized audio is already used today and can be scaled to the metaverse [4]. However, the constant updates to a user's listening point when moving within the metaverse pose a challenge to high-quality ambient sound. To address this, [4] proposes a binaural playback microphone recording system for virtual applications that allows users to move freely while always perceiving the sound accordingly. In addition, [4] suggests using EmFormer and WaveRNN neural speech coder to predict spectral characteristics of the streaming frame rate and generate the final audio, resulting in a proposed point-to-point binaural sound synthesis system with better performance than other solutions presented in the past.

Spatialized audio is one of the solutions mentioned by [4] as an example of technology already used today in telecommuting applications, which could be scaled to the metaverse. Meta's workrooms, a metaverse application developed by the Meta company for remote work, uses two servers to render and deliver digital content (environments, avatars, and other data) and to stream and exchange video and audio information using WebRTC, as explained by [15]. The modular architecture presented by Meta's metaverse services, in which digitally generated content is processed separately from multimedia content, could provide an opportunity for communications service providers, particularly unified communications as a service (UCaaS) provider, to offer their services in the metaverse as third-party providers to various metaverse applications requiring multimedia data. However, [15] notes that this service does not apply peer-to-peer optimization of its audio sessions, even when two users are in the same local network. This lack of optimization results in high processing costs and scalability issues, making it highly dependent on a client-server architecture without any decentralization, which goes against most proposals for metaverse architectures that prioritize decentralization and decentralized computing. This optimization failure highlights that even companies that pioneered the metaverse construction have critical operations flaws, which could lead to enormous cost savings for third-party providers who develop optimized alternatives.

3.2.11. Internet of Things

The Internet of Things (IoT) is an area that has gained popularity and demonstrated its usefulness in various domains. It can collect information, monitor, and remotely control various resources. According to [9], wearable and IoT devices growing demand will result in the collection of more data from the physical world in the coming years. This data will help create increasingly immersive and realistic virtual environments for the user in the metaverse.

The role of IoT in developing the metaverse is significant, as it can collect and monitor information from the physical world, creating increasingly immersive and realistic virtual environments for the user [9]. Furthermore, as pointed out by [10], major technology companies will use IoT as one of the building blocks, alongside VR, AR, AI, and Blockchain, to bring about the metaverse. The importance of IoT in the metaverse is further reinforced by [13], where the combination of IoT and the internet is cited as a critical component for the metaverse's network infrastructure, enabling the creation of a content-rich and interactive metaverse.

As a collaborative network of devices connected to the internet, the Internet of Things (IoT) facilitates peer-to-peer and device-to-cloud communication within a cloud environment. The IoT can play a crucial role in the metaverse by enabling high-quality augmented and virtual reality experiences through the interaction between physical and virtual spaces via a network of sensors and actuators [7], including delimiting the area of a virtual space to align with the available physical space in which a user is situated.

3.2.12. Brain-computer Interfaces

Brain-computer interfaces (BCIs) have the potential to become a genuine link between real and virtual realities, enabling users to interact with virtual environments or properties through their thoughts [2]. By collecting, processing, and interpreting electrical signals generated by the human brain due to cognitive activity, BCIs can revolutionize how users interact with machines in the metaverse [2]. Removing peripheral devices such as a mouse or keyboard becomes valuable in a reality where the graphical interface presented to users in the metaverse will mainly be through AR or VR [2]. While BCIs were initially developed to provide a method of communication for people with motor or verbal difficulties [33], their scope has expanded to numerous everyday actions [33].

From a different perspective, the potential applications of BCIs extend beyond motor or verbal difficulties, as noted by [33]. One such application is the generation of imagined speech, which enables users to communicate their thoughts in spoken form without vocalizing them. This innovation has the potential to revolutionize communication by providing users with a means to articulate their exact thoughts in their own words, like current speech recognition technology that transcribes spoken words into text. [33] suggests that imagined speech could become the future of communication and that the positive results obtained from pseudo-online BCI analyses can be adapted to the metaverse reality.

3.3. Business Component

Some have described the metaverse as the next iteration of the internet [3]. This virtual space offers various opportunities for its users, ranging from working, socializing, playing games, and meeting new people [3]. Several leaders of large companies have highlighted the potential for a metaverse-based economy, including the CEO of Nvidia Corporation, Jensen Huang, who predicts that it could generate higher turnover and investment than the current global economy

[7]. However, implementing the metaverse requires businesses to review and restructure their business models to take advantage of this technological revolution [3]. The metaverse has already started to affect the business world, with Netflix CEO Reed Hastings stating that video games like Fortnite are identified as the leading competitors in streaming services, highlighting the potential of virtual spaces and their threat to companies in seemingly unrelated business areas [34]. The Roblox platform, with 50 million games and 3 billion accumulated monthly usage, has surpassed services like TikTok or YouTube [4].

The metaverse restructures the current business model, creating new markets, stimulating the development of the economy and society, and expanding the space for human interaction [13]. Although new developments by large companies have recently made headlines, smaller companies have been developing services that move toward the metaverse for the past 25 years. Fortnite is an example, played worldwide by 350 million users and hosting massive virtual events and exclusive concerts with world celebrities [21]. While the metaverse has the potential to create a virtual economy, it will profoundly impact the real economy and bring about a new digital society with digital jobs that will create real value for the world economy [21]. Governments and several countries are actively involved in metaverse development, with 300 proceedings for patents or clearances referencing metaverse in their text and more than 20 proceedings containing metaverse in their title [13]. However, as [34] reminds us, all these expectations recall previous cases of VR applications, such as the Linden Lab video game Second Life, which generated considerable buzz but was eventually eclipsed by other less evolved but more user-friendly social networking platforms like Facebook or Twitter. [34] argues that the metaverse is different because of the technological progress in the last two decades that has made connectivity and VR easier to access and use than in the Second Life era.

In the communications industry, the metaverse provides an opportunity to create standards and communication functions that aim at interoperability, which could be advantageous for developers to speed up their implementations while facilitating their customers' connectivity to numerous services through viral advertising like that experienced on gaming platforms such as Steam, Xbox Live, or PlayStation Network [31]. This focus on building necessary solutions for the metaverse would also allow other service providers to focus on their core business (gaming, education, or tourism, for example) while being able to connect to other worlds, real or virtual, transparently. Communications operators can adapt to new sources of revenue in this new era of the metaverse by extending their infrastructure to virtual environments without requiring additional knowledge and offering new services to their customers [31]. For instance, new services like immersive communication functionalities for professional presentations or e-learning platforms or transferring chat messages (in text or audio format) to SMS are feasible [31]. In generic hybrid communication, the possibilities are endless for communications operators, even stating that they may finally get a significant piece of the virtual market [31]. To prove the viability of such solutions, [31] proposed a set of APIs accessible by a virtual world that can register its multimedia output streams, subscribe to incoming input streams, and control the signaling of the communication. The solution can be adopted in any multimedia engine, using the technology created through the API to interoperate seamlessly with other

worlds (virtual or real). [35] presents another example of the metaverse's potential in the communications industry, where it talks about the multi-billion-dollar market of Unified Communications as a Service (UcaaS).

After the Covid-19 pandemic, UcaaS became a sought-after solution by all kinds of industries, having grown 86% in 2020 due to companies' demand for solutions that allowed remote work. Companies like Zoom had a 2900% growth in the number of users between December 2019 and December 2020 and saw an increase in turnover of 317% in the same period [35]. UcaaS services have become an essential resource for all companies since this period. Solutions similar to these in the metaverse are expected to have a similar or even higher degree of success due to the spatial presence sensation factor introduced by VR. Additionally, [36] points out another opportunity for communications service providers in the metaverse regarding the 5G network. The compound annual growth rate of 5G will be 67%, mainly driven by new cell towers that will increase the coverage of this technology, enabling global wireless connectivity.

Cryptocurrencies and NFTs have created a new dimension in the virtual economy and are transforming how businesses interact with their customers in the metaverse. As mentioned in [3] and [14], blockchain technology is being utilized to enable virtual economic activities such as buying and selling virtual products and services and providing transparency and reliability in governance systems. In addition, the decentralized structure of blockchain allows small businesses to participate in the development of the metaverse and offers countless opportunities.

NFTs, on the other hand, have become a popular means of buying and selling digital art and proving the originality of any digital property bought or sold in the metaverse through smart contracts. Companies like Universal Music and Gucci have embraced this trend. They are creating new ways of interacting with their customers through the metaverse by selling limited-edition items and opening virtual exhibits. As mentioned in [14], adapting to the metaverse is critical for businesses to interact with younger customers increasingly interested in this new trend. Overall, cryptocurrencies and NFTs are transforming the virtual economy and providing businesses with new opportunities to engage with customers in the metaverse.

According to various sources, AR and VR technologies are increasingly popular due to their ability to provide immersive experiences that cannot be achieved through traditional methods [11][15]. Social VR is expected to continue growing in demand as it meets social needs and provides a sense of spatial presence, reducing fatigue compared to traditional video conferencing applications [15]. The adoption of VR technology is broader than end users, with 43% of manufacturing companies surveyed believing it will become mainstream within the next few years [20]. VR is now considered a key technology for national strategies in various countries such as the United States, South Korea, Japan, and China [6]. Meta, for example, views VR as the foundation for building the metaverse, as evidenced by the success of their Oculus Quest 2 VR headset, which has sold over 10 million units, making it the best-selling VR product in the world [15].

AR is attractive for the tourism industry, with its market expected to grow from $7 billion in 2020 to $152 billion in 2030, resulting in a significant increase in job opportunities within this sector [7]. In the United States, 54% of AR-related jobs are in the tourism industry [7].

Moreover, Apple's entry into AR and the metaverse, which was announced by Tim Cook, the company's CEO, generated a strong positive response from investors [37]. With the App Store currently offering 14,000 AR applications, this number is expected to increase even more with Apple's investment in the field [37]. In conclusion, AR has a promising future with increasing user adoption and is expected to have significant applications in various business sectors, such as gaming, manufacturing, and healthcare, with potential daily uses from parking assistance to supporting individuals with reduced visibility [38].

According to [3], the hardware necessary for the metaverse represents business opportunities, including selling computers, tablets, VR and AR devices, and technical support. In addition to user hardware, [3] notes the need for supporting equipment such as industrial systems, tracking systems, and sensors for scanning, as well as servers and computational capacity, including CPUs, GPUs, and network infrastructure, to process the various applications and services.

Regarding data, it has been stated by experts that it will play a critical role in the metaverse. As [13] suggests, data is a strategic resource essential in creating complex social and economic systems in this virtual space. The metaverse will have the potential to collect, aggregate, store, and analyze vast sets of data in a cross-industry manner. This capability will be instrumental in creating the virtual reality experience. [7] further reinforces this view by comparing social networks to data platforms designed to generate user information and suggests that the metaverse could be seen as a "gold mine" for data.

Investments in the metaverse have been significant, indicating its potential for growth and longevity. The technology sector's leading companies have already invested and plan to continue investing large amounts of money in metaverse projects [14]. Venture capital funds alone have invested $10 billion in the first ten months of 2021, and $30 billion were invested in companies related to blockchain or cryptocurrencies [14]. Meta has committed to investing approximately $10 billion in metaverse development and purchasing Oculus for $2 billion in 2014 [14][39]. This acquisition supported Facebook's development of the VR gaming platform Meta Horizon Worlds and the remote working application Meta Horizon Workrooms, accessible through Oculus Quest devices [39]. Microsoft has also entered the race for the metaverse, having acquired Activision Blizzard for $70 billion [17].

Furthermore, Microsoft has launched its own VR social space for remote collaboration, called Microsoft Mesh, which is currently limited to using a HoloLens headset. These investments will contribute to the metaverse's growth, reaching a market value of $1.5 trillion by 2029 [17]. Bloomberg has referred to this as an $800 billion opportunity [37].

3.3.1. Gaming

The gaming sector is the most well-known and famous of all the business areas most involved in the metaverse. According to [14], the virtual gaming market in 2020 reached a value of $180 billion and is projected to reach $400 billion by 2025. It is necessary to know its users in terms of demographic composition to understand the gaming sector's success. [14] states that the

projects currently exist and are considered the birthplace of the metaverse are attended by young users, with half of Roblox users being under 13 years old, 66% being under 16 years old, and only 14% being over 25 years old.

The gaming sector is a prominent industry involved in the metaverse, and gaming companies invest in enriching their users' experience. For example, Epic Games purchased Harmonix in 2021 to bring more sound and music experiences to the metaverse [14]. Additionally, the gaming sector has attracted companies from other business areas to integrate the promotion of their products and services in the metaverse. In June 2020, Roblox partnered with Warner Bros. and its subsidiary DC Films to develop a virtual experience of the Wonder Woman character, successfully bringing a movie and fantasy product into the metaverse world [14].

The technological advancements in the gaming industry have led to the development of powerful platforms in terms of computational capacity, scalability, load balancing, and low latency [34]. As a result, these platforms can be utilized by various companies from different sectors to develop complex applications that require significant computational resources without worrying about the infrastructure [34]. For instance, gaming companies have become significant players in the technology market by offering third-party businesses the opportunity to create their virtual reality (VR) experiences or integrate their services into existing virtual spaces [34]. These platforms are evolving into new types of platforms that can be utilized in diverse sectors of the economy and public life, thus posing a challenge to the existing digital platforms currently market leaders [34]. The emergence of these new platforms has allowed companies to adopt technologies such as augmented reality (AR) and VR more quickly, leading to the potential for large-scale digitization of work, entertainment, and services [34]. This observation is based on studying two game engines, Epic Games and Unity Technologies. Both have established themselves as platforms by opening their engines to areas outside of gaming, such as AI, architecture, product design, and TV and film production [34].

Although the potential for game engines to become platforms for other businesses is high, [34] states that only the Epic Games and Unity Technologies engines have the resources and flexibility to provide this service. However, it is a sign of the potential growth of this business area, whose power and importance will continue to increase with the growth of VR and AR technologies and the emergence of the metaverse.

3.3.2. Education

Education is expected to significantly benefit from the metaverse, with the increasing demand for online learning solutions due to the Covid-19 pandemic. Virtual spaces provide an immersive learning experience that transforms how knowledge is presented and retained [3][9]. Three-dimensional visual models of the content being taught allow for a better understanding than traditional media content in descriptive courses with theoretical content [9]. According to [4], teaching content in traditional media formats will continue to coexist with an education based on audiovisual content in the metaverse, which has excellent potential to become a popular learning format. [17] states that although the business and technology sectors are the

main actors of the metaverse, education is also a core branch of its development, with [20] mentioning that education has been part of the conception and development of the metaverse since the beginning.

The potential of the metaverse for education extends beyond improved content delivery, as it can enable education to reach areas with limited physical infrastructure or face sensitive political and socioeconomic situations that make in-person teaching difficult or impossible [7]. The metaverse can also enhance online teaching experiences. Education providers can use VR and AR to create online education and training spaces that simulate the face-to-face classroom environment [7]. However, [6] warns that a balance must be struck between these two technologies, as VR can cause eyestrain, headaches, dizziness, and nausea in environments involving rapid movement of digital content. While VR provides an immersive environment conducive to learning, better technologies are available for tasks that require simultaneous manipulation of physical and virtual objects.

3.3.3. Retail

The emergence of the metaverse presents several opportunities in the retail sector, with potential new business models to explore. Blockchain technology, one of the critical technologies of the metaverse, is particularly suited for online retail due to its high-security standards [11]. The virtual retail sector is expected to grow, driving the market to reach $7.4 trillion by 2025 [7]. Moreover, live commerce, a sales model that started in China and has since expanded worldwide, has shown excellent results [18]. This model involves streaming broadcast commerce that presents products by communicating with customers via chat. In 2020, it recorded $4.4 billion in transactions, validating the success of this new form of commerce. However, the current limitation of this model is its communication channel being limited to chat only [18].

The case of Nike is a practical example of how brands can benefit from the metaverse. In November 2021, Nike launched a virtual replica of its global headquarters on the Roblox platform, allowing a new way of interacting with users and potential customers. By offering virtual sneakers and other accessories, Nike created brand equity with gamified events [7]. Additionally, Nike has sold its products based on NFTs at exceptional prices, demonstrating the potential for valuation that NFTs offer due to their originality and uniqueness, despite virtual products typically having less value than their physical counterparts [7].

3.3.4. Healthcare

The metaverse offers a range of healthcare innovation possibilities, including telemedicine, fitness, and remote surgeries [9]. This paradigm shift, described by [9], allows doctors to conduct high-precision operations on patients thousands of miles away. While technology and business are critical drivers of metaverse development, healthcare is also expected to play a crucial role in its growth and initial adoption, as noted by [17]. The potential of the metaverse

in healthcare is particularly relevant in the Covid-19 pandemic, which has highlighted the importance of telemedicine and remotely delivered virtual services. As [7] points out, remote health services have already become a significant component of healthcare providers, with 95% of healthcare facilities offering remote patient care services (compared to pre-2020 figures of around 43%).

The metaverse introduces innovative opportunities in healthcare, such as telemedicine, fitness, and remote surgeries [9]. As emphasized by [17], healthcare will play a critical role in the metaverse's development and adoption, particularly since the Covid-19 pandemic highlighted the importance of telemedicine and virtual services. One of the significant advantages of the metaverse in health is telemedicine through VR, where therapy via VR is utilized to replace or enhance face-to-face consultations in a relaxed virtual environment with avatars similar to real life [17], being this the logical evolution of the current use of VR in medical training programs that have shown great success. VR and AR technologies are making their way into healthcare and the medical field, significantly improving medical training, processes, and procedures [20]. The startup Veyond Metaverse is one example of companies that aims to create a more immersive virtual healthcare experience for doctors, surgeons, and patients [17]. Moreover, according to [6], immersive VR healthcare applications are just as effective as or more effective than their physical environment counterparts.

3.3.5. Entertainment

As several sources indicate, the entertainment sector is a promising field for the metaverse due to its association with game engines, which can provide the necessary computational resources to support demanding VR applications [13][34][7]. Additionally, NFTs may have a significant role in this sector. They can provide access to events and sports games and offer exclusive perks such as premium content or personal interactions with celebrities [7]. [6] categories VR applications for entertainment into gaming, sports, and adult entertainment. VR applications in these areas, according to [6], offer greater interactivity and user stimulation than traditional media formats. For instance, in sports, users report higher satisfaction when viewing a sports event in immersive VR than in two-dimensional formats like television or computer screens.

3.3.6. Human Resources

The metaverse offers significant opportunities for the human resources sector, particularly in professional training and remote work options [21]. As businesses increasingly adopt remote working models due to the Covid-19 pandemic, the metaverse's development may help address challenges associated with this model's complexity [21]. AR and VR devices have facilitated large-scale remote work and socialization solutions with greater levels of immersion than conventional videoconferencing platforms [34]. Jikbang and Com2us, two IT companies in South Korea, have already introduced metaverse-based solutions to create online work environments comparable to offline ones. Many businesses already hold important events such

as recruitment briefings, discussion forums, or conferences in the metaverse [40]. The study in [40] concluded that metaverse-based immersive telepresence boosted motivation, information retention, interactivity, and enjoyment. [32] supports this idea, stating that virtual environments can facilitate professional project development and coordination, enabling capabilities that are not possible in conventional online environments.

3.3.7. Industry

The metaverse presents opportunities to increase productivity in industrial applications across various product life cycle stages. Firstly, the design process can be done entirely in the metaverse, using accurate, faster, and more cost-effective simulations than physical prototyping. Secondly, the metaverse can leverage digital twin technology to improve operational efficiency and reduce risks in the product manufacturing process. Additionally, the metaverse provides a shared space that is transparent to the physical location of each worker, facilitating collaboration among different areas and departments within a team and allowing for real-time interactions that enhance the efficiency and agility of both design and product lifecycle development [9].

CHAPTER 4

Interviews

As previously explained in this research, all the conducted interviews were made after the literature review to complete the information collected on the scientific and grey literature. In the previous chapter, this investigation successfully answered three out of the five research questions. This part of the research is dedicated to trying to understand and answer the two remaining questions, as the interviews were designed with this very objective. This part of the investigation also tries to understand, through interviews, the role of the current primary forms of online communication in the metaverse: audio, video, and text.

A total of 12 communication specialists were interviewed for this research, based on the methodology described on chapter 2. Approximately half of the interviewees have a business background in the communications industry, and the other half have a technical background in the area, formerly or actively working in one of the technologies identified on the technical component of the literature review of this research. Table 2 shows information regarding all the 12 conducted interviews, as well as a brief information on the background of each interviewee.

Table 2 – Information of the 12 industry experts interviewed for this investigation.

Interview Nº	Role	Experience
1	Open-Source Industry Expert	Business
2	Chief Operations Officer	Business and Technical
3	Research Director	Business
4	Executive Board Member	Business
5	Chief Commercial Officer	Business
6	Telco Industry Expert	Business and Technical
7	Channel Director	Business
8	CEO and Industry Expert	Technical
9	Senior Engineer	Technical
10	Datacenter Engineer	Technical
11	Datacenter Engineer	Technical
12	Datacenter Engineer	Technical

4.1.The impact of metaverse in the communication sector

A prevailing theme within the responses is the fundamental role of robust infrastructure. The consensus is that successfully integrating the metaverse into the communications industry hinges on the ongoing digital transformation efforts within telecom companies. The sentiment is that with a solid technological foundation, the industry's capacity to deliver value-added metaverse services would be sufficiently robust. This foundational perspective underscores that

the metaverse's potential can only be fully harnessed with a corresponding technological backbone.

Another recurrent theme is the gradual transition toward a metaverse-integrated communications landscape. The recognition of this gradual evolution is widespread among the responses, underlining that meaningful changes might extend beyond the five-year horizon. While some viewpoints highlight early initiatives in virtual workspaces and meetings, the overall sentiment is that the metaverse's full integration is a journey that will evolve with market dynamics and technological progress.

The distinction between the metaverse's impact on business-to-consumer (B2C) and business-to-business (B2B) spheres emerges as another significant dimension. There is a recognition that tailored communication strategies will likely be required for these two segments. The potential for omnichannel communication strategies to bridge this gap is acknowledged, underlining the need for flexible approaches that resonate with distinct consumer and business needs.

Insights into communication providers' stances and engagement in the metaverse landscape offer diverse perspectives. While some viewpoints highlight providers' cautious approach, waiting for industry-wide adoption before offering metaverse-related services, others suggest that larger providers take a proactive role in driving metaverse adoption by introducing their platforms. This variation underscores the complexity of the provider landscape, with differing levels of proactive engagement and strategic foresight. Regardless of the approach defended by each interviewee, it seems consensual that a significant impact in communications will take more than a 5-year window to happen. Whether the metaverse initiative starts with the communications providers or in other business sectors, there will always be constraints that will make it very difficult to see significant changes in the next five years.

If the metaverse is motivated by other sectors outside communication, the vision fits what is happening right now, according to the analysis done in the literature review. Companies will be limited regarding infrastructure and bandwidth, being one of the most critical factors mentioned in all answers for metaverse to have an impact. Even if the communication sector reacts to this increase in demand, it will undoubtedly take more than five years to invest in a new global infrastructure that will successfully respond to the demanding requisites of metaverse applications. In the case that metaverse is motivated by the communication industry, several interviewed specialists referred to this industry as very slow when it comes to modernizing its infrastructure and technology stack, making sure all moves companies make regarding new services already have substantial approval from public and companies, making this change in communication technologies to take also most probably more than five years to be accomplished.

The interviews also mentioned the energy sustainability problem. Metaverse infrastructure and required computational power will have enormous energy requirements that current technology will need help to supply with the rising awareness of climate change, carbon emissions and green energy. Multiple perspectives emphasize the challenge of resource consumption and its impact on metaverse adoption. This shared concern highlights the need for a sustainable approach that addresses resource availability and usage limitations.

The importance of digital inclusivity also emerges as a consistent theme, as various viewpoints underscore the necessity of overcoming digitalization gaps across regions and economies. This alignment reflects the aspiration for the metaverse to transcend boundaries and be accessible to a wide demographic. According to most interviewees, for the metaverse to become a critical factor in technology and communications, it depends on the global adoption of the technologies that make part of it. This last point could be a problem considering the different political, social, and technological landscapes of different countries or regions in the same country.

Another common viewpoint revolves around the absence of one agreeable everyday use case for metaverse, as it hangs as a popular but very fuzzy concept. It is yet to be determined what it will be or mean to businesses and end consumers, raising another mentioned problem: the need for common standards, both in hardware and software, for building a foundation for the metaverse technology stack. If, in one way, a lot of organizations and research papers see metaverse as the next iteration of the internet, in another way, the collected data, both in the literature review of this research and in the interviews, points to a starting in the opposite direction. While the internet started as a knowledge-sharing platform with the collaboration of companies, universities, and government agencies, that later grew up to the shape that we know now, based on communication, security, hardware and software standards, the metaverse seems to be appearing as a completely decentralized process, where each company tries to prevail its use case, with its standards, with presently few to no room for interoperability between the different leading platforms and solutions.

The implications of this analysis suggest that metaverse adaptation demands a holistic approach. All essential considerations are overcoming resource constraints, fostering inclusivity, facilitating business transformations, ensuring usability, navigating geopolitical influences, and establishing standards. Industry stakeholders should engage in collaborative efforts that account for these multifaceted challenges, fostering an ecosystem conducive to successful metaverse integration, which will likely take more than five years to accomplish, according to the interviewed specialists in the area.

Nonetheless, when the 5-tear window is removed from the analysis, the answers from almost all the interviewed specialists take an opposite direction when analyzing the possible opportunities, the metaverse will bring for the future of business, communications, and human interaction.

Regarding Enhanced Digital Mobility and Accessibility, a shared viewpoint emphasizes the potential for enhanced digital mobility, involving creating an immersive environment where individuals can navigate digital spaces akin to real-life experiences. This perspective is particularly noteworthy for its potential to address issues related to accessibility and provide virtual mobility experiences for disabled individuals. The transformation of industries and services also emerges as a prevalent theme. The consensus lies in the metaverse's capacity to address governmental, healthcare, and communication issues. Moreover, it is highlighted that the metaverse could lead to a paradigm shift in offices and workspace requirements, promoting flexibility and market adaptability.

The interviewee's perspectives also converge on the appliance of some metaverse-related technologies to foster innovation within tech companies. The consensus is that the metaverse provides a fertile ground for creating and managing services, particularly in managing the increasing complexity of technological landscapes. Regarding this topic, it is possible to relate the literature review of this investigation to the use of artificial intelligence to help manage the complexity of current and future computer networks, as well as user connections, load balancing features, or quality of service parameters.

There are differing opinions regarding the potential for market expansion through the metaverse. It presents vast opportunities to reach a wider audience and offer services across regions. However, others still need to figure out the growth opportunities. Nevertheless, there is agreement that the metaverse offers many opportunities for specific industries. Retail, for example, can create virtual spaces for customers to test and experience products before purchasing them. Gaming can provide more immersive experiences. Healthcare can offer advanced medical care through remote surgeries and telemedicine appointments, with IoT devices providing real-time patient data. The industry can save money by creating digital prototypes through digital twinning. Education can provide more immersive digital learning experiences and innovative ways to learn.

Ultimately, the interviewed specialists' answers highlight that successful metaverse integration hinges on a balanced approach that harnesses the potential while addressing uncertainties. Collaborative efforts among diverse stakeholders are crucial to realizing the metaverse's potential to create immersive experiences, transform industries, and redefine how we interact with digital spaces.

4.2.The role of current communication channels in the metaverse

When researching how the communication sector can adapt to the metaverse, one of the main questions is the future role of the current communication channels in a new technological environment. While the literature review of this research presents some valuable insights on this theme, further investigation is needed to comprehend how humans will interact in the metaverse fully and whether they will use the current virtual communications channels in a metaverse-like reality.

To further investigate this topic, it was asked to rate from 1 to 10 what importance they give to voice, text and video communication in the metaverse, with one meaning not important at all and ten meaning extremely important. As we can see from image 2 below, there is a strong consensus between all interviewed specialists that voice and video will still have a critical role in the future of communications in the metaverse. However, the opinions diverge when the technology is text-based, with much dispersion on the importance ratings. It is also worth mentioning that almost all the interviewees referred to video as a broad term, making it difficult to rate.

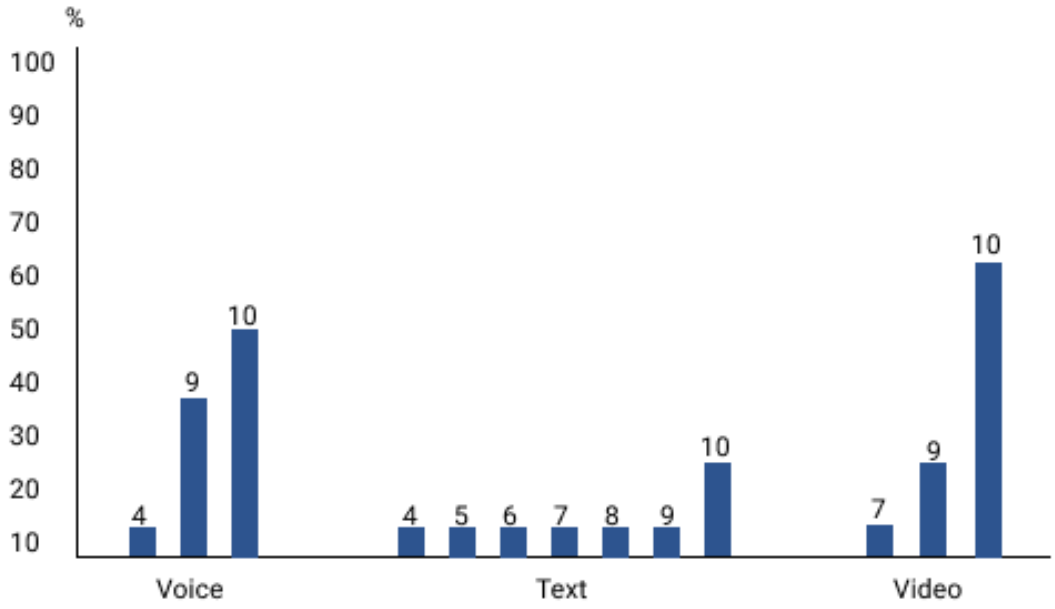

Image 2 – Percentage of specialists that rated from 1 to 10 the importance of voice, text, and video communication in the metaverse.

4.3.The future of communication businesses

To fully understand the transformation of communications companies to adapt to a metaverse reality, it is first necessary to comprehend what technological innovations are critical to accomplishing a global use case for metaverse regarding communication. Interviewees were asked about this topic to provide deep insights about critical innovations that need to occur.

Across the responses, a strong consensus emerges around the need for a secure, scalable, and reliable infrastructure. Respondents emphasize that this infrastructure should encompass both hardware and software aspects. They stress that the metaverse's growth relies on a robust foundation that is agile, scalable, and built upon trusted technology. This foundational requirement is viewed as non-negotiable, and opinions are divided between cloud-based and multi-cloud approaches as the right solution for providing the necessary reliability and scalability.

Connectivity emerges as a universal concern, with all respondents highlighting its vital role in metaverse communication. There is a shared belief that internet access and connectivity should be treated as a fundamental utility, like electricity or water. This perspective extends to bandwidth availability and efficiency. Respondents agree that substantial investment in broadband and bandwidth is essential to support seamless communication and interaction within the metaverse. However, opinions on the magnitude and scope of these investments vary, with some advocating for extensive investment in broadband infrastructure.

A significant theme that resonates across responses is the emphasis on data security and identity protection. Respondents unanimously agree that safeguarding user data is paramount as the

metaverse becomes a hub for personal and sensitive information in more significant volumes than ever before. Reference is made to the General Data Protection Regulation (GDPR) as a foundational framework for ensuring user privacy and control. However, opinions diverge on the detail required for data security, authentication, and permissions. Some respondents feel that more extensive elaboration is necessary to establish a trustworthy metaverse environment, while others allude to ongoing discussions and challenges.

The role of artificial intelligence (AI) also garners significant attention as a critical component in metaverse communication. Respondents unanimously acknowledge the potential of AI in revolutionizing communication by understanding various languages, processing speech, and summarizing conversations and all kinds of information. However, there is an underlying sentiment that AI is still evolving in this aspect, and there are limitations to its current capabilities. The reference to AI assistants like Alexa, deemed "dumb," highlights the gap between potential and current reality.

AR glasses and portable devices emerge as pivotal components for enabling ubiquitous communication within the metaverse. The interviewees envision a future where these devices are seamlessly integrated into daily life rather than confined to bulky and limited-use peripherals. The aspiration is for AR glasses and similar technologies to evolve beyond their current limitations and become widely accessible, user-friendly, and accessible at lower prices than in the present.

One outlier perspective emphasizes the role of sensor technology in enhancing the sensory experience within the metaverse. This viewpoint underscores the importance of visual and auditory immersion and tactile and sensory engagement. This holistic sensory approach could create a more immersive and engaging metaverse environment, transcending conventional communication boundaries. While on the interviews, this topic emerges as an outlier, it is worth mentioning since sensory technology and IoT was diagnosed as crucial components for metaverse in this research's literature review.

Interoperability between providers and technologies emerges as a less prevalent but significant theme. This perspective calls for seamless integration and communication between platforms and services within the metaverse. The ability to interact and communicate across different providers' ecosystems is seen as crucial for creating a cohesive and user-friendly metaverse experience. This less critical vision of interoperability, while somewhat contrasting with the input from the literature review, shows that in a short-term window, the metaverse will likely arise not as a global and single three-dimensional virtual space where users can seamlessly change between platforms and services, maintaining cross-platform ownership or virtual assets, but more in a three-dimensional internet, where users still rely on solid search engines to access separated virtual spaces, with each space providing its service of immersion and with their own and exclusive assets. However, progressively over time, a convergence of these platforms is expected, bringing the complete metaverse concept into reality.

When asked more specifically what the interviewed specialists would envision communication networks evolving to support the metaverse regarding infrastructure and connectivity, the responses collectively offer diverse insights. One prevailing consensus centre around the need

for secure, scalable, and flexible technology infrastructure. Respondents underscore the importance of moving away from traditional siloed telecom structures, advocating for a shift towards software-defined solutions that bring more flexibility, automation, and ease of management features that will enable a global infrastructure increase in capacity and complexity. This transition is vital to accommodate the metaverse's dynamic demands and facilitate the rapid deployment of services in response to varying needs.

An overarching theme emerges in the answers concerning the essential nature of connectivity. Respondents emphasize that high-speed, ubiquitous internet access is a cornerstone for the metaverse's successful functioning. This sentiment is bolstered by references to projects like Starlink that aim to democratize access to high-bandwidth connectivity, making it more universally available. On this topic, it emerges again in multiple answers the vision of having the perspective of connectivity as a commodity and not as a secondary and optional service in the short-term.

The significance of expanding infrastructure, mainly through increased fibre rollout, garners notable attention. Respondents agree that a robust communication network requires ongoing enhancements in connectivity infrastructure. This focus on fibre highlights the practical steps necessary to create the backbone for effectively supporting metaverse activities.

Divergence of opinions arises when contemplating sustainability, more particularly energy consumption. Some respondents acknowledge ongoing efforts by significant cloud providers to address these concerns. At the same time, the majority express that sustainability remains a challenge requiring further attention and innovation, considering the metaverse's needs regarding energy consumption.

In terms of outliers, two distinct perspectives emerge. One introduces the intriguing notion of individuals contributing excess bandwidth through personal antennas, likening it to generating and selling solar energy. This decentralized approach to bandwidth provision introduces an innovative dimension to the discussion. Another outlier perspective emphasizes the role of artificial intelligence (AI) in building trustworthy platforms for various applications within the metaverse. This viewpoint underscores AI's potential to enhance security, reliability, and user experience. While an outlier in the interviews, this vision is endorsed by several authors analysed in the literature review of this investigation.

With the fundamentals assessed on how communication technologies should evolve to host the metaverse, it is time to understand the opinions of the interviewed specialists on what companies in this sector should do to adapt to this new reality. A common thread among these recommendations is the critical importance of strategic planning. Respondents emphasize the need for meticulous research and careful infrastructure planning. They suggest a thoughtful approach in deciding which infrastructure components to manage internally and which ones to transition to cloud or hybrid cloud solutions. This foundational step is considered crucial before venturing into the metaverse.

Data privacy and ownership emerge as another consistent theme. Respondents unanimously stress the significance of aligning metaverse endeavours with data privacy regulations, with

GDPR as a notable reference point. They advocate for viewing data not merely as a commodity for profit but as an asset that users should have control over. The idea of users "owning" their data is highlighted across responses, reflecting a growing concern for digital privacy and transparency.

Customer-centricity is a widely endorsed approach. Several interviewees suggest that businesses should carefully evaluate their customer base to identify the right segments for engagement within the metaverse. They advise against funnelling all resources into a single approach and underscore the importance of maintaining alternative channels for customer interaction beyond the metaverse since the general adoption pace of all these new technologies will happen from one day to another, but slowly and progressively over several years. Continuous customer feedback is also seen as essential for success in this evolving landscape.

Another point of contention revolves around the core business approach to the metaverse. While the prevailing view is that providers should leverage the metaverse as a novel means to reach clients, a contrasting perspective suggests a heightened focus on cybersecurity and cybercrime prevention. This perspective advocates for providers to offer security as a service (SecaaS) in addition to providing infrastructure. This debate underscores the multifaceted nature of adapting to the metaverse, with differing strategic priorities and risk perceptions.

In terms of outliers, one viewpoint encourages telecommunications companies to seize the opportunity presented by the metaverse. This perspective underscores the potential for the telecom industry to break from historical patterns of missing technological revolutions and instead become leaders in adopting this new wave of technologies. It emphasizes proactive involvement and industry leadership, positioning the metaverse as pivotal in the industry's evolution.

In conclusion, the analysis of the provided answers reveals a rich tapestry of insights, offering valuable guidance for communications businesses considering adaptation to the metaverse. These recommendations span infrastructure planning, data privacy, customer-centricity, and the metaverse's pace of adaptation. Controversies regarding adaptation speed and strategic focus add depth to the discourse, while outliers emphasize the historical opportunity that the metaverse presents to the telecommunications sector.

CHAPTER 5

Findings

With the literature review and the interviews with specialists done, it is time for this investigation to try to answer the five research questions that mainly motivated this document, having a dedicated chapter to each question.

5.1. What is the metaverse?

During the literature review of this investigation, it was immediately noticed that the scientific community lacked a proper definition for this concept. While many definitions existed, there was no single agreed description for this concept. While not new, it recently became a hot topic for business, technology, and scientific research. Because of this, this investigation needed a metaverse definition that would work as the foundation for the remaining literature review and the conducted interviews with communication specialists. The criteria used to choose a definition for metaverse was to cite the definition found in the most cited article that was not a secondary source of information.

Applying this criterion to the base of knowledge gathered for the literature review resulted in the following definition of metaverse: "A collective virtual shared space, created by the convergence of virtually enhanced physical reality and physically persistent virtual space, including the sum of all virtual worlds, augmented reality, and the Internet."

5.2. What technologies work together to form the metaverse?

The answer to this research question takes a considerable part of the literature review, where a holistic approach was applied to understand every type of technology involved in the metaverse, plus the technologies that will need to be created or improved to enable the metaverse to become a reality. After the technical component of the literature review, a comprehensive notion of every technology that takes part in the metaverse and their relationships with each other was reached, which can be seen as the metaverse technical ecosystem and is represented below in image 3.

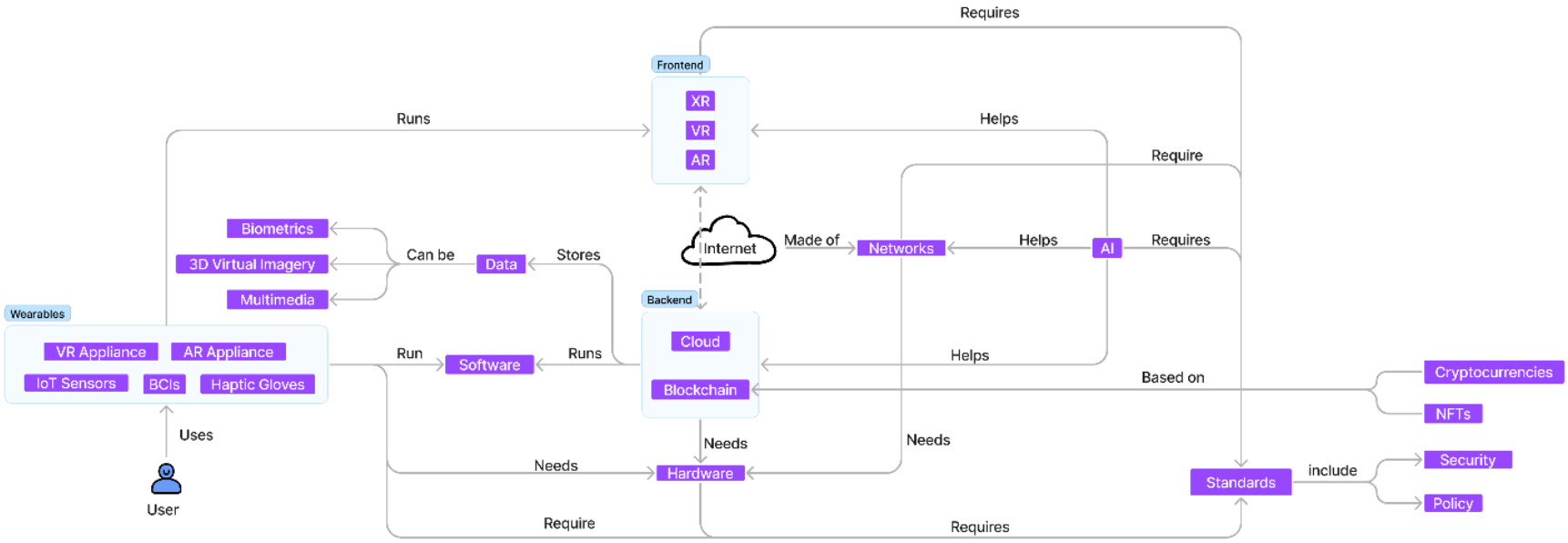

Image 3 – Metaverse technical ecosystem

5.3. What business areas will benefit more from the metaverse?

The answer to this research question is handled and analyzed on the business component of the literature review, where gaming, education, retail, healthcare, entertainment, human resources, and industry were identified as the most promising business sectors regarding metaverse opportunities mostly because of the three following main factors:

- **Potential to create more immersive experiences:** This factor is most influential in gaming, education, retail, and entertainment since increased experience immersion can enable an enhanced engagement environment for end customers and other businesses. In gaming and entertainment, the immersion factor will create a new market regarding digital experiences that will allow for services to be sold at higher price points and with additional customer satisfaction. This factor will also allow new ways to present educational content, leading to new learning methods and more democratic and easy access to high-quality education through highly immersive digital learning experiences. Finally, retail will bring more comfort for users, who can try several products (especially in fashion) in the comfort of their homes before buying them.

- **Create a new way of engaging with customers and partners:** These areas will benefit from this factor, particularly education, retail, healthcare, and human resources. Education and retail will benefit primarily because of what has been explained in the previous point since the ability to create more immersive experiences in these two areas will enable a new era in the digital learning scene and a greater sense of confidence from customers buying goods online. For healthcare, this factor will mean a new channel for providing healthcare services, with new ways of realizing medical procedures, like remote surgeries or an enhanced experience in telemedicine appointments, where a doctor can access real-time patient vitals, for example. In human resources, a virtual workspace with three-dimensional spaces for meetings and collaborations will enable companies to recruit and gather a global workforce without many of the physical constraints that present online collaboration tools have.

- **Save money through digitalization of experiments and prototyping:** Finally, this factor will bring more benefits to human resources and industry areas since a better online workspace can lead to a significant cut in travel expenses. For industry, the ability to build and test digital prototypes that replicate the physical environment through digital-twinning technology will significantly reduce costs on research and development and material goods currently needed to build prototypes and test versions of products.

5.4. How will the metaverse impact the communication industry for the next 5 years?

This research question was handled on the conducted interview's part since it was impossible to find solid input through the available documentation for the literature review. The answers obtained from the communication specialists showed that in the evolving landscape of communication providers' involvement in the metaverse, diverse viewpoints emerge, reflecting the complexity of the industry. Some providers are cautious, waiting for widespread industry adoption before venturing into metaverse-related services. Conversely, there are suggestions that larger providers may take a proactive role in driving metaverse adoption by introducing their platforms. However, a prevailing consensus among interviewees is that the transformative impact of the metaverse on the communication industry will likely not materialize within a five-year timeframe. Whether initiated by communication providers or other sectors, constraints related to infrastructure and bandwidth pose significant challenges. The metaverse's rapid growth, fuelled by other industries, may strain existing communication infrastructure, necessitating substantial investments in global infrastructure that exceed the five-year horizon scope. Furthermore, the sluggish pace of infrastructure modernization within the communication industry could further delay the implementation of new services and technologies, extending the timeline beyond the immediate future.

Beyond temporal constraints, the issue of energy sustainability looms large in discussions about the metaverse's development. The metaverse's infrastructure and computational demands are expected to have substantial energy requirements, raising concerns about resource availability and environmental impact in an era of heightened climate change and carbon emissions awareness. These shared concerns underscore the imperative for a sustainable approach that addresses the challenges associated with resource consumption and its implications for metaverse adoption. In sum, the metaverse's integration into the communication industry presents a complex landscape marked by diverse perspectives, temporal constraints, and pressing sustainability considerations, suggesting that its transformative effects unfold over a longer timeframe than initially anticipated.

5.5. How can the communication industry adapt to the metaverse?

Amid the evolving landscape of communication technologies and their integration with the metaverse, a common thread emerges among the recommendations provided by interviewed specialists on how companies in this sector should adapt to this new reality. Strategic planning takes center stage, with respondents emphasizing the critical importance of meticulous research and thoughtful infrastructure planning. They advocate for a discerning approach in determining which infrastructure components to manage internally and which to transition to cloud or hybrid cloud solutions, considering this foundational step as crucial before venturing into the metaverse.

Data privacy and ownership also feature prominently in these recommendations. Interviewees unanimously stress the significance of aligning metaverse endeavors with data privacy regulations, notably citing GDPR as a reference point. They advocate for a fundamental shift in perspective, viewing data not merely as a commodity for profit but as an asset that users

should have control over. The concept of users "owning" their data resonates across responses, reflecting a growing concern for digital privacy and transparency in an increasingly interconnected world.

As analyzed in the previous chapter of this investigation, the communications specialists referred almost unanimously that voice and video communication channels will have a prevailing and critical importance in the metaverse. Since these technologies are already broadly used in the present internet and virtual world, this could be the door for communication providers into the metaverse; by adapting their current services to the mentioned demands and concerns of specialists about the metaverse, the communication sector can bring voice and video communication channels to the metaverse by modernizing their standards and optimizing their services for a more secure, decentralized and quality of service-centered approach. This idea does not only seem the easiest way for providers to enter the metaverse, but also the more risk-free approach since this service optimization will improve current communication services, both from a security and bandwidth efficiency standpoints, that will bring benefits to end customers and businesses even if the metaverse stopped its development and never reaches a real use-case scenario.

CHAPTER 6

Conclusion

This master's thesis has provided valuable insights into the metaverse and its implications for the communication sector. Several key findings have emerged through a rigorous literature review and in-depth interviews with communication specialists. Firstly, a comprehensive definition of the metaverse has been established, laying the foundation for further exploration. The metaverse is described as a collective virtual shared space resulting from the convergence of physically enhanced reality and persistent virtual space, encompassing virtual worlds, augmented reality, and the internet.

A detailed examination of the technologies underpinning the metaverse has been undertaken, revealing a complex ecosystem of technologies integral to its development. This holistic understanding of the metaverse's technical components provides a roadmap for its realization. With the foundation of the metaverse and what technologies make part of this complex ecosystem, this study has identified specific business areas poised to benefit most from the metaverse, including gaming, education, retail, healthcare, entertainment, human resources, and industry. These sectors are expected to harness the metaverse's potential to create immersive experiences, facilitate new forms of engagement, and streamline digital experiments and prototyping.

One of the primary research questions addressed how the metaverse would impact the communication industry over the next five years. While a variety of perspectives were presented, a prevailing consensus emerged. The transformative impact of the metaverse on communication providers is anticipated to be substantial but unlikely to fully materialize within a five-year timeframe. Challenges related to infrastructure, bandwidth, and the gradual pace of adoption may delay the full realization of metaverse-related services. Furthermore, the communication industry's adaptation to the metaverse was explored, with strategic planning identified as a fundamental step. Meticulous research and careful infrastructure planning were recommended, emphasizing the need to differentiate between internally managed components and those suitable for transition to cloud or hybrid cloud solutions. Additionally, data privacy and ownership emerged as crucial considerations, with a shift towards viewing data as an asset users should control.

Considering these findings, optimizing voice and video communication channels facilitates the communication industry's entry into the metaverse. This approach aligns with current standards, enhances security, decentralizes services, and improves the quality of service. Importantly, it presents a relatively risk-free venue for providers to participate in the metaverse, potentially enhancing existing communication services even if the metaverse's development trajectory changes.

This master's thesis, while just a first step, has shed light on the metaverse's multifaceted nature and its implications for the communication sector. It provides a foundation for further research and offers valuable guidance to communication companies seeking to navigate this

transformative landscape. As the metaverse evolves, communication providers must remain adaptive, forward-thinking, and responsive to the changing digital landscape.

Bibliographic References

[1] Novak, K. (2022). Introducing the Metaverse, Again!. *TechTrends*, *66*(5), 737-739.

[2] Di Pietro, R., & Cresci, S. (2021, December). Metaverse: Security and Privacy Issues. In *2021 Third IEEE International Conference on Trust, Privacy and Security in Intelligent Systems and Applications (TPS-ISA)* (pp. 281-288). IEEE.

[3] ENACHE, M. C. (2022). Metaverse Opportunities for Businesses. *Annals of the University Dunarea de Jos of Galati: Fascicle: I, Economics & Applied Informatics*, *28*(1).

[4] Park, S. M., & Kim, Y. G. (2022). A Metaverse: Taxonomy, components, applications, and open challenges. *Ieee Access*, *10*, 4209-4251.

[5] Falchuk, B., Loeb, S., & Neff, R. (2018). The social metaverse: Battle for privacy. *IEEE Technology and Society Magazine*, *37*(2), 52-61.

[6] Dincelli, E., & Yayla, A. (2022). Immersive virtual reality in the age of the Metaverse: A hybrid-narrative review based on the technology affordance perspective. *The Journal of Strategic Information Systems*, *31*(2), 101717.

[7] Dwivedi, Y. K., Hughes, L., Baabdullah, A. M., Ribeiro-Navarrete, S., Giannakis, M., Al-Debei, M. M., ... & Wamba, S. F. (2022). Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice, and policy. *International Journal of Information Management*, *66*, 102542.

[8] Xu, M., Niyato, D., Kang, J., Xiong, Z., Miao, C., & Kim, D. I. (2022, May). Wireless edge-empowered metaverse: A learning-based incentive mechanism for virtual reality. In *ICC 2022-IEEE International Conference on Communications* (pp. 5220-5225). IEEE.

[9] Cai, Y., Llorca, J., Tulino, A. M., & Molisch, A. F. (2022). Compute-and data-intensive networks: The key to the Metaverse. *arXiv preprint arXiv:2204.02001*.

[10] Xu, H., Li, Z., Li, Z., Zhang, X., Sun, Y., & Zhang, L. (2022). Metaverse Native Communication: A Blockchain and Spectrum Prospective. *arXiv preprint arXiv:2203.08355*.

[11] Mishra, S., Arora, H., Parakh, G., & Khandelwal, J. (2022, June). Contribution of Blockchain in Development of Metaverse. In *2022 7th International Conference on Communication and Electronics Systems (ICCES)* (pp. 845-850). IEEE.

[12] Tang, F., Chen, X., Zhao, M., & Kato, N. (2022). The Roadmap of Communication and Networking in 6G for the Metaverse. *IEEE Wireless Communications*.

[13] Wang, D., Yan, X., & Zhou, Y. (2021, December). Research on Metaverse: Concept, development and standard system. In *2021 2nd International Conference on Electronics, Communications and Information Technology (CECIT)* (pp. 983-991). IEEE.

[14] Kshetri, N. (2022). Web 3.0 and the Metaverse Shaping Organizations' Brand and Product Strategies. *IT Professional*, *24*(02), 11-15.

[15] Cheng, R., Wu, N., Chen, S., & Han, B. (2022, March). Reality check of metaverse: A first look at commercial social virtual reality platforms. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)* (pp. 141-148). IEEE.

[16] Hirsch, P. B. (2022). Adventures in the metaverse. *Journal of Business Strategy*, (ahead-of-print).

[17] Rahaman, T. (2022). Into the metaverse–perspectives on a new reality. *Medical Reference Services Quarterly*, *41*(3), 330-337.

[18] Jeong, H., Yi, Y., & Kim, D. (2022). An innovative e-commerce platform incorporating metaverse to live commerce. *International Journal of Innovative Computing, Information and Control*, *18*(1), 221-229.

[19] exchange4media Staff. (2022, July 19). 'Metaverse is an important part of the future of communications.' Indian Advertising Media & Marketing News – Exchange4media. https://www.exchange4media.com/pr-and-corporate-communication-news/metaverse-is-an-important-part-of-the-future-of-communications-121423.html

[20] Mozumder, M. A. I., Sheeraz, M. M., Athar, A., Aich, S., & Kim, H. C. (2022, February). Overview: Technology roadmap of the future trend of metaverse based on IoT, blockchain, AI technique, and medical domain metaverse activity. In 2022 24th International Conference on Advanced Communication Technology (ICACT) (pp. 256-261). IEEE.

[21] Ilyina, I. A., Eltikova, E. A., Uvarova, K. A., & Chelysheva, S. D. (2022, April). Metaverse-death to offline communication or empowerment of interaction?. In 2022 Communication Strategies in Digital Society Seminar (ComSDS) (pp. 117-119). IEEE.

[22] Aathreya, S. (2022, July 24). A Vision of Enterprise Communications in the Metaverse. AVIXA Xchange. https://xchange.avixa.org/posts/a-vision-of-enterprise-communications-in-the-metaverse

[23] Jaber, T. A. (2022). Security Risks of the Metaverse World. *International Journal of Interactive Mobile Technologies*, *16*(13).

[24] News Desk. (2022, October 7). Telephony Communications Technologies launches its metaverse arm TCTx. TECHx Media. https://techxmedia.com/telephony-communications-technologies-launches-its-metaverse-arm-tctx/

[25] Chen, S. C. (2022). Multimedia research toward the Metaverse. *IEEE MultiMedia*, *29*(1), 125-127.

[26] Hughes, A. (2021, August 24). The Metaverse: where is telecom's place within "the next Internet"? Cerillion. https://www.cerillion.com/Blog/August-2021/The-Metaverse-where-telecom-within-new-Internet

[27] StackPath. (n.d.). https://www.electronicdesign.com/technologies/communications/article/21234728/electronic-design-communications-in-2022-from-5g-to-the-metaverse

[28] View all posts by Heng Shi Technology and Engineering Co. Ltd. (2022, January 24). Is Metaverse the future of communication? Heng Shi Technology & Engineering Company Limited. https://web.archive.org/web/20220128114241/https://hengshicoin.com/2021/10/27/is-metaverse-the-future/

[29] La, C. (2022, October 17). Hottest 2022 Digital Trend: the Metaverse. Faulhaber Communications. https://faulhabercommunications.com/hottest-2022-digital-trend-the-metaverse/

[30] Zimmermann, R., & Liang, K. (2008, October). Spatialized audio streaming for networked virtual environments. In Proceedings of the 16th ACM international conference on Multimedia (pp. 299-308).

[31] Verdot, V., & Saidi, A. (2011). Virtual Hybrid Communications. *Journal For Virtual Worlds Research*, *4*(3).

[32] Owens, D., Mitchell, A., Khazanchi, D., & Zigurs, I. (2011). An empirical investigation of virtual world projects and metaverse technology capabilities. *ACM SIGMIS Database: the DATABASE for Advances in Information Systems*, *42*(1), 74-101.

[33] Lee, S. H., Lee, Y. E., & Lee, S. W. (2022, February). Toward imagined speech based smart communication system: potential applications on metaverse conditions. In 2022 10th International Winter Conference on Brain-Computer Interface (BCI) (pp. 1-4). IEEE.

[34] Jungherr, A., & Schlarb, D. B. (2022). The extended reach of game engine companies: How companies like epic games and Unity technologies provide platforms for extended reality applications and the metaverse. *Social Media+ Society*, *8*(2), 20563051221107641.

[35] Tech vs. Tech: Unified communications vs. the Metaverse. (n.d.). L'Atelier. https://atelier.net:443/insights/unified-communications-metaverse-tech/

[36] StackPath. (n.d.-b). https://www.electronicdesign.com/technologies/communications/article/21234728/electronic-design-communications-in-2022-from-5g-to-the-metaverse

[37] Plotlights. (2022, March 28). What's Next for Communicators: The Metaverse. https://www.plotlights.com/blog/whats-next-for-communicators-the-metaverse/

[38] Metaverse: Introduction to the new era with the new norm of communication. (n.d.). https://www.ridebeam.com/newsroom/metaverse-introduction-to-the-new-era-with-the-new-norm-of-communication

[39] Kraus, S., Kanbach, D. K., Krysta, P. M., Steinhoff, M. M., & Tomini, N. (2022). Facebook and the creation of the metaverse: radical business model innovation or incremental transformation?. *International Journal of Entrepreneurial Behavior & Research*.

[40] Hwang, I., Shim, H., & Lee, W. J. (2022). Do an Organization's Digital Transformation and Employees' Digital Competence Catalyze the Use of Telepresence?. *Sustainability*, *14*(14), 8604.

[41] Liang, X., Chen, M., Zhu, W., Wang, Y., Luo, Z., Xu, M., & Wang, J. TCP/IP Model for Metaverse Networks and Some Potential Applications.

[42] Riva, G., & Wiederhold, B. K. (2022). What the metaverse is (really) and why we need to know about it. *Cyberpsychology, behavior, and social networking*, *25*(6), 355-359.

Appendix A – Abstract from published article

The metaverse is a term used to describe a new generation of the internet, where users can interact with each other and virtual objects and experiences in real-time. It is expected to significantly impact a wide range of industries, including communications, entertainment, and education. This research examines the potential impacts of the metaverse on the communications industry in the short term. It begins by defining the metaverse and discussing the key technologies enabling its development. It then goes on to identify the business areas that are most likely to be impacted by the metaverse. This research argues that the metaverse will significantly impact the communications industry in the short term. It will lead to the development of new communication technologies, platforms, and business models. It will also change the way that people communicate with each other and consume information. This investigation discusses how the communications industry can adapt to the metaverse. It argues that the industry needs to invest in new technologies and platforms and develop new business models. It also needs to focus on creating immersive and engaging user experiences.

Keywords: metaverse, communications industry, technology, business models, user experience