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Metaverse: Security and Privacy Concerns

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***Abstract*—The term “metaverse”, a three-dimensional virtual universe similar to the real realm, has always been full of imagination since it was put forward in the 1990s. Recently, it is possible to realize the metaverse with the continuous emergence and progress of various technologies, and thus it has attracted extensive attention again. It may bring a lot of benefits to human society such as reducing discrimination, eliminating individual differences, and socializing. However, everything has security and privacy concerns, which is no exception for the metaverse. In this article, we firstly analyze the concept of the metaverse and propose that it is a super virtual-reality (VR) ecosystem compared with other VR technologies. Then, we carefully analyze and elaborate on possible security and privacy concerns from four perspectives: user information, communication, scenario, and goods, and immediately, the potential solutions are correspondingly put forward. Meanwhile, we propose the need to take advantage of the new buckets effect to comprehensively address security and privacy concerns from a philosophical perspective, which hopefully will bring some progress to the metaverse community.**

Keywords—Metaverse, privacy, security, virtual universe, buckets effect

I. INTRODUCTION

Can Alice engage in immersive interaction with her friends who live thousands of miles away? Can Bob seamlessly move from the movie theater to the shopping center in an instant? Can Peter who has a leg disability stand and run like a normal person? Many people around the world may have such similar questions every day.

A recently popular term, metaverse, may be able to address these questions easily, and in fact, it is not a newborn but a palingenesis. The term “metaverse” was first invented in a novel named *Snow Crash* in 1992 [1], which was a combination of two words, ``meta" and ``verse". The former means beyond reality, i.e., in a virtual environment; the latter refers to the universe, which means that people can immerse themselves in this environment for living like reality. Since the term was put forward, its definition has been very diverse [2], e.g., lifelogging, future social networks, next generation Internet, and virtual world, which makes it cast a layer of mystery. Overall, however, a consensus is that users living in the real world link to and operate their avatars who are in the metaverse through access terminals in order to immerse themselves into a three-dimensional (3D) virtual world as shown in Fig. 1.

In a nutshell, various information including instructions of users is collected by sensors to sent the terminal; the terminal synthesizes the information from sensors and then sends it to the server by Internet to control the corresponding avatar in the metaverse; servers comprehensively process the information of a large number of users and reflect it in the 3D virtual world; each avatar activity sent by users is executed. Conversely, the status in the metaverse when avatars execute activities is fed back to servers, e.g., if a work of art is created by an avatar, its information such as content needs to be told to servers; servers record and generate the corresponding 3D virtual scenario that is broadcasted all user terminals; terminals display the real-time scenario in the metaverse to users after receiving server information and further send detailed instructions to sensors; each sensor sends a corresponding signal according to the instruction to immerse users into it. For example, it will be more realistic for the user if the sensor on the hand responds appropriately when the corresponding avatar shakes hands with others in the metaverse.

The metaverse can bring a lot of benefits to people in the real universe. The problems mentioned at the beginning of this article can be well addressed in the metaverse owing to the characteristic of virtuality. Meanwhile, the long-standing problem of discrimination in the reality may be alleviated. For instance, people with physical disabilities can move like ordinary people in the metaverse as long as they are conscious; there is no difference in physical strength between the elderly and the young; gender is no longer innate; looks can change at will; and skin color and race are no longer have to be known to others.

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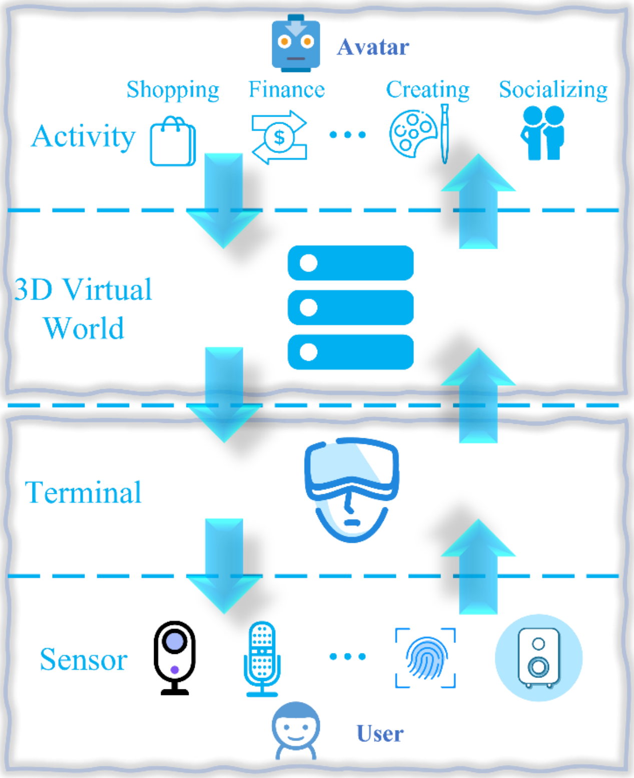

Fig. 1. The basic infrastructure of the metaverse.

On the other hand, the metaverse is confronted with new and serious security and privacy concerns despite its obvious value. First, more important and sensitive information in the real world through terminals may be stolen by malicious others since avatars have a closer relationship with users than other virtual worlds such as online games. Second, avatars have a lot of interaction with other avatars and non-player characters, which are not all intended to be understood by others. Third, there will inevitably be scenarios in the universe that make some people feel improper owing to cultural differences and others, not to mention harmful avatar actions such as harassment. Fourth, the ownership, illegal copy, and transaction of goods in the metaverse are also thorny challenges. The simplest solution to address the metaverse's security and privacy concerns is to restrict people from entering it [3], yet this crudest method utterly negates its benefits, which is equivalent to tossing out the baby with the bath water. In this article, we focus on the potential emerging security and privacy concerns of the metaverse itself and then propose alternative solutions that do not completely damage the interests. The key points of this article can be summarized as follows:

- We analyze the concept of the metaverse and propose that it is a super 3D virtual-reality (VR) ecosystem compared with other VR technologies.
- The serious challenges of security and privacy concerns in the metaverse are pointed out and summarized.
- Some potential solutions for these security and privacy concerns in the metaverse are proposed correspondingly.
- The new buckets effect is applied to think philosophically about how to deal with security and privacy concerns in a comprehensive way in the metaverse.

Fig. 2. An illustration of the main technology composition of the metaverse.

II. OVERVIEW OF METAVERSE

Intuitively, the boundary between the metaverse and VR, augmented reality (AR), and mixed reality (MR) appears to be hazy. In fact, the metaverse can be highly summarized as a super virtual-reality *ecosystem* based on the Internet, which is composed of inter-disciplinary technologies as shown in Fig. 2, e.g., VR, AR, MR, artificial intelligence, machine learning, computer vision, speech recognition, blockchain, and the Internet of things. By contrast, VR/AR/MR is only a kind of virtualized and digitized technology, and it does not necessitate a comprehensive ecosystem, rules, and the Internet, despite being an important component of the metaverse.

The term "ecosystem" implies that the components of the metaverse interact and restrict each other, and are in a relative stable dynamic equilibrium state, forming a persistent and unified virtual world. Meanwhile, a large number of users are the foundation of the ecosystem. If there are no users, it can only be labeled a 3D virtual vision system rather than be called ``verse" no matter how perfect it is. Just like a place with all kinds of goods but without customers who pay the bill, it can only be called a warehouse rather than a shopping mall. In truth, users create demand to stimulate the development of the metaverse, which in turn attracts users to enter, resulting in a positive ecosystem. In other words, a metaverse without users is doomed to failure, which also implies that perhaps only a few metaverse platforms will eventually flourish and the others will die. This trend is already evident on current Internet platforms, e.g., people prefer to choose Instagram for sharing pictures and Tiktok for short videos, despite the availability of alternative ones.

There are two main reasons why the metaverse recently can be palingenesis after this concept was put forward many years. First, the COVID-19 epidemic has trained people to be familiar with the virtual digital world and promoted the socializing to shift from offline to online to some extent [4]. Second, the recent significant progress like Big Bang of the above related technologies as shown in Fig. 2 makes it possible to build a metaverse technically.

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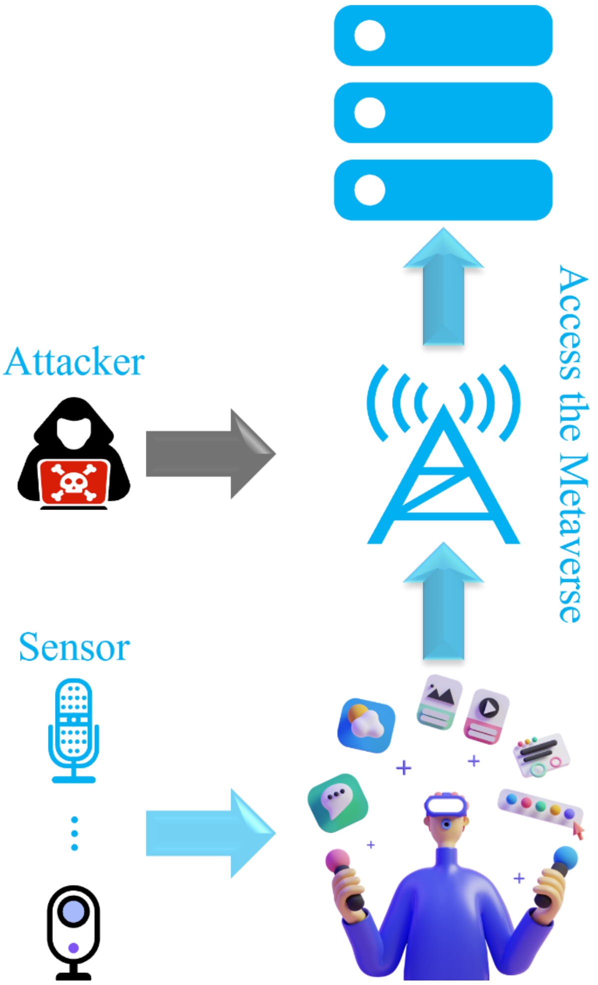

Fig. 3. An illustration of the metaverse being attacked by the attacker.

III. Security and Privacy Concerns

The development of anything is inevitably accompanied by security and privacy concerns with no exception to the metaverse. Specifically, these concerns can be divided into four categories:

- User information: multi-sensor fusion is one of the characteristic of the metaverse as shown in Fig. 1, making a large amount of user information to be collected. There is no doubt that sensors are necessary since they help users to improve the experience resulting in immersing themselves in the metaverse. On the other hand, although many users may not be noticed or even realized the problem [3], some user information collected by sensors, e.g., related physiological, physical, biometric, and social, is too personal. If it is leaked, it will greatly endanger the security and privacy of users [5]. Hence, it is critical that user information is protected.
- Communication: one of the features of the metaverse is its high interactivity and sociality, and thus a lot of communication inevitably takes place. Many activities, e.g., sharing, cooperating, and increasing mutual trust and understanding, in the metaverse are difficult to be done without the help of communication. Although it may not contain the above-mentioned user information, most users are nevertheless unwilling to tell those who are non-communicators since communication content is highly private and sensitive. As a result, it is important to protect communication and it should be done in such a way that non-communicators are prevented from comprehending and recovering the contents of the communication while legal communicators can.
- Scenario: it is conceivable to encounter the same security and privacy concerns as the real realm since the metaverse is a surreal universe. There are two main aspects to be considered: the scenario itself and avatars in the scenario. For the former, as a great number of users are clustered on a metaverse platform (and in fact there are not many alternative platforms to pick from), their understanding of cultures, religions, and so on will inevitably vary. Therefore, the scenario will not meet everyone's wish and even cause misunderstanding for some avatars. For the latter, the influx of users will inevitably introduce some malicious and immoral ones who may insult, track, or even sexually harass other avatars in the metaverse, and these activities have appeared in online games [6].
- Goods: the metaserve has the characteristics of imagination, high creativity, high degree of degree of freedom, and high personalization. Thus, avatars can create all kinds of goods, such as the character modeling, appearance, costumes, buildings, and artworks, according to personal wishes. These goods can be applied by creators or sold, i.e., they are either created through efforts or at the cost of money (of course, they may also be freely given by friends), implying that they include both spiritual and financial values. Avatars do not wish the value to be illegally damaged, e.g., an avatar tailors a personalized dress for themselves and may not want to see it on others. Meanwhile, goods transactions may also be damaged by malicious users and avatars also have a demand to anonymize rights in the transactions. Hence, it is important for the secure protection of goods themselves and transactions in the metaserve.

IV. User Information

User information has always been a very important and sensitive concern related to security and privacy in modern society. More detailed user information in the metaverse will be collected than previous platforms such as society networks due to the characteristics of the immersion, the indistinguishability of virtual and reality, and multi-sensor. This makes illegal third parties more interested in this information and may attack through the network as shown in Fig. 3. Meanwhile, the information is no longer directly under the actual physical control of users as long as it is transmitted out from the terminal, which implies that information is at risk after leaving the terminal, and in other words, the protection of user information needs to be carried out at the terminal.

It is worth noting that everyone has vary views on privacy since everyone has different cultural habits and acceptance. In addition, any solution cannot protect all information without paying any price. Therefore, the solution should be targeted protection for the goal that users want to achieve, and no one can perfectly prevent from all risks except to give up the use

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directly. Next, we will state some solutions to protect user information in the metaverse.

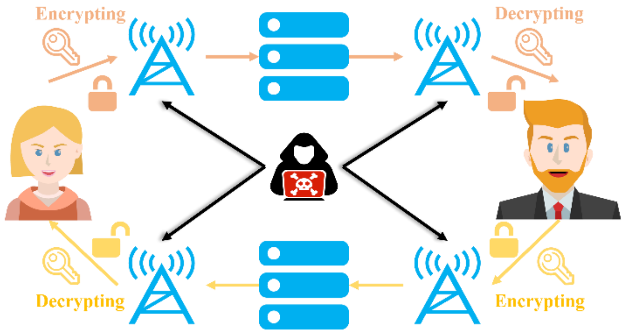

Fig. 4. An illustration of the communication being protected.

For single accurate signal information such as heartbeat information obtained by the sensor, it can be protected by only shielding the signal and prohibiting transmission. On the other hand, visual multimedia including image and video, which occupy the mainstream in the metaverse, contains a lot of sensitive information and much accurate information can also be extracted from it, e.g., heart rate [7], health, and social status. It can not be simply shielded since visual multimedia is inextricably related to the application of the metaverse. Therefore, specific treatment and protection are needed, which can be classified into three categories: generalized, white-list, and black-list.

Generalized protection means that users desire to protect some visual content since they feel there is probably a privacy issue. It is protected in a general way without considering specific and fine privacy compared with the solutions of white-list and block-list. In the multimedia visual content, only one part may be needed and other parts are redundant. For example, it only needs people to appear and background which may reveal too much information is unnecessary in the video conferencing in the metaverse. This problem can be solved by matting, i.e., the visual content can be divided into those that need to be preserved and abandoned and then processed accordingly. It has been applied in practice, e.g., Zoom and Tencent Conference have allowed users to choose virtual background options a year ago. Similarly, the solutions such as face swapping and 3D model replacement can be applied in light of the privacy risk that faces may pose.

White-list protection refers to that everything is processed and protected in addition to the information selected by users (which similar to the white list), and this is a targeted protection compared with the above. As a simple example, a smile competition is organized in the metaverse and the avatar with the brightest smile can win the game. The face content of the user is required for participating in the competition, but the user may only wish to employ the facial content for analysis smile. Hence, the face in the multimedia should not contain any information except smile. For this problem, Wu *et al.* proposed a solution to train a model through machine learning to protect visual content, which only retains the usability of specific information but other will be deleted and cannot be extracted [8].

Black-list protection implies that nothing about the visual content in the multimedia is processed except what users choose (which similar to the black list). This kind of protection often aims at the face, resulting in a highly accurate with good visual observability. For such protection, faces are often destructed into specific vectors for further accurate processing and each vector represents a signal. Such vectors are typically separated into two classes: identity and attributes. Some vectors pertaining to the information that users desire to protect are processed to be protected while the rest remain unchanged. Then, these vectors are integrated and reconstructed into the protected face by generating models called anonymization and attribute protection, respectively, depending on whether the identity or attribute is processed.

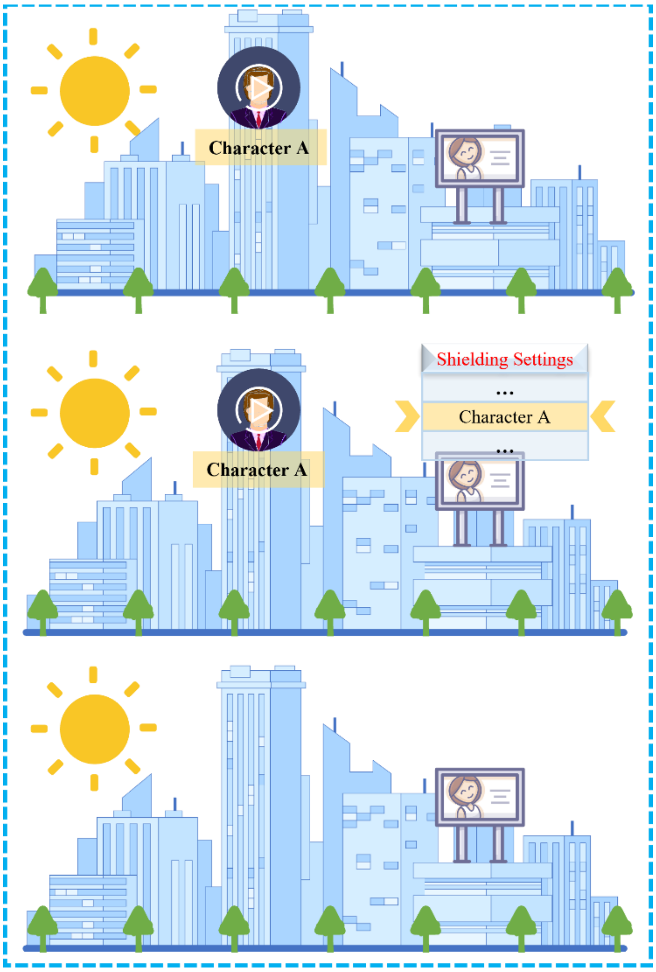

Fig. 5. An example of the scenario shielded according to user selection.

V. Communication

Interaction and social are required in the metaverse and thus frequent communication occurs. Communication is carried out by avatars on the surface but it is actually controlled by users. For the participants in the communication, they only want the target party, i.e., legitimate receiver, to know the content of the communication, while the third party is unaware. It indicates that the content can not be directly eliminated in the solution, as in the case of user information, but it must be able to be recovered for the target party.

A powerful solution to this goal is encryption as shown in Fig. 4, i.e., the sender sends the information after encrypting with the key and the legitimate receiver decrypts

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it employing the correct key after receiving it. Thus, the meaningless ciphertext is transmitted in the course of communication and attackers cannot decrypt it as long as they do not have the correct key even if the ciphertext is intercepted. By the way, the key and encryption algorithm are primarily responsible for the security of the ciphertext, i.e., the ability to prevent attackers without the correct key from breaking the ciphertext. For the key, it should be long enough, i.e., the key space is large enough, to prevent the attacker from using exhaustive attack, and meanwhile, the communication will be in danger once the key is leaked and thus the key should be kept confidential and replaced on a regular basis. For the encryption algorithm, it should go through enough cryptographic tests and analysis to prevent possible attacks, and then the algorithm that meets the corresponding security standards is selected according to the actual needs.

Although general encryption schemes for visual multimedia including video and image, converting the meaningful visual content into useless noise-like one, have been able to meet the needs of security and privacy, they do not think about visual observability. In fact, this feature may be important for enjoying the communication. Senders share a large number of encrypted images that are all noise-like ones and cannot be distinguished by browsing, and in other words, they cannot be selected unless all of them are decrypted, which may be a poor experience for receivers. Thumbnail-preserving encryption can be applied to alleviate the contradiction between privacy security and visual observability [9], which erases the fine details of the visual content but preserves the coarse one. The final result is similar to the mosaic effect, which implies that certain visual information can be obtained by browsing the ciphertext but the details cannot be learned until decrypting.

VI. SCENARIO

Some conflicts arise from time to time in the real world, such as those arising from religious, political, gender, and sexual minorities, as a results of various cultures and ideas from different people. This phenomenon is even more severe in the virtual world due to lack of distance and other restrictions, e.g., cyberbullying on social networks and scale violence in online games, which will undoubtedly degrade the experience and create discomfort. But for users of current network platforms, they can escape from these unpleasant places and form small virtual communities with people who have similar interests and opinions so as to avoid some negative effects. However, this way does not seem to exist for the metaverse since itself is a complete universe and it is difficult for a tiny group of individuals to make a fresh start. Meanwhile, just as in the real world, there are malicious avatars in the metaverse who are evil to others, such as harassment and stalking [3].

For a user-friendly metaverse environment, a setting window should be provided to allow users to set to prevent some scenarios around their avatars. For example, a propaganda video of a political figure is playing outside a building, but some avatars dislike him/her and thus they choose to shield him out as shown in Fig. 5. It is worth noting that the scenario does not disappear from the metaverse but can not be seen for the specific avatar, which can also be called as the personalized scenario presentation. Similarly, for the offensive and insulting content of other avatars' speeches and texts, specific keywords can also be set to detect them through the voice and text detection model for shielding.

On the other hand, this solution is difficult to detect avatar aggressive and bullying behavior. First, the meaning of avatar behaviors is often subtle and whether it is malicious needs to be combined with the actual situation and context. Second, behaviors themselves are highly diverse and many malicious ones have no clear definition compared with the speech and text. For example, it is not always deemed malicious for an avatar to play with a gun, but it is malicious if the gun points towards other avatars, making it is impossible to judge whether there is malicious by simply detecting the gun unless supplemented with specific circumstances. According to researches, the detection of malicious bullying by the avatar can combine multiple factors such as body-pose, facial emotion, hand gesture, object, and social, resulting in a satisfactory outcome [10].

For the harassment and stalking, the preceding solution is not useful since even though these avatars are shielded in our own scenario, we still exist in malicious avatar scenarios and they can still do this kind of activity. A good solution for it is to disappear suddenly, e.g., cloaking and teleportation [3], and as a result, the malicious avatars cannot find the target one. Furthermore, a user can create multiple avatars and randomly select different ones each time when he/she accesses the metaverse to prevent some ill-intentioned avatars from looking for patterns over time.

VII. GOODS

As Lee *et al.* pointed out [2], creation is an important part of the sustainable development of the metaverse. In addition, the high degree of freedom and open environment of the metaverse also greatly encourages the emergence of the creation activity driven by individualized psychological needs or money, which means that a large number of goods produced by creation will appear. No matter what the motivation, the owner of the goods will not want others to illegally copy and abuse it. Based on this point, it is necessary to take methods to protect it.

A viable solution is invisible watermarking, a technique aimed at embedding a specific mark related to identity in the goods as they are created or the ownership is transferred. It will not affect the visual effect of its own goods in the metaverse owing to invisibility, and can be extracted or detected when needed. Therefore, some functions, including content protection, authentication, and tamper-resistance, are realized [11], which further deters malicious avatars from stealing and illegally copying goods. Moreover, compared with the real-world scenario, watermarking is more suitable for the metaverse. In the real world, it is essentially a modification of visual content no matter how invisible it is, which will destroy some physical features, and thus the existence of watermarking can be illegally detected by some technical means. This difficulty, however, does not exist in the metaverse which is a generative digital scenario rather than a physical one, and it is difficult to detect it by existing means even if the watermarking is made on it.

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The blockchain is an excellent solution to the problems of ownership, traceability, and transfer of goods, which has the following characteristics: decentralization, tamper resistant, and anonymity [12]. Decentralization enables each avatar to participate in blockchain activities fairly, leading that avatars are able to register the ownership of each goods by themselves, which is the premise of protection. Tamper resistant is due to the fact that tampering with the blockchain require more than 51% of the computing power support in the system. It is not the interests of those with a lot of computing power since they need to maintain the stability of the system to obtain the maximum benefits. Therefore, there is no need to be concerned about its effectiveness following ownership registration. Anonymity allows the avatar not to worry about disclosing who has the ownership after registration, nor about the exposure of its identity during a transaction. Furthermore, the blockchain has an effective tool, the smart contract [13], which can prevent both parties from defaulting in the transaction of goods. Specifically, the two sides of the transaction need to reach an agreement in advance and then draw up a contract to sign. Once the conditions stipulated in the contract are met, it begins to be executed automatically and is not changed by human will. Hence, the transaction of the ownership of goods in the metaverse can be carried out safely.

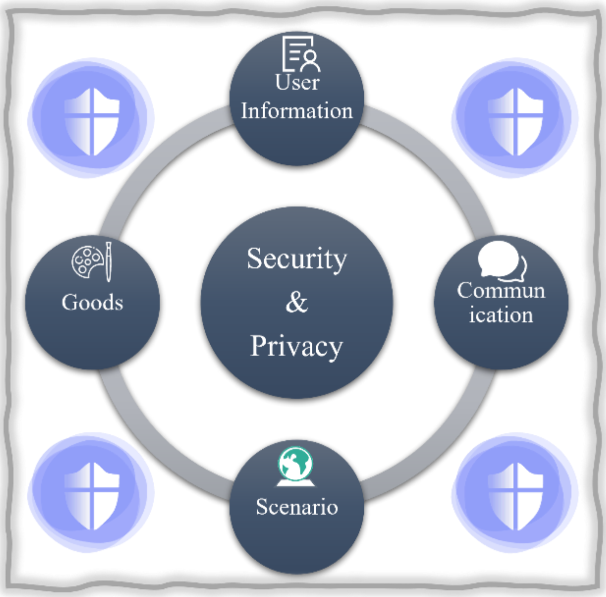

Fig. 6. An example of the new buckets effect for protecting security and privacy.

VIII. New Buckets Effect

There is no doubt that the above solutions can achieve a protective effect in dealing with their corresponding security and privacy concerns when standing at the angle of the raised problem. Meanwhile, it is common for researchers to notice the shortcoming of existing solutions and strive to continuously improve them to achieve better effects, like classic buckets effect, in which each board can be enlarged to contain more water. However, there are gaps between each board, and if it is not fastened, no matter how much water is contained, it will leak. Similarly, if people simply study a single problem in isolation and turn a blind eye to others, they may be able to put forward corresponding and effect solutions, but they are not very helpful to mitigate the security and privacy of the whole ecosystem. For example, when an avatar chats with others in the metaverse, he/she may disclose trivial daily in unexpected ways, and then expose his/her user information from the real world. If the intentional avatar takes advantage of this and deliberately communicates with the avatar, the user information may be successfully obtained in this way.

Therefore, it is necessary to add a lock ring on the bucket to minimize water leakage, i.e., new buckets effect. Similarly, a comprehensive rather than peer-to-peer consideration of how to address security and privacy concerns, coming up a package of solutions, is necessary. It should be to allow users to choose and execute multiple and closely related solutions simultaneously, which may effectively alleviate concerns in the metaverse as shown in the Fig. 6. The statement may help better protect the security and privacy of the metaverse, but it also poses a greater challenge for researchers, which makes them need to design a systematic and coherent solutions based on the thinking of comprehensive and global.

IX. Conclusion and Discussion

Security and privacy concerns are inevitable in the development of everything and need to be solved. In this article, the concept of the metaverse is first refined and the security and privacy concerns of the metaverse are analyzed and summarized involving user information, communication, scenario, and goods. Then, through reflecting on the key problems we summarized, corresponding potential solutions based on shielded, machine learning, encryption, watermarking, blockchain, and so on are proposed, which adhere to the user-centered, allowing users to choose personalized and appropriate ones to address these concerns. Last, through philosophical reflection, this article puts forward the idea of drawing lessons from the new barrel effect for comprehensively and effectively alleviating the security and privacy concerns of the ecosystem. We hope that the relevant concerns we raised can attract attention in the metaverse community and provide some assistance in mitigating them.

It should be noted that the privacy and security of the metaverse and the privacy and security of classical (or current) computers are an inherited and evolving relationship. As mentioned above, any present-day privacy and security concerns can be found and amplified in the metaverse. In essence, the meta-universe is a web virtual space built on the basis of Web 3.0, which is an accumulation of countless hardware, software, protocols, etc. Any of these constituents with privacy and security risks will be inherited into the metaverse and bring a crisis to the metaverse. Meanwhile, even if individual constituents have no privacy security concerns, their combination can pose significant risks.

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Virtual Reality Skateboard Extending Metaverse

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***Abstract* – Implementing a virtual reality skateboard which would be further expanded into the Metaverse, a cyberspace where multiple people can come together and interact virtually. Further implementation of this VR experience into the Metaverse will be conceptualized in the research paper published along with the project. The motive behind the project was to let people experience certain activities which are hard to realize in the physical world. Our project consists of 2 parts, hardware, and software. The hardware consists of a skateboard, Arduino, VR headset, jumper wires, mini breadboard, an HC-06 Bluetooth module, an MPU-6050 accelerometer or gyro, and a 9V battery with a battery box that has an on/off switch and a barrel plug (to power the Arduino board). Software is a mobile application that is developed using the Unreal Engine, on which the terrain is built and the user wearing the VR headset can experience the virtual world thus created. The software and hardware will be connected using the plugins which are available in Unreal.**

***Keywords* – Metaverse, augmented reality, IoT, VR headset, Game Based Learning (GBL), Arduino, Unreal, Virtual Reality**

I. Introduction

VR (Virtual Reality) is an artificial experience where the user can interact in a 3-Dimensional space making them feel the surroundings real. The environment is created artificially through sounds, images, and objects. The environment can be perceived through a virtual reality helmet or headset. VR is one of the most strongly emerging technologies capable of holding much of the advancements and growth in technology [1]. Nowadays a keen usage of VR is seen in gaming where the creators are getting real-world gaming experience for the players by providing them with virtual objects with cutting-edge capabilities increasing players' engagement and interest in the game [2]. Virtual Reality can be in form when the objects (the physical entities in the real world can thus be created virtually in virtual reality space) and avatars (virtual representation of the user with which it interacts with the virtual world controlling its movements) remain in synchronization with each other. Whether it be object-object, avatar-avatar, or avatar-object, harmonized space is essential [3].

Coming to one such VR-operated game called Virtual Reality Skateboard in which a player plays the skateboard game with the help of a VR headset, skateboard. The game terrain is created using the Unreal Engine, with which the player can experience a virtual world having different virtual objects necessary for the playing of the game. This is the frontend part which is connected to the hardware part (IoT is responsible for the hardware simulation which helps in noting the speed, direction, and movement of the player), the VR headset, skateboard, Arduino, and Bluetooth module. The connection between the front end and the hardware part is done by converting the game to an APK file and connecting it to the Arduino code [4].

Virtual Reality is a boon where people can cherish a new world where they interact with objects without the actual presence of those objects [3].

Adding to the scope of virtual reality lies Metaverse which is a cyberspace that is a world in which many virtual, augmented reality small worlds can interact creating a mass environment that is connected through the internet. It is concentrated on social connection, it is the near future where multiple users can interact sitting in different parts of the country [5]. The different virtual worlds comprising the Metaverse should be working in harmony that is in complete synchronization with each other. It is crucial to remember that users in a virtual environment, or a portion of the Metaverse, should view the same information as other users do. Additionally, users may communicate with one another in a regular and timely manner. In other words, how users should perceive virtual items and user participation in a shared virtual environment would be crucial. The simultaneous activities of all the objects, avatars that represent their users, and their interactions, such as those between object-avatars, object-objects, and avatar-avatar, must be merged at the center of creating the Metaverse through the composition of various virtual shared spaces. The dynamic states and events of the virtual spaces should be synchronized by and reflected in all participating processes in virtual environments [1].

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This is what if applied to the skateboard can make multiple players in different locations play together in the environment of Metaverse making the playing more efficient without the actual interaction of the players, they can play whenever and wherever they want just need to be connected through the internet to create cyberspace [2].

The paper is organized as follows: Section 2 gives a thorough description of all the papers that define Metaverse and how it is implemented with IoT. Section 3 gives a detailed description of the project implementation which includes the hardware implementation, frontend implementation, and packaging of the frontend into an Android application. In Section 4 we conclude by giving the results and the future scope of the project.

II. Literature Review

The paper stated the real meaning of Metaverse where they featured it to be an internet application. It describes Metaverse from five aspects which are network infrastructure, management technology, basic common technology, virtual reality object creation, virtual reality convergence, and showcasing the technical infrastructure of Metaverse. The paper mentioned the characteristics of Metaverse to be multi-technology, sociality, and hyper spatiotemporality along with its different applications along with the challenges [6].

The paper tried to obtain real insight into the actual meaning of what is Metaverse. He states that there is no absolute definition of Metaverse even though multiple phrases and acronyms have been suggested. Without a clear concept, a debate breaks out, and creating a structure for a virtual world becomes difficult. A definition was offered by several scholars, however, there are still issues with each definition and it is simply impossible to apply it to modern technology. The main aim was to define a "virtual world" that is specially aligned with technology by using the basic theories to sample technologies. The resultant outcome is compared to other similar work and it is used to categorize technologies like virtual and mixed reality, Metaverse, pseudo-persistent video games, and MANets. It breaks down the characteristics of different technologies, a comparison of the definitions, an ontology showing relationships between various terms and definitions, and the use of pseudo-persistence to classify technologies that simulate persistence [2].

The paper presented that Metaverses are examined as a platform for game-based learning. A relatively new class of Internet applications is Metaverses like Second Life. Their functionality is comparable to that of an online 3-dimensional multi-player game but is different in a way that the users can create their avatars and are not restricted by predetermined goals of any kind by the game. Metaverses demand more host server systems and network traffic as compared to games. This paper contributes to the understanding of the Metaverse by presenting the case study of Game-Based Learning (GBL) in the Metaverse environment and analyzing the Quality of Service provided by the Metaverse under a variety of evaluator-induced network conditions [7].

The paper stated that progress in areas like immersive realism, ubiquitous access, identification, interoperability, and scalability is necessary to transform a collection of separate virtual worlds into Metaverse. The present state and improvements required for the creation of a usable Metaverse are discussed for each sector. The development of Metaverse is dependent on multiple factors like institutional and public interests, ongoing hardware performance improvements, and factors that limit the realization of the goal such as the computational limitations and the collaboration between virtual world stakeholders and developers [5].

The paper is about the design and implementation plans for an IT convergence framework for games as IoT services. First, he examined the factors to take into account while designing and implementing an IT convergence framework for games that leverage user mobile devices and a variety of sensors in an Internet of Things environment, along with the associated solutions. Then, by developing games and tracking user interactions in the IoT environment, they demonstrated the potential of games in the IoT ecosystem. By this, they showcased the amalgamation of IoT and gaming which is an important stage of developing hardware games [8].

The complex term, "the Metaverse", is defined as a broad shift of interaction between the users and the technology. The companies refer it to as persistent virtual worlds that exist even when the player is not playing. Many companies envision the Metaverse as a virtual world with a digital economy, a place where users can create, buy and sell goods. Companies like Meta, Microsoft, and so on are defining and developing Metaverse in their own words. Meta defines the Metaverse as a place with virtual houses where avatars of individual people can interact. Microsoft defines it as a virtual room for individuals to chat with their remote workers or train their new hires [9].

Metaverse lets us perform social gaming which allows interaction with other players, earning money by creating and selling assets virtually, adding more players in the virtual world, and allowing mixed reality experience. AR, VR technology, blockchain, cryptocurrency, IoT, and artificial intelligence are the few technologies that empower metaverse development. Data security, child control services, and incorporation of NFTs are still some of the challenges faced for the development of gaming in the Metaverse [10].

The Metaverse, which was first featured in video games, has drawn interest from a variety of industries, including literature, the arts, music, and education. The Web of Science database's 40 journal articles with the term "Metaverse" are the subject of this review article. Daily tasks like working, traveling, shopping, and attending school will be made possible by the Metaverse, giving users a stronger sense of identity and continuity in their experiences. These modifications' socio-cultural and psychological implications will also be investigated. Big data, data science, and artificial intelligence

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researchers can use the Metaverse as a working platform because it will assist current study themes and expose new ones. The Metaverse will see more scientific studies and richer material emerge as technical infrastructure advances and academics' interest grows [11].

This study analyzes Metaverse research, including avatars, XR, and the necessary components (hardware, software, and contents). It reviews trends in user interaction, implementation, and application, and discusses the importance of interaction in storytelling. The study also examines Metaverse domains like Ready Player One, Roblox, and Facebook Research. The study highlights the potential for social influence, limitations, and open challenges in the future [12].

This exploratory study investigates the multi-dimensional features of pre-service teachers' readiness to build technology-enhanced learning environments. It examines pre-service English teachers' VR-making and Metaverse-linking experiences, highlighting the importance of instructional VR content design in the language classroom. The study also highlights the role of the Metaverse in transforming one-way interaction between digital content knowledge and student learning to meta-modal learning extended through social connection and interaction with a teacher. This Metaverse design benefits teachers and students in terms of learning adaptivity and sustainable education. The findings can provide insights into future professional development and support preservice teachers' dispositions toward teaching with emerging technologies for sustainable education. Future research should validate the theoretical and pedagogical benefits of VR and document trajectories of VRM in pre-service teachers' professional development to provide a wider audience and message [13].

This paper proposes an approach for integrating social interactions into games while maintaining immersion. Due to VR, social interactions might become unimportant as it destroys the illusions of the happenings in the real world. But some authors contradict this point of view and suggest that it gives a joyful gaming experience. Some participants experienced cognitive immersion while playing with other players. Expansion of the game space means integrating immersion as well gaming. Some design techniques are unification (where every detail, like the game theme, surroundings, and the music is designed to facilitate the immersion), storytelling (to help players bond with the virtual world), stimulating communication (with other players there is a chat section), and assigning roles and responsibilities to all the players. The authors conducted a case study on Lunar Escape which is a collocated multiplatform VR game and explained the different roles and tasks available for each of the roles. Thus, with this case study, the authors were able to explain the design approach for a VR game which includes both social interaction and game features [14].

Conclusively the paper provides us with statistical and definition-oriented information where no directives for the doing and working of the virtual reality skateboard are provided, moreover, the implementation of Metaverse through virtual reality skateboard is also not provided. The papers are related peripherally to the main aim.

After the comprehensive study of the above papers, much understanding of the subjects like Virtual Reality and Metaverse can be made. Their impact on the technology and their uses are greatly mentioned and through this one such utility of creating Virtual Reality Skateboard embarked through which virtual reality can be experienced by creating a skateboard game in which the player is signified as a character in the game developed using Unreal Engine. It doesn't cease here but the concept can further be extended into Metaverse where multiple users in their own virtual reality environments can come together by interacting with each other in virtual reality environments forming the Metaverse.

III. Materials and Methods

In this paper, we designed a prototype of the Metaverse implementation of a virtual reality skateboard. It is a single-player game, where the player will be standing on the skateboard, which has an Arduino connected to it capturing all the player movements, and will be wearing a VR headset, which will show the terrain on which the player is playing [7].

The entire implementation is divided into two parts, one is the hardware part and the other is the frontend part (the Skateboard Game developed Using Unreal Engine). The hardware part captures all the player's movement and is connected to the frontend part.

The hardware and frontend parts are connected using the plugins available in Unreal Engine.

Fig.1 shows the activity diagram which shows the interaction between the player and the game.

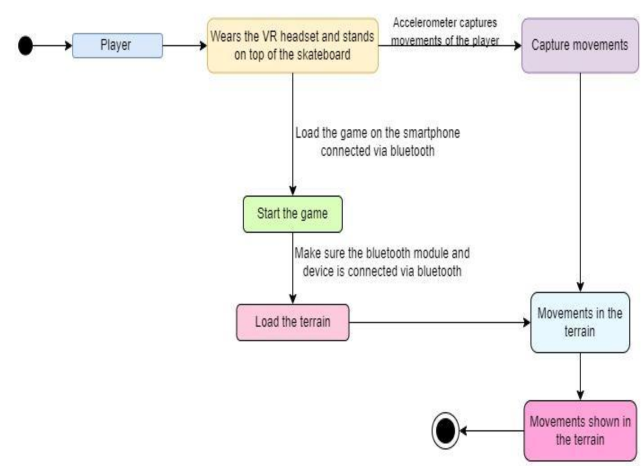

Fig. 1. Activity diagram showcasing the directives required for implementing the Virtual Reality skateboard

A. Hardware requirements

- Arduino UNO [15]: It is an ATmega328P-based microcontroller board with 6 PWM outputs, 14 digital

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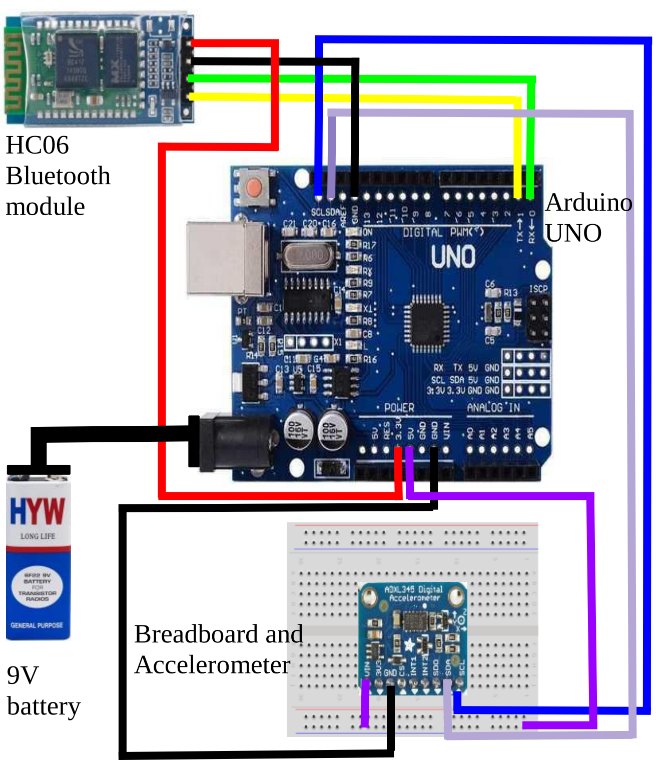
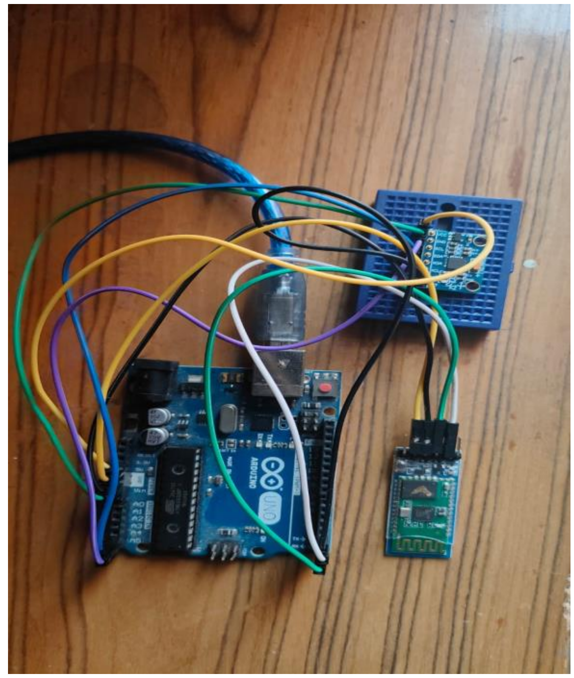
input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB port, a power jack, an ICSP header, and a reset button. It already has everything needed to support the microcontroller, so all that is required to get it going is a USB connection to a computer, AC-to-DC power converter, or battery.

- HC06 Bluetooth module [16]: For transparent wireless serial communication, the HC-06 is a class two slave Bluetooth module. The user can operate it with complete transparency once it has been associated with a master Bluetooth device, such as a computer, smartphone, or tablet. All information received via the serial input is immediately broadcast over the radio.
- MPU6050 - Triple Axis Gyro Accelerometer Module [17, 18]**:** The MPU6050 module makes use of the well-liked MPU6050 Sensor, which combines a three-axis gyroscope and an accelerometer into a single unit. A sensor and microcontroller can easily and directly communicate with one another thanks to an I2C connection.
- VR headset [19]: Virtual reality headsets allow users to experience information in a 360-degree environment that allows them to turn and gaze about just like they would in the real world. This replaces the player's natural environment.
- Skateboard [20]**:** The skateboard has IoT technology installed on it, which will provide a virtual reality experience of the metaverse.



(a)


(b)


(c)

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(d)

Fig. 2. (a) Circuit diagram (b) Hardware connection (c) Hardware connection connected to the skateboard (d) VR headset made at home

The circuit diagram is shown in Fig.2. (a) and the implementation of the circuit diagram is shown in Fig.2. (b). MPU6050 module should be positioned correctly with the yarrow pointing upwards, aligning it with the nose of the board. The VCC, GND, SDA, and SCL pins of MPU6050 should be connected to the 5V, GND, A4 (SDA), and A5 (SCL) pins of Arduino respectively. The VCC, GND, TXD, and RXD pins of the HC06 Bluetooth module are connected to the 5V, GND, RX (pin 0), and TX (pin 1) pins of Arduino respectively. Fig.2. (c) shows that the hardware connection is placed under the skateboard. The hardware connection was screwed to the skateboard.

Fig.2. (d) shows the VR headset made at home. The VR headset, Fig.2. (d), was made out of thick paper and two convex lenses of 45mm focal length. The thick paper is cut into rectangles of different sizes, two rectangles with two holes to fit the convex lenses, three rectangles to cover the sides, one rectangle to form the base, and another rectangle to support the phone that will be kept inside the VR [21].

B. Frontend

The frontend part of the implementation is done on Unreal Engine 4.27.2. Unreal is an open-source game engine that consists of components that are shared by many video games. It can be easily used to create 3D models and realistic images. It consists of tools to integrate with other commercial software and provides tools to document the virtual world created by the developer [22].

The terrain is created by downloading the already available free assets in Unreal.

The asset provides props that can be edited according to the developer's requirements. The road prop provided has to be duplicated, rotated, and grouped to form a block of the road. This block of the road has to be duplicated and grouped multiple times to form the basic road structure of the terrain.

The brick ground prop provided, in a similar way as the road mesh, needs to be duplicated and grouped together to form the base of the park structure of the terrain. A pavement prop is already available in the asset which can be placed over the park structure. To add details to the terrain, the tree mesh along with the leaves VFX can be added along the road structure, bush mesh along with the bush VFX can be added along the pavements, and bench prop and switched-on street light can be added along the road structure. A fountain VFX can be added on top of the pavement and a bridge, a river body, a food truck, and a couple of chairs are already available props that can be added on top of the parking structure [4].

The character mesh, an FBX file, is downloaded from a third-party website. After loading the file as a component into the Unreal Engine, a blueprint is created for the character, which helps in the movement and speed of the movement of the character [20]. The axes of the character are adjusted and the controls are added. In Unreal Engine, the controls for the character can easily be built using the existing controls like moving forward, backward, rotating, and controlling the speed. The controls are defined using a flow graph, hence it is easy for the user to understand the movement of the character [4, 21].

(a)

(b)

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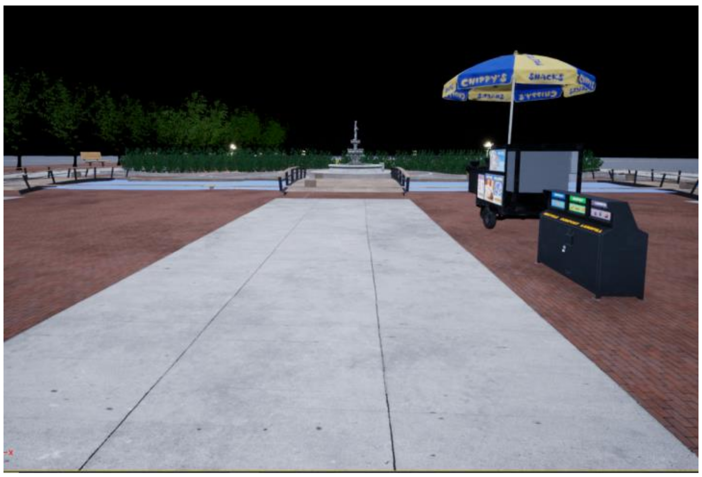
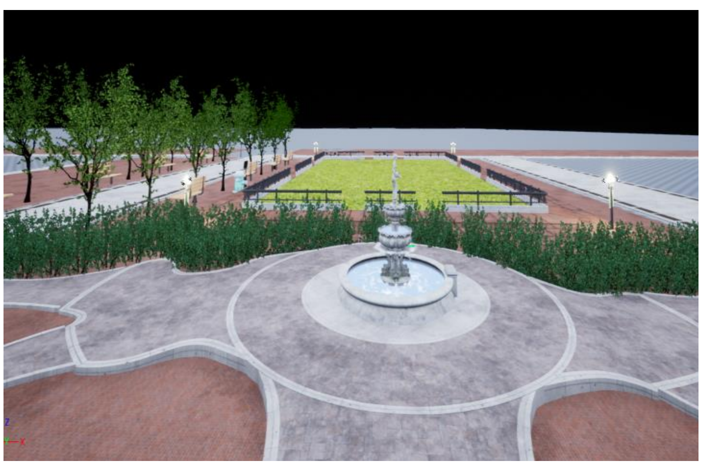
(c)



(d)



(e)

Fig. 3. (a) Top view of the terrain (b)The starting position of the player (c) Ground (d) Pavement to the fountain (e) The fountain

Fig. 3 shows the terrain created using the Unreal Engine. Fig.3. (a) shows an overall view of the terrain, Fig.3. (b) shows the starting point of the player, Fig.3. (c) shows the ground, Fig.3. (d) shows that pavement to the fountain and Fig.3. (e) shows the fountain area from which the pavements are connected to the roads.

The various poses of the character are shown in Fig.4. (a) and (b).

(a)

(b)

Fig. 4. Character animation in the skateboarding state (a) Standing on the skateboard pose (b) Pushing the ground pose

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C. Packaging for Android

The frontend application is loaded into an Android device, hence the necessary APK files are needed to be downloaded and uploaded to the IoT application [11].

Android SDK, NDK, and JDK files are required to convert the game created into an Android application. All these files are downloaded from the links available on the Unreal Engine website. For loading the files into the Unreal Engine, the system variables need to be edited and the path where these files are stored is copied into the Android Platform option [4,11,22].

IV. CONCLUSION

The terrain built using the Unreal Engine gives the virtual reality experience of riding a skateboard. This is created using the assets and props provided by the Engine. By simple drag, drop, and resize the virtual world for the player to ride the skateboard is created. The collision option allows the props to become opaque so that the player does not go through it.

The character with the game is created by downloading the required FBX file, which contains the character mesh, and the animation mesh required is also downloaded as the FBX file. These files are loaded into the Engine, the character axes are adjusted to the terrain mesh, speed and movements are adjusted and finally, the character can move according to the player's movements.

The front end is exported as an APK file to be loaded into the Android platform and using the VR headset the player is able to ride the skateboard virtually [11].

The hardware consists of an Arduino with an accelerometer and Bluetooth module connected to it. All these components are connected to the skateboard. The Bluetooth module is used to connect it to the mobile phone connected to the VR. The accelerometer is used to detect the motion of the player and the Arudino, a microcontroller controls the Bluetooth module and the accelerometer [7].

Since this game is created virtually, it can be further expanded into Metaverse, where multiple players can play virtually in their own virtual world connected through the internet where they can experience the leisure of gaming even when they are geographically separated [5].

This paper acts as a testimony to the creation of a virtual reality skateboard through which the Metaverse Environment can be perceived. It provides structured directives for the implementation of the virtual reality skateboard. All the papers presented are peripherally related to the objective whereas this paper provides in-depth knowledge leading to the formation of Metaverse through Virtual Reality games (here in skateboard riding). With more technologies like Artificial Intelligence and Spatial and edge computing, the response time to the user's action can be reduced, which further enhances the user's interest in using this system [23].

V. FUTURE SCOPE

This prototype opens up a plethora of ideas that can be further implemented into the Metaverse. The games which require multiple body movements like badminton, tennis, and so on, can also be implemented into the Metaverse. Multiple players from different parts of the world can play together in the Metaverse. There can be multiple championships that can be held in the Metaverse as it breaks the geographic barrier for the players to play together.

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AUTHOR CONTRIBUTIONS

KK- Kanishka Kataria, JC- J Chandana, AR- Athira Raghumadhavan, KG- Komal Gandhi, KR- Kartik Raja, SG- Shilpa Gite.

KK brainstormed and structured the project outline. KK was also involved in the planning of the project. KK defined the project scope and documentation, was involved in the hardware and software requirements, terrain building of the skateboard game, implementation of the project, wrote the black book for the same, and was a major contributor in writing the manuscript.

JC brainstormed and structured the project outline. JC was also involved in the planning of the project. JC defined the project scope and documentation, was involved in the hardware and software requirements, terrain building of the skateboard game, implementation of the project, wrote the black book, and was a major contributor to writing the manuscript.

AR brainstormed and structured the project outline. AR was also involved in the planning of the project. AR was involved in building the terrain, character placement, testing and debugging the game, implementation of the project, and was involved in writing the black book.

KG brainstormed and structured the project outline. KG was also involved in the planning of the project. KG was involved in building the terrain, character placement, testing and debugging the game, implementation of the project, and was involved in writing the black book.

KR brainstormed and structured the project outline. KR was also involved in the planning of the project. KR was involved in

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the hardware requirements, testing, and debugging of the game, implementation of the project, and was involved in writing the black book.

SG helped by guiding us throughout the project. All authors read and approved the final manuscript.

Conflicting Interests

The authors declare that they have no conflicting interests.

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From Fiction to Reality: Harnessing the Power of Imaginative Narratives to Shape the Future of the Metaverse

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***Abstract* – This scholarly paper presents an innovative conceptual framework that draws upon insights from fictional narratives to inform the evolution of the metaverse, a burgeoning digital ecosystem with transformative potential. The study examines key elements of fictional works, including world-building techniques, social interaction dynamics, narrative structures, and ethical considerations, to illuminate the complexities of designing immersive virtual environments. Our primary findings indicate that consistency and coherence in world-building significantly enhance user immersion and engagement in virtual environments. Furthermore, the integration of diverse cultural and historical elements in the metaverse can foster inclusivity and enrich user experiences. Additionally, ethical considerations, such as privacy, digital identity, and accessibility, are paramount to the development of a responsible and inclusive metaverse. These findings underscore the importance of fiction as a source of inspiration, foresight, and caution for metaverse development. The proposed framework aims to amalgamate the imaginative realms of fiction with the practical applications of virtual environments, thereby facilitating the creation of a metaverse that is engaging, inclusive, and ethically responsible.**

***Keywords* – Metaverse, fictional works, world-building, social interactions, ethics**

I. INTRODUCTION

The metaverse, an expansive and interconnected digital universe, has captured the imagination of technologists, futurists, and creators worldwide. It encompasses a wide range of virtual environments where users can interact with one another and engage in activities that range from gaming and socializing to education and commerce. As the metaverse continues to evolve and grow, it is crucial to study the elements that contribute to its development and understand its potential impact on society.

The term "metaverse" is derived from the combination of "meta-" meaning transcending, and "universe," indicating a boundless virtual space [90]. The metaverse can be defined as a collective, immersive virtual space that integrates various digital environments and platforms, allowing users to interact in real time through avatars and other digital representations [32]. It facilitates social, economic, and cultural activities, blurring the lines between the physical and digital realms.

Fictional works have long served as a source of inspiration and exploration for technological advancements and societal change. Science fiction, in particular, has played a significant role in envisioning the potential of virtual environments and digital interactions [5]. By examining fictional works, researchers can gain insights into the design and structure of immersive virtual worlds and draw upon these creative narratives to inform the development of the metaverse.

Studying fictional works offers several benefits for metaverse research:

To begin with, fictional narratives challenge our perception of reality and encourage us to imagine the possibilities of future technology [18]. This can inspire new ideas and innovations in the development of the metaverse. Tolkien's Middle-earth, as depicted in "The Hobbit" and "The Lord of the Rings," has been a tremendous source of imagination and inspiration for metaspace research. The intricate world-building found in Tolkien's works, detailed geography, languages, and history, has served as a model for creating immersive and layered environments within the metaverse [95].

In addition, fictional works often involve the creation of complex and detailed worlds, providing valuable lessons in designing engaging and immersive virtual environments [106]. William Gibson's concept of "cyberspace" in his novel "Neuromancer" has played a significant role in world-building for metaspace research. Coined by Gibson in 1984, the term "cyberspace" refers to a virtual realm where individuals can traverse a digital landscape and engage with information and

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other users [58]. This visionary depiction of a fully immersive virtual environment has directly influenced the development of the metaverse concept.

Fictional works can also help researchers understand the potential social structures and interactions in the metaverse, addressing issues such as inclusivity, governance, and conflict resolution [44]. Stephenson [96]'s novel "Snow Crash" has played a significant role in providing Social Dynamics for metaspace research. By introducing the metaverse concept, a virtual world where users interact through avatars, the novel sparked interest and imagination in the possibilities of virtual environments for social interaction, commerce, and entertainment [96].

Furthermore, by examining ethical themes and dilemmas in fictional narratives, researchers can better anticipate and address the ethical challenges that may arise in the metaverse [11].

Overall, by analyzing the key aspects of fictional works and their application to the metaverse, we can derive valuable insights into designing immersive, engaging, and realistic virtual environments. In turn, this will enhance the metaverse's potential for social, economic, and cultural impact. Moreover, understanding the intricacies of fictional worlds can help developers and researchers anticipate potential challenges and opportunities, ultimately leading to the creation of a more inclusive, dynamic, and sustainable metaverse.

In this study, we employ an integrated approach that combines a comprehensive literature review with an analysis of selected case studies to explore the relationship between fictional works and virtual environments, particularly the metaverse. The literature review enables us to identify key themes and concepts, which subsequently inform our case study selection. The chosen case studies represent a diverse range of fictional works and provide a comprehensive understanding of various aspects of fictional narratives that can inform the development of the metaverse. By utilizing both theoretical and practical perspectives, we aim to develop a well-rounded and nuanced analysis of the challenges and opportunities associated with the design and implementation of virtual environments.

The conceptual framework for this research is centered around the idea of adapting and applying world-building principles, social structures, narrative techniques, and ethical considerations from fictional works to the development of the metaverse. By exploring the various aspects of fictional worlds and their implications, we aim to extract valuable insights that can inform the design, implementation, and governance of the metaverse, ensuring a rich, immersive, and inclusive user experience.

Our framework encompasses four main dimensions: world-building, social interactions and communities, narrative structures and user experience, and ethical considerations. Each dimension is interconnected, as lessons from one area may inform approaches in another. By analyzing the various aspects of fictional worlds, we seek to develop a holistic understanding of the factors that contribute to their immersive and engaging qualities. These insights will be used to inform the design of metaverse environments, fostering meaningful user experiences that cater to diverse needs and preferences while addressing potential ethical challenges. A visualized conceptual framework is presented in Figure 1:

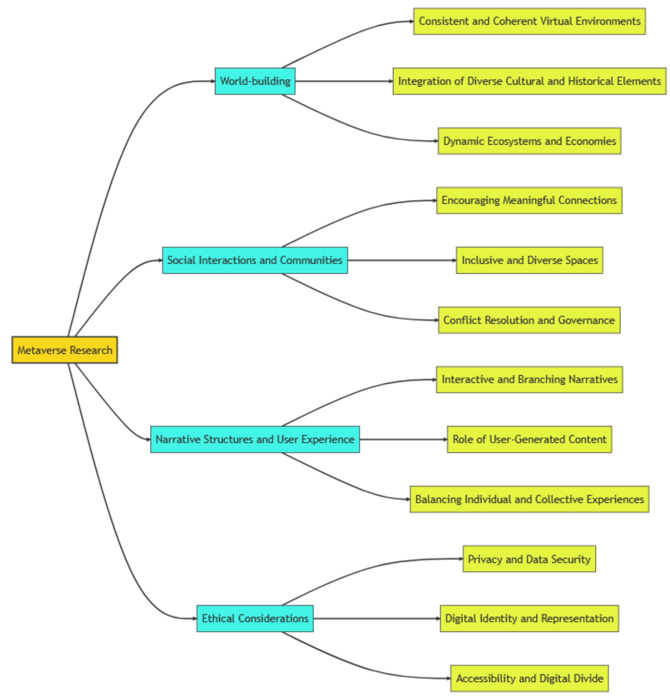

FIG. 1: CONCEPTUAL FRAMEWORK

This study contributes to several research strands, each with its distinct significance and implications for metaverse development. By examining fictional works, researchers can gain valuable insights into various aspects of the metaverse, ultimately informing its design, implementation, and potential impact on society.

Firstly, this research strand focuses on understanding the principles of world-building in fictional works and applying these insights to the design of virtual environments within the metaverse. By analyzing the construction of complex and detailed fictional worlds, researchers can derive best practices for creating immersive, engaging, and coherent virtual spaces [101, 106].

Secondly, the study of social interactions and communities in fictional works can contribute to the development of inclusive and diverse social systems in the metaverse. Researchers in this strand explore the potential social structures, governance mechanisms, and conflict resolution strategies within virtual environments [7, 44].

Thirdly, this research strand examines the narrative techniques employed in fictional works and their implications for storytelling and user engagement in the metaverse. By exploring interactive and branching narratives, researchers can gain insights into how to design captivating and personalized experiences for users in virtual environments [1, 69].

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Lastly, the examination of ethical themes in fictional works can help researchers anticipate and address potential ethical challenges in the metaverse. This strand of research focuses on issues such as privacy, data security, digital identity, representation, and accessibility, aiming to create a more inclusive and ethically responsible virtual environment [11] [33].

The interdisciplinary nature of this study enables researchers to draw upon a diverse body of literature, ensuring a comprehensive understanding of the metaverse and its potential applications. By bridging the gap between imaginative narratives and real-world virtual environments, this research can contribute to the development of a more engaging, inclusive, and ethically responsible metaverse that has the potential to transform the way we live, work, and interact in the digital age.

II. Literature Review

The literature review for this study covers four key dimensions: world-building, social interactions and communities, narrative structures and user experience, and ethical considerations. Each dimension is interconnected and contributes to our understanding of how insights from fictional works can inform the development of the metaverse.

A. World-building

World-building is a fundamental aspect of many fictional works, particularly in science fiction and fantasy genres. It involves creating rich, detailed, and immersive environments that serve as the backdrop for narratives and characters [106]. In the context of the metaverse, world-building principles can be applied to create engaging and realistic virtual environments that foster a sense of presence and immersion for users.

Several studies have explored world-building in fictional works and their potential applications to virtual environments. For example, Taylor [101] discusses the importance of designing virtual worlds that provide users with a sense of agency, allowing them to interact with and shape the environment. The development of XR can enhance this sense of agency [86]. This concept can be seen in Neal Stephenson's Snow Crash [90], where the metaverse is a highly interactive and malleable space that responds to user input.

Another important aspect of world-building is the use of environmental storytelling, which involves embedding narrative elements within the virtual environment itself [48]. This technique can be observed in works like William Gibson's Neuromancer [35], where the cyberpunk setting conveys a sense of a dystopian future through its vivid descriptions of the virtual world.

In addition, world-building should be considered with a view to minimizing barriers and limitations to user participation. Brain-computer interface technology can help construct a metaverse where anyone, including people with disabilities, can sustainably participate in digital games without restrictions [28]. This idea can be seen in Neal Stephenson [90]'s “Snow Crash”, where he describes a metaverse as a virtual world where there are no constraints and where participation is unlimited [28].

B. Social Interactions and Communities

The study of social interactions and communities within fictional works can provide insights into the potential social dynamics and structures of the metaverse. In her seminal work, Hayles [44] explores the role of virtual communities in shaping social interactions and the formation of digital identities. Similarly, Boellstorff [7] investigates the nature of sociality and governance within virtual worlds, offering insights into how these principles can be applied to the metaverse.

Notable fictional works that address social dynamics in virtual environments include Ready Player One by Ernest Cline [17], which explores the power dynamics and inequalities within the virtual world of OASIS, and Tad Williams's Otherland series (1996-2001), which delves into the formation of virtual communities and their impact on individual identity. Bayram [14] reveals that people's leisure time habits will change as metaverse and avatar participation in virtual worlds such as Sandbox and Decentraland replace physical participation. This change in behaviour will influence the way of social interactions in the future.

C. Narrative Structures and User Experience

Understanding the narrative structures and techniques employed in fictional works can inform the design of engaging and personalized user experiences in the metaverse. Aarseth [1] and Murray [69] both explore the concept of interactive storytelling and the potential for branching narratives in digital environments, offering insights into how to create immersive and responsive virtual worlds.

Noteworthy examples of interactive storytelling in fiction include the Choose Your Own Adventure series, which allows readers to make choices that shape the narrative's outcome, and David Mitchell's Cloud Atlas [70], which employs a complex, multi-layered narrative structure that connects disparate storylines across different time periods.

D. Ethical Considerations

Examining ethical themes and dilemmas in fictional works can help researchers anticipate and address potential ethical challenges that may arise in the metaverse. Brey [11] discusses the importance of considering the ethical implications of virtual environments, while Floridi and Taddeo [33] highlight the need for ethical guidelines to govern the development and use of the metaverse.

Several fictional works have explored ethical issues related to virtual environments, such as privacy, digital identity, and representation. For instance, The Circle by Dave Eggers [31] raises concerns about privacy and surveillance in a digital society, while The Minority Report by Philip K. Dick [26] explores the moral implications of using predictive technology to prevent crime. Additionally, Cory Doctorow's Little Brother

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[22] delves into the themes of digital privacy, surveillance, and resistance in a near-future dystopian society.

III. METHOD

A. Integrated Approach: Literature Review and Case Studies

In order to develop a comprehensive understanding of the relationship between fictional works and virtual environments, particularly the metaverse, we employed an integrated approach that combined a literature review with an analysis of selected case studies.

We conducted a comprehensive literature review to identify key themes and concepts related to the metaverse, world-building, social interactions and communities, narrative structures, user experience, and ethical considerations [1] [8] [77] [101]. This review provided the foundation for our conceptual framework and informed our case study selection.

Based on the key themes and concepts identified in the literature review, we selected a diverse range of fictional works representing various genres, time periods, and cultural backgrounds, with a particular emphasis on science fiction and speculative fiction, as these genres often address themes related to technology and virtual environments. The selection process was informed by previous studies on the relationship between fiction and technology [100] [107].

The final case list for this study comprises five fictional works chosen based on their relevance to the metaverse, their exploration of various themes, and their impact on the development of virtual environments. These works provide a comprehensive understanding of the various aspects of fictional narratives that can inform the development of the metaverse. The case list is presented in Table I:

TABLE I: CASE LIST

Case No.	Title	Author	Year	Genre
1	Snow Crash	Neal Stephenson	2000	Science Fiction, Cyberpunk
2	Ready Player One	Ernest Cline	2011	Science Fiction, Dystopian
3	The Metamorphosis of Prime Intellect	Roger Williams	1994	Science Fiction, Technological Singularity
4	Neuromancer	William Gibson	1984	Science Fiction, Cyberpunk
5	The Diamond Age	Neal Stephenson	1995	Science Fiction, Postcyberpunk

These cases were chosen based on their relevance to the metaverse, as well as their exploration of various themes such as world-building, social interactions, narrative structures, and ethical considerations. These works are widely recognized for their impact on the development of virtual environments and serve as valuable sources of information for understanding the potential challenges and opportunities that the metaverse presents.

In this study, we have selected five cases related to the metaverse that represent diverse genres, themes, and settings, providing a comprehensive understanding of the various aspects of fictional narratives that can inform the development of the metaverse. Through the process of analyzing these cases, we have developed a robust conceptual framework that addresses key areas, such as world-building, social interactions, narrative structures, and ethical considerations.

The theoretical saturation has been reached in this study, as the selected cases have provided us with a thorough understanding of the various dimensions of the metaverse as portrayed in fictional works. Theoretical saturation is achieved when no new insights, themes, or patterns emerge from the analysis of additional cases, indicating that further data collection is unlikely to contribute significantly to the understanding of the phenomenon under study [71].

The current state of theoretical saturation suggests that the addition of more cases would not significantly enhance our understanding of the metaverse or contribute novel insights to the conceptual framework developed in this study. Furthermore, the selected cases have already provided a rich and diverse range of perspectives, covering a broad spectrum of fictional portrayals of the metaverse, which strengthens the study's validity and generalizability.

In conclusion, the theoretical saturation reached in this study supports the claim that no additional cases are required to further our understanding of the metaverse, as the existing cases have provided sufficient depth and breadth in terms of insights and themes relevant to the development of the conceptual framework.

B. Data Analysis Process

The data analysis process remains the same as described, with the integration of insights from the literature review and case studies. Through the analysis of these cases, we derive valuable insights related to the key themes of world-building, social interactions and communities, narrative structures and user experience, and ethical considerations. These insights are then triangulated with the findings from the literature review to ensure the validity and applicability of the information derived from the case studies [21].

By combining the insights gained from the literature review and case studies, we are able to develop a more robust and comprehensive understanding of the challenges and opportunities associated with the design and implementation of virtual environments, such as the metaverse. This integrated approach allows us to draw from both theoretical and practical perspectives, contributing to a well-rounded and nuanced analysis of the topic.

We extracted relevant data from the selected fictional works, focusing on passages and sections that dealt with the key themes identified in the conceptual framework. The data was organized and coded according to these themes, allowing us to systematically analyze the content and draw insights that could inform the development of the metaverse.

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Subsequently, we conducted a thematic analysis of the coded data, identifying patterns and trends across the selected fictional works. This analysis allowed us to derive valuable insights related to the key themes of world-building, social interactions and communities, narrative structures and user experience, and ethical considerations. For each theme, we examined how the fictional works addressed the relevant issues and what lessons could be drawn for the development of the metaverse [9].

To ensure the validity of our findings, we triangulated the insights gained from the analysis of fictional works with existing literature on the metaverse and virtual environments. This process allowed us to compare our findings with established theories and empirical evidence, helping to confirm the relevance and applicability of the insights derived from fictional works [21].

Here is an example of the data coding process.

The original passage from the book "Snow Crash":

"Hiro Protagonist, the avatar of the hacker-hero, finds himself in the metaverse, a virtual reality where users can interact with each other and access digital information. The metaverse is visually rich, with detailed environments and avatars that users can customize."

Data analysis:

Code: "World-Building - Visuals" (for the description of the metaverse's visual richness)

Code: "World-Building - Customization" (for the mention of customizable avatars)

Code: "Social Interactions - Communication" (for the reference to users interacting with each other)

This passage provides insight into the importance of visually rich environments and customization options for user engagement in the metaverse. Additionally, it highlights the need for effective communication tools to facilitate social interactions between users. These insights can then be compared and contrasted with the findings from other cases to inform the development of the metaverse.

By following this systematic data analysis process, we were able to draw valuable insights from the selected fictional works and apply them to the development of the metaverse, contributing to a more robust and comprehensive understanding of the challenges and opportunities associated with the design and implementation of virtual environments.

IV. World-Building

World-building is a crucial aspect of fictional works, particularly in genres such as science fiction and fantasy, where authors create intricate and detailed environments for their narratives [106]. These fictional worlds often feature unique geographical, social, cultural, and political systems that contribute to their immersive qualities [23]. By examining the techniques and principles of world-building in literature, researchers can gain valuable insights into the development of compelling and engaging virtual environments in the metaverse.

A. Application of World-building Concepts to the Metaverse

Drawing on the lessons of world-building in fictional works, researchers can apply these principles to the development of the metaverse, fostering immersive and captivating virtual spaces that facilitate meaningful user experiences.

One of the key aspects of world-building in fictional works is the establishment of a consistent and coherent environment [106]. This involves developing logical and cohesive systems that govern the world's physical, social, and cultural aspects. In the context of the metaverse, designers can utilize these principles to create virtual environments that adhere to consistent rules and logic, enhancing immersion and believability [4].

Another application of world-building in fictional works is the integration of diverse cultural and historical elements, creating rich and multifaceted worlds [44]. By integrating these elements into the metaverse, developers can foster a sense of depth and realism, encouraging users to explore and engage with the virtual environment. Moreover, this approach can promote inclusivity and cultural exchange, fostering a sense of global community within the metaverse [68].

Moreover, fictional worlds often feature dynamic ecosystems and economies that evolve and adapt over time [23]. This dynamism contributes to the immersive quality of the narrative, as it mimics the complexities of real-world systems. In the metaverse, researchers and developers can draw upon these principles to create virtual environments that respond to user interactions and feature robust economic systems, fostering a sense of agency and participation among users [16].

By incorporating the principles of world-building from fictional works into the development of the metaverse, researchers can create virtual environments that are immersive, engaging, and responsive to user needs. These environments will not only foster meaningful experiences for users but also contribute to the overall growth and sustainability of the metaverse as a whole.

B. Examples of World-building in Fiction and Their Relevance to the Metaverse

This subsection will provide examples of world-building in fictional works that offer valuable insights into the design and development of immersive virtual environments in the metaverse.

Tolkien's Middle-earth, featured in works such as "The Hobbit" and "The Lord of the Rings," is renowned for its intricate world-building, which includes detailed geography, languages, and history [10]. The depth of Middle-earth's lore and the interconnectedness of its various elements can serve as an inspiration for the metaverse, where designers can create rich, layered environments that offer a sense of immersion and

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exploration [94]. Here is a specific example highlighting the coherence and attention to detail in Tolkien's world-building; Tolkien created numerous races in Middle-earth, each with its language, history, and culture [95]. For example, the Elves have their beautiful language of Quenya and Sindarin, while the Dwarves have Khuzdul. These languages are not just random collections of words but fully developed linguistic systems with consistent grammar and vocabulary. The existence of different languages adds depth and realism to the world, reflecting the diversity of its inhabitants.

In his novel "Neuromancer," Gibson coined the term "cyberspace" and envisioned a virtual world where users can navigate through a digital landscape and interact with data and other users [35]. This vision of a fully immersive virtual environment has direct implications for the development of the metaverse, as it highlights the importance of creating spaces that allow for seamless interaction and navigation [27]. It offers a compelling example of coherent world-building. In Gibson's vision, cyberspace is a virtual reality network accessed through computer interfaces, where users can navigate and interact with digital information and environments [13]. Gibson establishes a set of rules and terminology that govern the functioning of cyberspace. He describes it as a three-dimensional space, often visualized as a vast interconnected web or matrix [58]. Users access this space through interfaces, typically using a combination of virtual reality goggles, data gloves, and neural implants. The jargon and slang used by characters, such as "deckers" (cyberspace hackers) and "ICE" (Intrusion Countermeasures Electronics), add depth and coherence to the world [37].

Stephenson's novel "Snow Crash" introduced the concept of the metaverse, a virtual world where users interact through avatars and engage in various activities [90]. The novel's depiction of a vast, interconnected digital space offers insights into the design of virtual environments that facilitate social interaction, commerce, and entertainment, directly informing the development of the contemporary metaverse [16]. Stephenson [96] introduces a complex economic system within the Metaverse, where currency, called "Kongbucks," is used for transactions. The Metaverse has a marketplace where users can buy and sell virtual goods, services, and information. This economic structure adds depth to world-building, reflecting the impact of virtual reality on commerce and the potential for virtual economies to emerge.

These examples illustrate how fictional works can inform the development of the metaverse by offering insights into the principles and techniques of world-building. By drawing upon the lessons of these imaginative narratives, researchers and developers can create engaging and immersive virtual environments that foster meaningful user experiences and contribute to the growth and sustainability of the metaverse.

V. Social Interactions And Communities

Fictional works often present unique social structures and interactions that provide insights into the dynamics of human relationships and the organization of societies [74]. By examining these fictional settings, researchers can explore the ways in which different social systems and communication methods impact interpersonal connections, collaboration, and conflict resolution. This analysis can inform the design of metaverse communities and social systems, ensuring that they foster meaningful and productive interactions among users [5].

A. Lessons for Designing Metaverse Communities and Social Systems

Drawing from the analysis of social structures and interactions in fictional worlds, researchers can derive valuable lessons for designing metaverse communities that promote meaningful connections, inclusivity, and effective governance.

To start with, fictional narratives often depict deep and meaningful connections between characters, offering insights into the factors that contribute to the formation and maintenance of such relationships [2]. In the metaverse, developers can utilize these insights to create social features and systems that promote empathy, collaboration, and shared experiences, fostering a sense of belonging and community among users [99].

Besides this, inclusivity and diversity are crucial aspects of fictional worlds, allowing for a range of perspectives and experiences to be represented [44]. By embracing these principles in the metaverse, developers can create spaces that welcome users from various backgrounds and promote cultural exchange and understanding [77]. This approach not only enriches the user experience but also fosters a more resilient and adaptive virtual community.

Furthermore, currently, social interactions in the metaverse bring about negative effects such as harassment, provocation, and echo chambers, which are challenges that platform governance is expected to address. Fictional works often depict various approaches to conflict resolution and governance, providing insights into the strengths and weaknesses of different strategies [74]. In the metaverse, researchers can draw upon these lessons to design systems and processes that address disputes and facilitate fair decision-making, ensuring a harmonious and cooperative virtual environment [7].

By applying the lessons learned from the analysis of social structures and interactions in fictional works to the design of metaverse communities, researchers can create virtual spaces that foster meaningful connections, inclusivity, and effective governance. These factors are essential in ensuring the long-term success and sustainability of the metaverse as a platform for social, economic, and cultural engagement.

B. Examples of Social Interactions and Communities in Fiction and Their Relevance to the Metaverse

This subsection will provide examples of social interactions and communities in fictional works that offer valuable insights for designing metaverse communities and social systems.

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Le Guin's "The Dispossessed" explores two contrasting societies with different social structures, ideologies, and governance systems [62]. By examining the consequences and challenges faced by these societies, researchers can gain insights into the importance of inclusivity, consensus-based decision-making, and equitable resource distribution in the metaverse [47].

Isaac's "Foundation" series presents a future galactic empire where a mathematician predicts its collapse and creates a plan to mitigate the ensuing chaos [50]. The series explores the role of social dynamics, political intrigue, and conflict resolution in large-scale societies. These insights can inform the design of governance structures and conflict resolution mechanisms within the metaverse [73].

In "Ready Player One," Cline depicts a virtual world called the OASIS, where users can engage in various activities, form alliances, and compete against each other [17]. The novel highlights the importance of fostering meaningful connections, inclusivity, and collaboration in virtual spaces, as well as the potential risks and challenges associated with online communities [98].

In 'The Minority Report', dedicated elites with the ability to predict people's criminal attempts were charged with preventing crime to ensure security [26]. By learning from it, the Metaverse platforms can use technology to anticipate negative behaviours and stop them in advance.

These examples demonstrate how fictional works can offer insights into social interactions and communities, informing the design and development of metaverse communities and social systems. By drawing upon these lessons, researchers can create virtual environments that foster meaningful connections, inclusivity, and effective governance, contributing to the overall success and sustainability of the metaverse.

VI. Narrative Structures And User Experience

Fictional works employ various narrative techniques to engage readers and maintain their interest throughout the story [85]. These techniques include character development, pacing, plot structure, and the use of suspense, among others. By examining these narrative elements, researchers can gain insights into the ways in which storytelling can capture and hold the attention of audiences, informing the development of metaverse experiences that foster user engagement and satisfaction [69].

A. Implications for Metaverse Storytelling and User Engagement

Drawing on the narrative techniques found in fictional works, researchers can derive valuable lessons for metaverse storytelling and user engagement, including the use of interactive and branching narratives, the role of user-generated content, and the balance between individual and collective experiences.

First, fictional works often employ non-linear and branching narrative structures, providing readers with a sense of agency and the opportunity to explore multiple story paths [85]. In the metaverse, developers can adopt these techniques to create interactive and immersive experiences that adapt to users' choices and actions, fostering a sense of autonomy and personal investment in the virtual world [1].

Secondly, fictional works can inspire users to create their own stories and content, fostering a sense of ownership and participation in the narrative [48]. In the metaverse, user-generated content can play a significant role in shaping the overall experience, as it allows users to contribute to the world's development and evolution. By providing tools and platforms that facilitate content creation and collaboration, developers can encourage users to actively engage with the metaverse and shape their own narratives, leading to a more dynamic and personalized experience [79].

Additionally, fictional works often balance individual character arcs with overarching storylines that involve multiple characters and communities [85]. In the metaverse, developers can seek to strike a similar balance between individual user experiences and collective narratives, allowing users to pursue personal goals while also participating in shared events and activities. This approach can foster a sense of community and connection among users while also catering to diverse interests and playstyles [75].

By applying the narrative techniques and principles found in fictional works to the design of metaverse experiences, researchers can create engaging and immersive virtual environments that cater to the diverse needs and preferences of users. This approach can enhance user satisfaction and promote long-term engagement with the metaverse, ensuring its continued growth and success as a platform for social, cultural, and economic interaction.

B. Examples of Narrative Techniques in Metaverse Environments

To illustrate the application of narrative techniques from fictional works in metaverse environments, this section presents some examples that demonstrate the successful implementation of interactive and branching narratives, user-generated content, and the balance between individual and collective experiences.

One example of a metaverse environment that employs interactive and branching narratives is the virtual world of "Second Life" [49]. In "Second Life," users can participate in various storylines, interact with non-player characters (NPCs), and influence the outcome of events based on their choices and actions. This level of interactivity allows users to shape their own experiences and feel a sense of agency within the virtual world [6]. In “Ready Player One”, different interactions between the user and the scene can trigger different storylines [17]. For example, in a speed race, the protagonist Wade makes a very different choice from the other players, driving his car in reverse and triggering the hidden entrance to the underpass so he obtains the first key.

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"Minecraft" [65] is a popular example of a metaverse environment that heavily relies on user-generated content. In "Minecraft," players can build and modify their own virtual worlds, create their own narratives, and interact with other players in a shared environment. The game's success can be attributed to its emphasis on user-generated content, fostering a sense of ownership and participation among players [25].

"World of Warcraft" [29] is a massively multiplayer online role-playing game (MMORPG) that exemplifies the balance between individual and collective experiences. In "World of Warcraft," players can pursue personal goals and complete individual quests while also participating in group activities, such as raids and dungeons, that involve collaboration and teamwork. This balance enables the game to cater to a wide range of player interests and playstyles, fostering a sense of community and connection among users [108].

VII. Ethical Considerations

Fictional works, particularly those in the science fiction genre, often explore ethical themes and dilemmas related to technology, society, and human behavior [107]. These narratives can provide valuable insights into the potential ethical challenges that may arise in the development and implementation of the metaverse. By examining these themes, researchers can anticipate and address potential ethical concerns, ensuring that the metaverse is designed with the well-being of its users and society in mind [8].

A. Addressing Ethical Challenges in the Metaverse

By examining ethical themes in fictional works, researchers can identify and address various ethical challenges that may arise in the metaverse, including issues related to privacy and data security, digital identity and representation, and accessibility and the digital divide.

Fictional works often explore the implications of surveillance and data collection in technologically advanced societies [111]. In the metaverse, ensuring privacy and data security is crucial for protecting user information and maintaining trust in the virtual environment. Researchers and developers should prioritize the implementation of robust privacy and security measures, as well as the development of transparent data policies that respect user rights [33].

Fictional works often explore themes related to identity and representation in virtual worlds, addressing issues such as authenticity, self-expression, and the potential for discrimination or prejudice [100]. In the metaverse, it is essential to develop systems and policies that allow users to represent themselves accurately and authentically while also protecting them from potential harm or discrimination. Researchers should consider the ethical implications of digital identity management and work toward inclusive solutions that respect user autonomy and diversity [45].

Fictional narratives often address the potential for technological advancements to exacerbate social inequalities and widen the digital divide [22]. In the development of the metaverse, researchers should prioritize efforts to make the virtual environment accessible to users from diverse backgrounds and with varying levels of technological literacy. Addressing the digital divide is crucial for ensuring that the metaverse remains an inclusive and equitable platform for all users, regardless of socioeconomic status, geographical location, or disability [109].

By examining ethical themes in fictional works and applying these insights to the development of the metaverse, researchers can anticipate and address potential ethical challenges. Ensuring that the metaverse is designed with privacy, digital identity, and accessibility in mind will contribute to a more inclusive, equitable, and ethically responsible virtual environment. This approach will not only foster user trust but also promote the long-term sustainability and success of the metaverse as a platform for social, cultural, and economic engagement.

B. Examples of Ethical Considerations in Metaverse Environments

To illustrate the application of ethical considerations from fictional works in metaverse environments, this section presents some examples that demonstrate the successful implementation of privacy and data security measures, digital identity and representation policies, and accessibility initiatives.

A metaverse environment that has successfully implemented privacy and data security measures is "VRChat" [102]. In "VRChat," user data protection is prioritized, and the platform employs encryption methods to ensure that sensitive information remains secure.

"Second Life" [49] provides an example of a metaverse environment that prioritizes digital identity and representation. In "Second Life," users can create and customize their own avatars, allowing for a high degree of self-expression and personal identity exploration. The platform also has community guidelines and policies that promote inclusivity, respect, and tolerance, helping to create a safe and welcoming environment for users of diverse backgrounds [83].

"Mozilla Hubs" is a metaverse environment that demonstrates a commitment to accessibility and addressing the digital divide. "Mozilla Hubs" is designed to be accessible on a variety of devices, including low-cost virtual reality (VR) headsets, smartphones, and personal computers. The platform also provides a range of accessibility features, such as captioning and spatial audio options, to accommodate users with disabilities.

By examining these examples, researchers can better understand how ethical considerations can be successfully integrated into the design and development of metaverse environments. Implementing privacy and data security measures, ensuring inclusive digital identity and representation policies, and prioritizing accessibility can contribute to a more ethically responsible and inclusive virtual environment, fostering user trust and promoting long-term sustainability and success.

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While we have discussed several successful implementations of ethical considerations in the metaverse, it is equally important to examine instances where ethical considerations have been less successful or have led to controversies.

One such example is the controversy surrounding the use of personal data in virtual environments. In the metaverse, users' activities generate a vast amount of data, which can be used to enhance user experience but also raise privacy concerns. For instance, Facebook's transition into Meta has been met with skepticism due to the company's past controversies related to data privacy [97]. These controversies highlight the need for robust data privacy regulations in the metaverse.

Another ethical challenge in the metaverse is the potential for an increased digital divide. While the metaverse offers numerous opportunities for social interaction, education, and commerce, access to these opportunities may be limited for individuals who lack the necessary technological resources or skills [43]. This digital divide could potentially exacerbate existing social inequalities, underscoring the need for equitable access to the metaverse.

In the realm of content moderation, the metaverse also faces significant ethical challenges. The open and immersive nature of the metaverse makes it a potential platform for harmful content, such as hate speech or harassment. Balancing the need for content moderation with the preservation of free speech is a complex ethical issue that metaverse developers must address [38].

By examining these less successful or controversial ethical considerations, we can gain a more nuanced understanding of the ethical challenges in the metaverse and develop more effective strategies to address them.

C. Mental health caused by AI and Non-Player Characters (NPC)

The excessive use of metaverse and mental health becomes a challenging issue that needs to be overcome. During covid-19, the face to face conversations between people declined. Communicating with people or artificial intelligence become a new trend, which will affect users' mental health due to the increased dependence on the internet [57].

Recent research with sufficient evidence shows that the continuous use of communication and interaction in a fictional world could lead to abuse and addiction to virtual reality [64]. In 2021, global internet users faced a significant threat within the Metaverse, with mental health problems and addiction to virtual reality constituting 47% of the dangers, as revealed by recent data and facts [52].

D. Economic systems and digital currencies in the metaverse

The emergence of novel economic systems and digital currencies within the metaverse brings various ethical and regulatory challenges. As the metaverse evolves and becomes more integrated into our daily lives, it is crucial to consider the implications of these systems on individuals, societies, and existing economic structures.

Privacy and data protection are significant concerns in the metaverse due to extensive data collection and tracking of users' behaviors, preferences, and interactions [12]. Striking a balance between personalized experiences and protecting user privacy will be critical. In the metaverse, users generate vast amounts of data through interactions, including personal information, preferences, and behavioral patterns [57]. This data can be valuable for targeted advertising, profiling, and enhancing user experiences [3]. However, it raises concerns about collecting, storing, and using personal data. It is crucial to establish clear guidelines on what data is collected and how it is used and ensure user consent and control over their data.

The financial stability of the metaverse economy is a critical aspect that warrants careful consideration. As the metaverse continues to evolve and expand, its economic framework becomes increasingly significant. Like traditional economies, the metaverse economy is built upon various financial mechanisms and transactions. Virtual currencies, such as cryptocurrencies or metaverse-specific tokens, facilitate trade and commerce within the metaverse [3]. However, maintaining financial stability within this virtual realm requires establishing robust regulatory frameworks and ensuring the integrity of economic systems [3]. The metaverse economy could be vulnerable to fraud, money laundering, and market manipulation without proper oversight and safeguards. Therefore, implementing measures to prevent and mitigate these risks is crucial for safeguarding the financial stability of the metaverse economy. Additionally, the interconnected nature of the metaverse with the real-world economy necessitates careful consideration of the potential spillover effects [34]. Fluctuations or disruptions in the metaverse economy could impact real-world financial systems. Promoting transparency, accountability, and sound financial practices is essential to foster trust and confidence in the metaverse economy [34]. By addressing these challenges and ensuring financial stability, the metaverse can promote a sustainable and prosperous economic ecosystem that benefits individuals and businesses within this virtual frontier.

It is crucial to establish a robust regulatory framework for the metaverse economy to address these risks, focusing on investor protection, fraud prevention, and financial stability [3]. Collaboration between metaverse platforms, developers, and regulatory bodies is necessary to implement measures like user authentication protocols, transparent marketplaces, and mechanisms to combat fraud. Additionally, educating users about potential risks and promoting responsible behaviour within the metaverse can help mitigate the impact of financial instability and fraud on individuals and the overall economy.

VIII. Conclusions

In this study, we have delved into the realm of fiction to unravel insights that can inform the development of the

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metaverse. Our exploration of various narrative aspects such as the intricacies of world-building, the nature of social interactions, the complexity of narrative structures, and ethical considerations, have shed light on the potential design and implementation pathways for virtual environments.

Our analysis highlighted the importance of Taylor's [101] assertion on the need for consistent and coherent world-building. In the context of the metaverse, this translates into creating immersive environments that are bound by a set of rules and logic that users can understand and engage with. Furthermore, the examination of social systems in fictional narratives underscores the need for inclusivity and diversity, as posited by Nakamura [77], paving the way for a metaverse that is representative of our diverse global community.

The study also brought to light the significance of interactive and branching narratives, as suggested by Aarseth [1], which can enhance user engagement in the metaverse by offering them agency in shaping their virtual experiences. However, with the opportunities offered by the metaverse, come ethical challenges related to privacy, digital identity, and accessibility. These issues, discussed extensively by Bostrom and Yudkowsky [8], are of paramount importance and must be carefully considered in the development of virtual environments.

Despite these insights, our study is not without its limitations. For instance, the selection of fictional works analyzed may not be exhaustive or representative of all possible narratives that can inform the metaverse. As [30] suggest, there might be other literary works that could yield valuable insights into the development of virtual environments. Additionally, our focus on Western literary traditions may have inadvertently limited the scope of our findings, as Dourish [24] points out the value of incorporating diverse cultural perspectives into the design and development of the metaverse.

Moreover, given the rapidly evolving nature of technology and virtual environments, Hayles argues that insights derived from fiction might lose relevance over time. This necessitates continuous reassessment of our understanding of the metaverse in light of societal shifts and technological advancements. Furthermore, interpretation of fictional works is inherently subjective, and different researchers may draw varying conclusions from the same text. Eaglestone [30] encourages embracing these alternative perspectives in future research to ensure a more holistic understanding of the metaverse.

Looking forward, these insights can guide future research into various aspects of the metaverse. One potential area of investigation is the development of AI-driven non-player characters (NPCs) that can create more dynamic and immersive experiences [72]. Another is the exploration of novel forms of economic systems and digital currencies in the metaverse, focusing on value creation, distribution, and governance [15].

The impact of long-term immersion in the metaverse on psychological and emotional well-being is also worthy of examination, as is the creation of interventions to promote mental health [55]. Furthermore, understanding how virtual environments can be leveraged for skill development, collaboration, and knowledge transfer can expand the metaverse's applications in education, training, and professional domains [19]. Lastly, the environmental footprint of the metaverse, particularly in terms of energy consumption, also warrants consideration, emphasizing the need for sustainable design and infrastructure [113].

By continuing this multifaceted exploration, we can contribute to the evolution of the metaverse, enabling it to be not only engaging and immersive, but also inclusive, ethically responsible, and sustainable. This comprehensive approach will shape the future of the metaverse, ensuring its viability as a robust platform for a broad range of social, cultural, and economic interactions.

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Learner-Centered Analysis in Educational Metaverse Environments: Exploring Value Exchange Systems through Natural Interaction and Text Mining

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Abstract **– Amid Education 4.0 and the Fourth Industrial Revolution, we explore the integration of self-directed learning within the metaverse. This study envisions empowered learners, merging the metaverse's immersive potential with self-directed learning. Using text mining and co-occurrence analysis for student responses prompts questions about their preference over traditional methods. Text mining extracts nuanced insights from open-ended responses, surpassing structured data. Co-occurrence analysis reveals hidden concept relationships, enhancing student engagement and understanding. Beyond XR, the metaverse encompasses avatars, virtual experiences, and value systems. Educators navigate this landscape with text mining, shaping value exchange through engaging content. Integrating real-world experiences in the metaverse merges immersion and personalized learning. Challenges include data precision and semantic intricacies in co-occurrence graphs. Future solutions involve real-time adaptability and sentiment analysis for holistic insights into learner emotions. This study envisions a synergy of self- directed learning and the metaverse, bridging digital and physical realms. Learners navigate interconnected experiences, fostering autonomy. Uncovering the metaverse's potential contributes to education for digitally adept learners.**

Keywords **– Education 4.0, learner-centered, educational metaverse, blockchain, value exchange, text-mining**

I. INTRODUCTION

The advancement of virtual reality (VR) and augmented reality (AR) technologies has created new opportunities for educational experiences [1]. One emerging concept in this field is the educational metaverse, which surpasses traditional VR representations and offers seven-layered environments that enhance learner-centered experiences and facilitate value exchange systems [2].

However, the metaverse goes beyond the simple transformation of the physical world into a digital realm [3]. Virtual reality (VR) and augmented reality (AR) technologies are tools rather than being synonymous with the metaverse. It embraces the opportunity to meet new needs and establish conventions distinct to the digital world. Looking back at human history, tools are initially perceived as natural and necessary creations. It is essential to recognize that tools have played a significant role in shaping and creating humans. Human intelligence has evolved through continuous trial and error in tool usage and the accumulation of their value. Dissatisfaction with existing tools has driven changes in the tools themselves and the workforce. Even in the face of tool loss or insufficiency, humans persistently seek advancements and contemplate improvements. The evolution of these innovations has been instrumental in the development and progress of human civilization.

The metaverse concept extends beyond 3D or extended reality (XR), AR, VR, and mixed reality (MR) technologies. It encompasses digital avatars and the representation of shared ecological value. However, it is essential to acknowledge the potential existence of a recoverable paradox within the metaverse. This paradox arises from the belief that combining the variability of the virtual world with the physical world can enhance the governing value of the metaverse. For instance, blockchain technology can revolutionize the credit system of universities, enabling the traceability of course values based on cryptocurrency.

This study conducts a learner-centered two-hour lecture course to challenge students' preconceived notions of an XR-dominated educational metaverse. Students actively under-stand and imagine the educational metaverse beyond XR concepts, emphasizing the value exchange system. Following the course, students are assigned to identify educational scenarios that cannot be realized within the metaverse. For a comprehensive analysis, their perceptions are collected through various materials, such as video recordings, written feedback, and audio files.

Text mining techniques are increasingly used to analyze and assess learning outcomes in educational settings [4]. Through text mining, it becomes evident that students recognize the limitations of XR-restricted academic cases and develop a profound understanding of the role of blockchain in the educational metaverse. They also grasp the significance of the development and definition of the seven-layer theorem in shaping a learner-centered educational metaverse.

This paper explores the potential of analyzing educational metaverse environments from a learner-centered perspective through natural interaction and text-mining techniques. Based on the feedback and confirmation from students, we have

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become more convinced of the critical influence of "value exchange" in an education-centered approach. This has reaffirmed three beliefs for us:

- Educational metaverse should not be confined to XR transformation alone without exploring the essence of value exchange. This has led to the misconception of prioritizing XR for the sake of XR, disregarding the true purpose.
- We should not negate the existence and necessity of the metaverse due to the disparities between virtual and physical realms. Instead, we should leverage value exchange to facilitate the transfer of value and amplify opportunities for value circulation through blockchain technology.
- The concept of an educational utopia can only exist if we are entirely self-sufficient and do not rely on any form of exchange to fulfill basic needs. However, even the slightest dependency on others creates a need for value exchange. The educational metaverse aims to assist learners in rediscovering their value position- ing, developing their worth, and being seen, utilized, and transferred. This process naturally leads them to identify the learning skills and knowledge they need to strengthen.

In conclusion, the educational metaverse seeks to empower learners to redefine their value and acquire the necessary skills and knowledge to enhance their worth. It recognizes the fundamental role of value exchange in the educational ecosystem, providing learners with opportunities to be identified, utilized, and have their value transferred. We can foster a more dynamic and effective educational environment by emphasizing value exchange.

This study explores the potential of self-directed learning in the metaverse, considering its implications for Education 4.0 and the Fourth Industrial Revolution. It emphasizes education's alignment with technology and learner-centered methods. The research delves into value exchange systems using natural interaction, text mining, and analysis. The metaverse transcends XR technologies, encompassing avatars and shared ecological value. Educators' role in adopting technology and text-mining for efficient learning is highlighted. The metaverse requires valuable content for user engagement. Integrating real-world experiences enhances its essence. This study unveils the metaverse's potential for learner-centered education in Education 4.0's context, aided by text mining analysis.

The subsequent section reviews learner-centered analysis, metaverse's value exchange, natural interaction, and text mining. Section 3 details the course design approach, emphasizing pedagogically meaningful activities. Section 4 discusses outcomes and feedback. Section 5 outlines limitations and suggests future directions. The paper concludes in Section 6.

II. Literature Review

The literature reviewed in this section highlights the relationship between Education 4.0 and learner-centered approaches, emphasizing integrating digital technologies and personalized learning experiences [5], [6]. Education 4.0 represents a paradigm shift in education, driven by rapid technological advancements, and aims to prepare learners for the Fourth Industrial Revolution [7]. Learner-centered approaches prioritize individual needs, interests, and goals, promoting active engagement and self-directed learning [8]. Integrating these two concepts is essential in designing effective educational environments [2].

Additionally, exploring learning outcomes through natural interaction and text-mining techniques offers new possibilities for assessing learners' progress and providing personalized feedback [4]. Natural interaction allows learners to interact with educational content using intuitive interfaces. At the same time, text mining enables the analysis of written responses and discussions [9]. Combining these techniques supports the development of adaptive learning systems and informs instructional design in a learner-centered Education 4.0 environment [10].

Furthermore, based on a value exchange system, the educational metaverse provides a platform for creating and exchanging valuable educational content and resources [11]. This aligns with the broader concept of the metaverse as a platform for value creation and exchange [12]. The educational metaverse offers interactive and immersive learning experiences, fostering more profound understanding, creativity, and learner collaboration [13].

Overall, the literature emphasizes the importance of learner-centered approaches, the integration of emerging technologies, and the value exchange system in shaping effective and engaging educational environments within the context of Education 4.0 [14].

The following subsections provide detailed insights into the relationship between Education 4.0 and learner-centered approaches, the use of natural interaction and text mining in assessing learning outcomes, and the concept of the educational metaverse based on a value exchange system [2], [3], [15].

A. *Relationship between Education 4.0 and Learner-Centered Approaches*

Education 4.0 signifies a profound paradigm shift in education, driven by the rapid pace of technological advancements and the imperative to equip learners for the challenges of the Fourth Industrial Revolution. This transformation is underpinned by a strategic emphasis on seamlessly integrating digital technologies, personalized learning experiences, and learner-centered pedagogies [16]. The intricate interplay between Education 4.0 and learner-centered approaches holds a central position within educational discourse, captivating considerable interest among scholars and researchers [17].

The contours of Education 4.0 encompass an array of emerging technologies, including artificial intelligence, virtual reality, augmented reality, and robust data analytics, each orchestrated to amplify and enrich the learning experience [18].

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Conversely, learner-centered approaches pivot on an intrinsic dedication to address learners' individualistic needs, aspirations, and trajectories, propelling active engagement and fostering self-directed learning [19]. Fusing these two foundational concepts is an indispensable cornerstone in designing effective educational environments. By holistically intertwining Education 4.0's technological prowess with the tailored dynamics of learner-centered methodologies, educators are primed to nurture learners capable of absorbing and applying pertinent knowledge and skills within a digitally interconnected realm.

Empirical evidence accentuates that the deployment of learner-centered strategies within the realm of Education 4.0 yields marked enhancements in learning outcomes [20]. By positioning learners at the epicenter of the educational narrative, educators can intricately customize instruction, finely calibrated to match learners' distinct requisites, inclinations, and cognitive patterns. This approach engenders heightened engagement, motivation, and critical thought, concurrently deepening the fabric of comprehension woven around the subject matter.

The subsection encapsulates the dynamic interplay between these two pivotal pillars. Education 4.0's technological tapestry harmoniously converges with learner-centered paradigms, invigorating the educational narrative for learners navigating an era of profound digital transformation.

B. *Exploring Learning Outcomes through Natural Interaction and Text Mining*

Moreover, using natural interaction and text mining techniques in assessing learning outcomes has gained attention in recent years [21]. Natural interaction refers to intuitive and immersive interfaces allowing learners to interact with educational content using gestures, speech, or other natural modalities. Text mining, on the other hand, involves extracting valuable information from large volumes of text data, enabling researchers to analyze and evaluate learners' written responses, discussions, and reflections [22].

The combination of natural interaction and text mining offers new possibilities for assessing learning outcomes in a learner-centered Education 4.0 environment. By analyzing learners' interactions, responses, and textual data, educators can gain insights into their progress, strengths, and areas for improvement. This information can inform instructional design, provide personalized feedback, and support the development of adaptive learning systems that cater to individual learners' needs [23], [24].

C. *Educational Metaverse based on Value Exchange System*

The educational metaverse involves creating virtual and natural interactive learning environments where learners can interact with digital content, engage in simulations, and collaborate with others in a shared space. The value exchange system within this metaverse entails creating and exchanging valuable educational content and resources among learners, educators, and other stakeholders [2, 11].

The concept of the educational metaverse based on the value exchange system aligns with the broader idea of the metaverse as a platform for value creation and exchange. It emphasizes the importance of meaningful and valuable content in attracting and engaging users within the educational context. Learners can have more interactive and immersive learning experiences, allowing for a deeper understanding of complex concepts and fostering creativity and collaboration.

III. METHODOLOGY

The methodology employed in this study involved implementing a pedagogical strategy known as "book discussion. [25]" After attending a lecture on a specific topic delivered by the speaker, students are divided into groups and assigned a related theme for further discussion. One month later, students are tasked with critically examining and identifying the impractical aspects of the theories presented by the speaker through their group presentations. These presentations served as a platform for students to challenge the speaker's assumptions and hypotheses by providing evidence and counterarguments. Following the student presentations, the speaker had the opportunity to clarify any misconceptions that may have arisen during the lecture by addressing the points raised in the students' reports. Additionally, the speaker could reassess their assumptions based on the students' rebuttals and refine any aspects of their original hypotheses subject to criticism.

A. *Research Subjects*

The research subjects for this study were master students enrolled in a course specifically designed to explore emerging technologies and digital media. These students formed a diverse group with varying prior knowledge and understanding of the metaverse concept.

The students engaged in various learning activities throughout the course, including lectures, discussions, and hands-on projects. These activities were designed to introduce the meta- verse concept and facilitate the student's understanding shift from perceiving it solely as AR/VR/XR (Extended Reality) to recognizing it as a personalized learning system rooted in value exchange.

B. *Research Tools*

Text mining techniques were employed as the primary research tool to track and analyze the students' cognitive transition. The methodology involved collecting and analyzing textual data generated during the course, including written responses, discussions, and reflections.

At the beginning of the study, an initial survey was conducted to assess the students' preconceived notions and understanding of the metaverse. This served as a baseline for comparison throughout the research process.

Throughout the course, the students participated in book discussions, attended lectures, and engaged in interactive activities emphasizing the metaverse as a value-based learning environment. These activities encouraged critical thinking,

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collaborative learning, and the exploration of personal perspectives.

The student's written responses, discussions, and reflections were collected and subjected to text mining techniques, specifically natural language processing algorithms. These techniques enabled the researchers to identify patterns, track shifts in cognitive processes, and extract valuable insights from the textual data.

By analyzing the textual data using text mining techniques, the researchers gained a deeper understanding of the student's cognitive development and their evolving perceptions of the metaverse as a personalized learning system driven by value exchange. This analysis provided valuable insights into the student's mental journey and the factors influencing their conceptual shift regarding the metaverse.

C. Class Activity Design for Book Discussion

In this educational program, a total of 4 hours is allocated over one month. The first 2 hours are dedicated to the teacher providing a comprehensive introduction to the concept of the educational metaverse based on the value exchange system. During this time, students are encouraged to actively engage in the discussion, ask questions, and seek clarification.

1. Teacher to Students (2 hours): Following the initial 2- hour session, students are given 24 hours to reflect on the material covered and provide feedback. They are specif ically prompted to break down complex information into constituent parts and examine their relationships. This exercise encourages critical thinking and a deeper understanding of the topic.
2. Teacher and Students are together (1 month): Once the feedback is collected, the teacher organizes the students into teams for further exploration. The teams collaborate and discuss various scenarios to identify aspects that cannot be executed within the educational metaverse. This group activity fosters teamwork, critical analysis, and problem-solving skills.
3. Student to Teacher (125 mins): Over the next month, the teams work together to delve into their assigned topics, considering different perspectives and potential limitations. They engage in thorough discussions and reflections, drawing on the knowledge gained during the initial lecture and incorporating their feedback. The aim is to present their findings and thoughts at the end of the month, showcasing their collective insights and conclusions. Following the last 2-hour session, students are given 24 hours to reflect on the material covered and provide their feedback. Each team has 25 minutes for presentations and discussions. The following is a break- down of the time allocation for each team's activities:
   a) A Team Presentation (20 minutes): Bring the students together for a team presentation. Please encourage students to think critically and for- mulate their thoughts and opinions about the teacher's themes, characters, or plot. Pose ad- ditional thought-provoking questions to stimulate deeper analysis and critical thinking.
   b) Teacher's Reflection (5 minutes): The teacher sum- marizes the main points discussed after a team presentation. Teachers encourage students to reflect on their learning and insights from the teacher's main theory discussion.

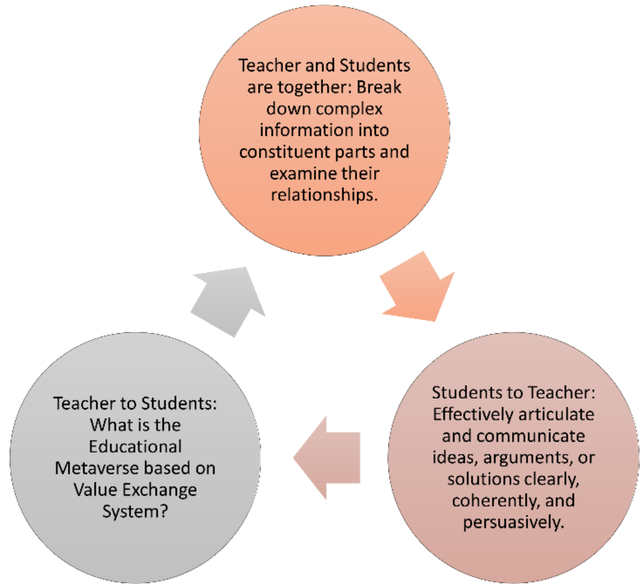

FIG. 1: The cycle of speculation in the critical thinking process emphasizes the active engagement of students in evaluating the teacher's proposition regarding an educational metaverse focused on value exchange systems.

There are a total of 24 master's students participating in this course. For the "Teacher and Students are together" task, the students are divided into five groups, and four groups comprise five members, while one group consists of four.

This structured approach gives students ample time to absorb the material, critically analyze it, engage in collaborative discussions, and present their reflections. By incorporating various stages of individual and group work, the program encourages active participation and comprehensive exploration of the educational metaverse based on the value exchange system.

In Fig. 1, the cycle of speculation in the critical thinking process emphasizes the active engagement of students in evaluating the teacher's proposition regarding an educational metaverse focused on value exchange systems. Notably, their efforts uncover the limitations present in the existing XR-based educational metaverse, as supported by the data they gather. This compelling evidence further strengthens the argument that the fundamental basis of an educational metaverse should revolve around the core concept of value exchange systems.

D. Extract Learning Outcomes from Verbatim Transcripts

Extracting learning outcomes from verbatim transcripts and utilizing text mining and co-occurrence analysis techniques provides a robust approach to deriving valuable insights from

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textual data. This methodology offers several advantages and requires considerations for assessing reliability and validity.

The collected verbatim transcripts, including written responses, discussions, and reflections, serve as the basis for the analysis. Text mining and co-occurrence analysis techniques identify the dataset's patterns, associations, and themes. The following categories and content descriptions were derived from the generated texts:

1. Teacher's Presentation: Transcriptions of the teacher's presentation on the educational metaverse and the value exchange system, encompassing explanations of the educational metaverse concept, introductions to the value exchange system, and insights on the potential of blockchain in education.
2. Students' Feedback: Students provided textual feedback regarding the educational metaverse and the value exchange system. This category includes positive comments, suggestions for improvement, reflections on the discussions, and opinions on the limitations of the XR- based educational metaverse.
3. Group Discussions and Students' Reflections: Written reflections provided by students after a month, summarizing their thoughts and key takeaways from the course. The content encompasses reflections on the importance of value exchange in education, insights gained from group discussions, an understanding of the seven-layer theorem in the educational metaverse, ideas for enhancing the value exchange system, identification of educational scenarios that cannot be realized, and proposals to overcome limitations.
4. Analysis and Insights: Textual analysis of the collected data to identify patterns, trends, and insights related to the educational metaverse and the value exchange system. This category includes the identification of common limitations in the XR-based educational metaverse, understanding the role of blockchain in enhancing the credit system, and exploring the learner-centered aspects of the educational metaverse.

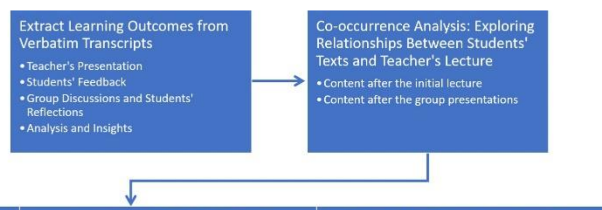
To ensure the reliability and validity of the findings, it is important to address the following:

- Reliability: Assess the consistency and stability of the automated text mining and co-occurrence analysis. Consider test-retest reliability by analyzing a subset of the data at different time points and evaluate inter-rater agreement if multiple researchers are involved.
- Validity: Ensure the content validity of the analysis by selecting appropriate keywords, phrases, or patterns that accurately capture the relevant concepts. Consider criterion validity by comparing the results with established measures or expert judgments. Additionally, assess construct validity by aligning the identified patterns and associations with relevant theoretical frameworks and concepts.

Despite the need for reliability and validity assessments, text mining and co-occurrence analysis offer valuable benefits for extracting learning outcomes:

- Efficient and Scalable Analysis: These techniques allow for efficiently processing large volumes of textual data, enabling the extraction of insights from extensive datasets.
- Unbiased Exploration: Automated analysis techniques minimize researcher bias, facilitating the discovery of unexpected patterns and relationships within the data.
- Pattern Detection: Text mining and co-occurrence analysis reveal underlying connections and associations by examining the co-occurrence of terms and patterns, providing a comprehensive view of the educational metaverse and the value exchange system.
- Hypothesis Generation: These methods can generate hypotheses and research questions for further investigation, contributing to the development of future studies and guiding research directions.

By incorporating text mining and co-occurrence analysis, this research approach enhances the understanding of learning outcomes within the context of the educational metaverse and the value exchange system, ultimately contributing to advancing knowledge in this field.



	Content after the initial lecture	Content after the group presentations
Student 1	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...
Student 2	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...
...	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...
Student 24	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...	Students' feedback after receiving feedback from the teacher ... Word1, Word2, Word3, ...

FIG. 2: The Segmentation of Students' Texts and Teacher's Lecture.

E. Co-occurrence Analysis: Exploring Relationships Between Students' Texts and Teacher's Lecture

A text-mining approach has been designed to segment students' feedback into two categories to analyze these different types of texts and transcriptions. The first category includes the content provided immediately after the initial lecture, capturing their initial impressions and understanding. The second category comprises the content generated after the group presentations, including their reflections and responses to the feedback provided by the teacher. Figure 2 is the segmentation of the texts, and the following are the specific segments:

1. Content after the initial lecture: This segment in- cludes students' initial responses and impressions of the teacher's

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lecture and their understanding and perspectives on the importance of value exchange in education.

2. Content after the group presentations: This segment comprises students' observations and reflections following the group discussions and presentations. They can share new insights, perspectives, and experiences gained during the discussions.

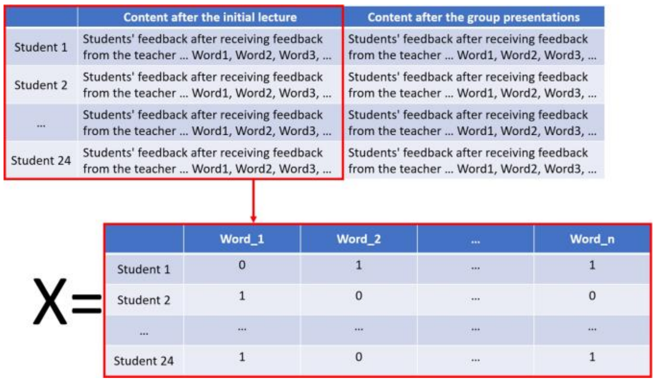

FIG. 3: To create a term-to-document matrix by segmenting students' texts and the teacher's lecture.

By categorizing the text into different categories and performing term extraction, you can create a term-to-document matrix, denoted as X (see Figure 3), where each row represents a student, and each column represents a word extracted from the student's transcriptions. The entries in the matrix represent the frequency or presence of each word in each student's text. To generate co-occurrence matrices [26], we can use two different approaches:

1. Word Co-occurrence Matrix (XTX): Transposing the term-to-document matrix X, we obtain XT, where each row represents a document, and each column represents a term. Multiplying XT with X yields the term co-occurrence matrix, where each entry represents the number of times two terms co-occur within the same document. This matrix captures the co-occurrence patterns of terms in one of the datasets.

2. Student Co-occurrence Matrix (XXT): Multiplying X with its transpose XT generates the student co- occurrence matrix, where each entry represents the number of terms that two students share in common. This matrix captures the similarity or overlap in the understanding characteristics among the students.

When we have two categories, such as students' initial feedback and group presentations and feedback, and each type can generate two co-occurrence matrices, we will ultimately obtain four co-occurrence graphs for analysis. The four co-occurrence graphs represent the relationships and patterns of co-occurrence between words or phrases within each category. By analyzing these graphs, we can gain insights into the connections and associations between terms or concepts within the students' feedback and their interactions with the teacher's lecture text.

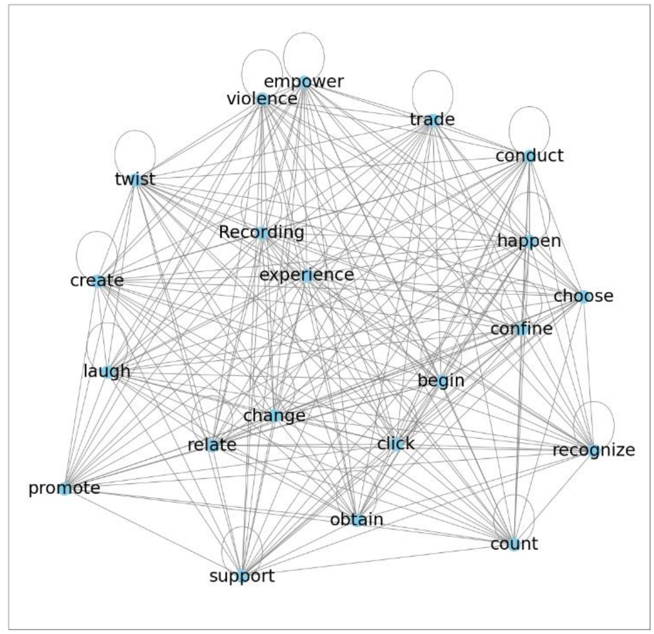

FIG. 4: A co-occurrence graph from the Word Co-occurrence Matrix.

For example, Figure 4 depicts a co-occurrence graph derived from a word co-occurrence matrix. This graph visualizes the relationships between words by representing them as nodes and using edges to indicate their co-occurrence patterns. Let's consider a corpus of news articles about technology. In the co-occurrence graph, each word corresponds to a node, and the connections between nodes represent the frequency or occurrence of these words appearing together in the text. Words that frequently occur together will have strong connections, while words that rarely co-occur will have weaker or no connections. By examining the co-occurrence graph, we can observe which words frequently appear together in the text and identify clusters or groups of related terms. For instance, words like "technology," "innovation," and "digital" may form a closely connected cluster, indicating their thematic relevance. On the other hand, words like "technology" and "nature" may have weaker connections, suggesting less frequent co-occurrence and potentially indicating contrasting concepts.

Analyzing the structure of the co-occurrence graph can help researchers understand the semantic relationships between words and uncover underlying themes or topics within the text. This information can be helpful for task modeling, retrieval, or text summarization.

In summary, co-occurrence graphs visually represent word relationships in a text and offer insights into the clustering, association, or thematic relevance between words. By examining these graphs, researchers can gain a deeper understanding of the structure and content of textual data.

IV. RESULTS

The steps for conducting a co-occurrence analysis between students' reflections and the teacher's perspective are as follows:

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1. Data preprocessing: Convert the students' reflection data into a suitable tokenization format, remove stopwords, and define keywords.

2. Feature extraction: Transform the preprocessed words into a document-to-term matrix, which serves as the basis for feature vectors representing students' views on specific terms.

3. Build a co-occurrence matrix:

   a) Build a word co-occurrence matrix: Use the extracted feature vectors to construct a co-occurrence matrix, where each element represents the number of times two features appear together in the same student text.

   b) Build a student co-occurrence matrix: Utilize the extracted feature vectors to establish a co-occurrence matrix. Each element represents the number of times two members occur together using a specific term.

4. Construct co-occurrence networks: Based on the co-occurrence matrices from steps 3(a) and 3(b), create separate co-occurrence networks for word and student perspectives, where nodes represent features and edges represent co-occurrence relationships.

Visualization and analysis: Visualize the co-occurrence networks and community structures using graph theory, enabling further analysis of patterns and trends in students' reflection changes.

FIG. 5: The steps for conducting a co-occurrence analysis between students' reflections and the teacher's perspective.

Figure 5 illustrates the application of the analysis above steps, enabling a comprehensive understanding of the significant themes present in students' reflections during two instances, the interrelationships between these themes, and the changes observed over time. This analysis provides valuable insights into students' learning processes and their values and beliefs shifts.

Each co-occurrence graph visualizes the frequency and strength of co-occurrence between terms. Nodes in the graph represent individual terms, and the edges between nodes indicate co-occurrence relationships. The thickness or intensity of the edges reflects the strength of the co-occurrence. By examining the co-occurrence graphs, we can identify clusters or groups of related terms within each category. These clusters represent common themes, concepts, or ideas appearing in texts. Analyzing the structure and patterns of the graphs helps us understand the interrelationships and recurring topics within the students' feedback and their connection to the teacher's lecture. Analyzing these four co-occurrence graphs provides a total value of the links and associations in the students' feedback, highlighting the shared understanding, key concepts, and focus areas within each category. It assists in uncovering patterns, trends, and the overall coherence of the discussions and reflections related to the educational content.

Analyzing these co-occurrence matrices can provide insights into the co-occurrence patterns of words and the shared understanding characteristics among students. Researchers can apply techniques such as clustering, network analysis, or dimensionality reduction to explore the relationships and patterns within the matrices, thereby gaining a deeper understanding of students' learning outcomes and collective understanding.

Co-occurrence analysis is a powerful text technique that allows us to delve into the relationships between the texts of the 24 students and the teacher's lecture. By identifying co-occurring patterns, we can uncover associations and connections within the texts, shedding light on the student's level of understanding and engagement. In this analysis, we preprocess the texts by removing stop words and punctuation, ensuring that the data is in a suitable format for examination. Subsequently, we construct a co-occurrence matrix, which captures the frequency of words appearing together in the students' texts and value teacher's lecture. The co-occurrence matrix serves as the foundation for our exploration. Examining the patterns within this matrix allows us to discern words or phrases that frequently co-occur in the texts. Such co-occurrences offer insights into the students' incorporation of ideas from the teacher's lecture into their reflections. If particular terms or concepts consistently appear together, it indicates the students' firm grasp and assimilation of those ideas. This analysis also enables us to identify key themes or topics that emerge across the texts, highlighting areas of shared understanding, agreement, or divergence between the students and the teacher. By comprehensively studying the co-occurrence patterns, we gain valuable insights into the level of engagement, comprehension, and assimilation of the lecture content among the students.

Figure 6 illustrates that the co-occurrence graph reveals three central nodes: "Us (我們)," "Metaverse (元宇宙)," and "Value (價值)." The links originating from these major nodes demonstrate their dynamic interactions and relationships. Regarding "Us," we connect with the meta value by embracing Education 4.0, which harnesses cutting-edge educational technologies and digitalization to elevate the quality of learning and teaching experiences. Moreover, we engage with Value through the Education Metaverse, integrating values and ethical end-social responsibility principles into the learning journey. In this interaction, the Education Metaverse is seen as an ecosystem of value exchange, utilizing blockchain and digital tokens to verify and store learners' Value. This value exchange system allows learners to gain recognition and rewards through participation and contributions, actively engaging in the value circle. The interaction of the Education Metaverse has significant implications for the behaviors and meanings within the value circle. Through educational approaches and interactions among learners, they can explore and practice behaviors and definitions related to values, ethics, and social

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responsibility in the virtual world. The Education Metaverse provides a new learning environment where learners can experience and apply these value concepts and interact and collaborate with other learners. This article emphasizes the importance of Education Metaverse, Education 4.0, and value exchange. These concepts form an interactive system that promotes learners' value creation and growth. Additionally, the article reminds us to reflect and conduct further research on Education Metaverse while addressing potential challenges and issues.

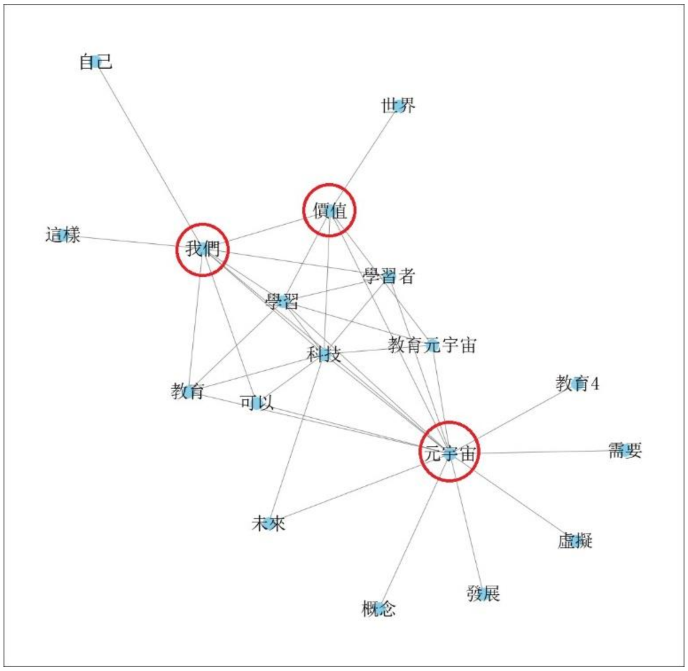

FIG. 6: Word Co-occurrence Graph from the Content after the Initial Lecture.

Figure 7 illustrates a co-occurrence graph in which four central nodes are identified: "Metaverse (元宇宙)," "Us (我們)," "Value (價值)," and "Experience (體驗)." The Metaverse establishes a connection with Us through blockchain technology, facilitating various activities and interactions within the metaverse. Blockchain technology achieves this through data verification, storage, and transmission. The metaverse intersects with "Value" through creation, transfer, and environment. Within the metaverse, individuals can create and experience different values and cultures that can be shared and communicated. "Value" is linked to Experience through education and content. Education and content play crucial roles in the metaverse, providing learning opportunities and serving as carriers and conveyors of values. These interconnected elements form a value exchange system where Experience is critical. Through participation and experiences, we receive recognition and rewards for the "Value" we contribute while contributing our experiences and importance to the metaverse. Ultimately, this system completes a loop as experiences return to the blockchain, where our actions and deals are verified and stored. This loop allows us to continually participate, create, and exchange value within the metaverse. The co-occurrence graph illustrates the relationships and interactions among the "Metaverse," "Us," "Value," and "Experience." This system facilitates value creation, sharing, and exchange while offering diverse learning and experiential opportunities.

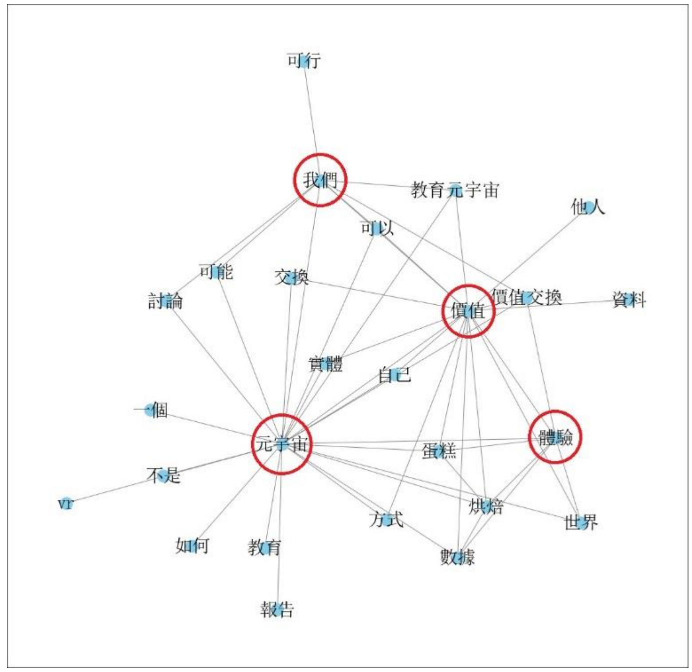

FIG. 7: Word Co-occurrence Graph from the Content after the Group Presentations.

The difference between Figure 6 and Figure 7 lies in their focus on the central nodes and their interconnections. The first paragraph describes a co-occurrence graph with major nodes of "Us," "Metaverse," and "Value," emphasizing the role of Education 4.0 and the Education Metaverse. It highlights the value creation and growth students achieve through integrating these concepts. On the other hand, the second paragraph introduces "Experience" as an additional central node in the co-occurrence graph and emphasizes its relationship with value. Based on these differences, it can be inferred that the students who wrote these texts have undergone some cognitive changes. They may have started to realize the crucial role of Experience in the Education Metaverse and its interconnectedness with value. This shift in awareness might lead them to value practical experiences in the learning process and consider them integral to value creation and exchange. Additionally, they might contemplate how values can be conveyed and shared through education and content, recognizing the potential for practicing and applying these values in virtual environments. In writing these texts, these students have undergone a cognitive change in their understanding of the Education Metaverse, Education 4.0, and value exchange. They have become aware of the importance of Experience in value creation and exchange and have started contemplating how to embody these values within virtual learning environments. These cognitive changes reflect their deeper reflection and understanding of education and learning.

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Figure 8 shows that 0 is the teacher and 1–24 are the students' IDs. The student co-occurrence graph is from the content after the initial lecture. In Table I, although the viewpoints of students 2 and 7 have lower co-occurrence with the teacher, careful examination of their descriptions reveals exciting insights. Student 2 emphasizes the curiosity sparked by understanding the teacher's life story, the pursuit of being valued, and self-directed and collaborative learning trends. On the other hand, student 7, in their conversation with the teacher, expresses a contradiction regarding the different statuses of education in the past and present society. They believe that learning should be connected to life experiences and that students should be the drivers of their knowledge. The emergence of the educational metaverse empowers teachers to serve as facilitators, enabling equal communication and fostering a deep understanding of the meaning and value of learning for students. The article also highlights the importance of student-centered teaching approaches, leveraging technology and innovative methods. Educators should guide students to develop the necessary skills to face future challenges. The above observations highlight the nuanced perspectives of students, further emphasizing the relevance of the value exchange system in the educational metaverse.

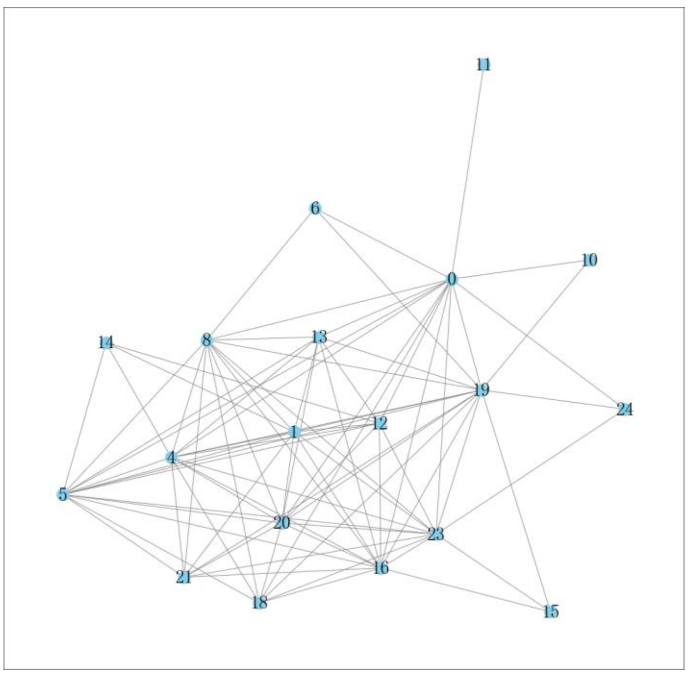

FIG. 8: Student Co-occurrence Graph from the Content after the Initial Lecture.

Figure 9 shows that 0 is the teacher and 1–24 are the students' IDs. The student co-occurrence graph is from the content after the group presentations. Table I shows that the co-occurrence between students and the teacher's perspectives has significantly strengthened in the second round of feedback. All students' views now demonstrate a high degree of alignment with the teacher's viewpoint. This indicates that students clearly understand and can articulate the discourse surrounding an educational metaverse centered around a value exchange system. They can depict a narrative that closely aligns with the teacher's perspective. This suggests that students have embraced the concept of an educational metaverse where the value exchange system plays a central role. They have internalized its principles and can articulate their thoughts in a manner consistent with the teacher's discourse.

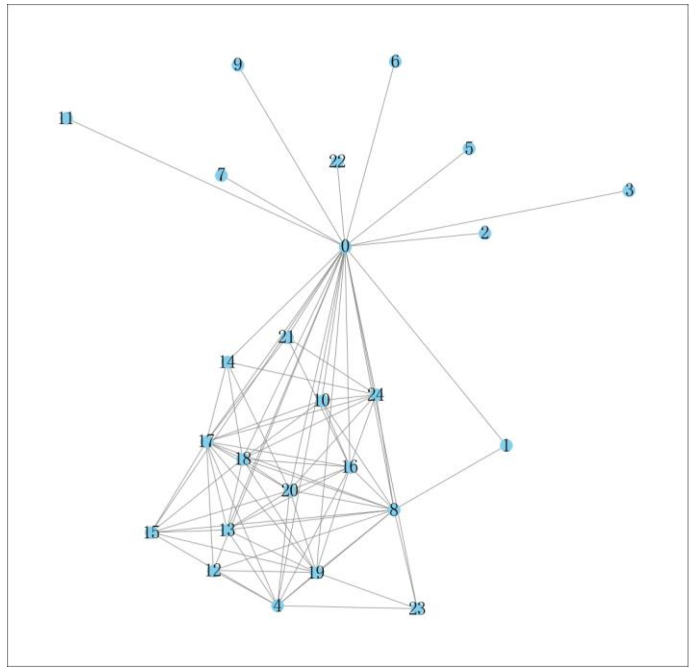

Fig. 9: Student Co-occurrence Graph from the Content after the Group Presentations.

TABLE I: The table shows the co-occurrence weights between students and teachers in the student co-occurrence matrix for two segmentation scenarios. The first two columns correspond to the weights after the initial lecture, and the last two columns correspond to the weights after the group presentations.

Stu. IDs	**Weight in Fig. 8**	**Stu. IDs**	**Weight in Fig. 9**
19	506	8	1128
20	359	4	818
16	348	19	801
23	343	15	707
5	322	20	687
4	312	17	575
8	300	12	562
18	228	23	553
13	205	18	536
11	192	13	526
24	178	16	500
6	178	24	446
12	163	11	442
10	151	3	427
17	140	1	412
15	139	9	344
14	137	10	334
1	127	6	331
21	123	14	308
9	93	5	282
22	87	2	249
3	78	7	247
2	64	21	230
7	38	22	208

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V. Discussion

In the study, the responses provided by students were analyzed using text mining and co-occurrence analysis techniques. The choice of these methods over traditional measures like written exams, questionnaires, or statistical comparisons raises the question of why such an approach was preferred. The rationale behind this preference lies in the ability of text mining and co-occurrence analysis to capture nuanced and context-rich information from open-ended responses. Unlike traditional methods that may provide structured but limited insights, text mining allows for identifying patterns, themes, and relationships within the textual data. Additionally, co-occurrence analysis helps unveil connections between concepts that might not be as readily apparent through conventional means. By adopting these advanced techniques, the study aims to uncover more profound and holistic insights from the students' responses.

Co-occurrence weights are numerical values that quantify the strength or frequency of co-occurrence between entities or elements. In the context of the provided data, the co-occurrence weights represent the degree of association or alignment between the students' IDs and the teacher's viewpoint. Each entry in the data specifies the co-occurrence weight between a student's ID and the teacher's view. A higher weight indicates a stronger co-occurrence or alignment, suggesting that the student's viewpoint closely corresponds to the teacher's perspective.

These weights quantitatively measure how students' view-points agree with the teacher's. By analyzing and comparing these weights, we can identify the level of convergence or divergence between different individuals' perspectives within the given context. The co-occurrence weights can be used to identify patterns, similarities, or disparities in the responses and viewpoints of the students concerning the teacher's perspective. They provide valuable insights into the degree of agreement or alignment among the participants and help analyze the overall coherence or consensus within the group. From the rankings of student weights, we can observe the cognitive transition process of students during two stages of the study. Here are some descriptions based on the changes in student weight rankings:

1. In the initial lecture stage (Fig. 8), student ID 19 holds the highest weight (506), indicating that this student had a strong presence and active engagement during the discussions. Students 20, 16, and 23 also hold relatively high weights, suggesting their significant contributions to the talks.
2. After the group presentations (Fig. 9), the ranking of student weights has shifted. Student ID 8, who held the 7th position in the initial lecture stage, now has the highest weight (1128). This indicates a notable increase in their engagement and participation during the group presentations. Students 4, 19, and 15 also experienced significant rank improvements, suggesting their enhanced understanding and contributions during the reflection and presentation stages.
3. It is interesting to note that some students experienced a decrease in their weight rankings from the initial lecture to the group presentation stage. For example, student ID 21 dropped from the 14th to the 22nd position, and student ID 22 fell from the 24th to the 21st position. This suggests that these students may have had a relatively limited contribution or engagement during the group presentations compared to the initial lecture.
4. The changes in student weight rankings indicate a dynamic process of cognitive transition and knowledge assimilation. Students who initially held lower weights in the initial lecture stage, such as student ID 24 and student ID 12, made significant progress and climbed the rankings in the group presentation stage, demonstrating their active involvement and understanding of the discussed topics.
5. Overall, the variations in student weight rankings reflect the evolution of students' cognitive journeys and their level of engagement and contributions throughout the study. The orders provide insights into the shifts in students' participation, understanding, and collaboration during the different stages of the research, highlighting the dynamic nature of their learning process.

At the end of the month-long course, students were asked to provide written reflections, summarizing their thoughts and key takeaways. The reflections encompassed various aspects, including:

1. Importance of Value Exchange in Education: Students recognized the significance of value exchange systems in education. They reflected on how value exchange can foster meaningful and engaging learning experiences. Students identified the role of value exchange in promoting collaboration, creativity, and critical thinking.
2. Insights from Group Discussions: Students highlighted the value of engaging in group discussions. They acknowledged the diverse perspectives and ideas shared during these discussions. Students appreciated the opportunity to learn from their peers and gain new insights into the educational metaverse.
3. Understanding of the Seven-Layer Theorem: Students demonstrated their understanding of the seven-layer theorem in the educational metaverse. They reflected on how the theorem shaped their perception of the learner-centered environment. Students recognized the importance of the sevenlayer theorem in creating a holistic and comprehensive educational metaverse.
4. Enhancing the Value Exchange System: Students brainstormed ideas for enhancing the value exchange system in the educational metaverse. They proposed strategies to ensure an equitable exchange of educational resources and content. Students explored innovative approaches to incentivize active participation and contribution within the value exchange system.

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5. Identification of Unrealizable Educational Scenarios: Students critically analyzed the limitations and constraints of the educational metaverse. They identified educational scenarios that cannot be realized within the current framework, and students reflected on the challenges and proposed potential solutions to overcome these limitations.

The group discussions and students' reflections provided valuable insights into their learning journey throughout the course. These reflections serve as a basis for further exploration and improvement in designing learner-centered educational environments and refining the value exchange system within the educational metaverse.

The process of cognitive migration can be observed from the graph, indicating that students initially recognize the relationship between the metaverse and the value exchange among individuals. Furthermore, students have come to understand that to facilitate the exchange of value between the metaverse and individuals, it is necessary to engage in immersive experiences. This signifies a progression in their understanding, highlighting the importance of experiential learning in the metaverse.

VI. Conclusions

Despite the potential of using co-occurrence graphs and text mining techniques to analyze and understand the relationships between words in a given dataset, there are some limitations and areas for future work to consider.

1. Data quality and completeness: In the context of the metaverse, ensuring the accuracy and completeness of data used for analyzing learner interactions, virtual experiences, and value exchange systems is crucial. Future work can focus on developing methods to collect comprehensive and reliable data to construct accurate models and matrices for analysis.

2. Semantic understanding: While co-occurrence graphs provide insights into word relationships, the metaverse context requires a deeper understanding of words' semantic and contextual meaning. Future research can explore techniques to incorporate semantic analysis and natural language processing to capture the nuanced meaning and context specific associations within the metaverse environment. Dynamic item analysis: The metaverse is a dynamic and evolving space. Future work can explore dynamic approaches to capture the changing nature of learner interactions, value exchange systems, and virtual experiences within the metaverse. This could involve real-time analysis of learner behavior and interaction patterns to adapt and personalize the learning experiences accordingly.

3. Integration of additional features: In addition to text mining techniques, future research can explore integrating elements such as sentiment analysis, sentiment mining, or user feedback analysis within the metaverse. This can provide a more comprehensive understanding of learners' experiences, emotions, and preferences, enabling the development of tailored interventions and personalized learning approaches.

4. Application in diverse educational contexts: While the current discussion focuses on selfdirected learning in the metaverse, future work can expand the application of these concepts to other educational contexts within Education 4.0. This could include exploring how value exchange systems, learner-centered approaches, and technology integration can be implemented in various educational settings, such as online learning platforms, virtual classrooms, or collaborative learning environments.

In conclusion, understanding the educational metaverse as a value exchange system is crucial in shaping the future of learner-centered education in the context of Education 4.0 and the Fourth Industrial Revolution. Integrating digital technologies, personalized learning experiences, and the emphasis on individual needs and goals align with the learner-centered approaches advocated in modern education. By leveraging natural interaction, text mining, and co-occurrence analysis, valuable insights can be derived from learner interactions, discussions, and reflections within the metaverse.

However, it is essential to recognize the limitations and areas for future work utilizing co-occurrence graphs and text mining techniques. Ensuring data quality and completeness, incorporating semantic understanding, and exploring dynamic item analysis is essential for capturing the complex and evolving nature of the metaverse. Additionally, integrating sentiment and user feedback analysis can provide a more holistic understanding of learners' experiences and inform personalized interventions.

Furthermore, applying value exchange systems and learner-centered approaches should not be limited to the metaverse but extended to diverse educational contexts within Education 4.0. These concepts can be implemented in online platforms, virtual classrooms, and collaborative learning environments by embracing technology integration, promoting active engagement, and fostering collaboration.

Understanding the metaverse as more than an XR platform is crucial in this rapidly changing educational landscape. It is about recognizing its potential as a personalized learning ecosystem where learners actively participate, exchange knowledge, and engage in meaningful interactions. By embracing the concept of value exchange, we can harness the power of the metaverse to cultivate deeper understanding, creativity, and collaboration among learners, ultimately preparing them for the challenges and opportunities of the Fourth Industrial Revolution.

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CONFLICTING INTERESTS

The author(s) declare that they have no conflicting interests.

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A Bibliometric Analysis: Metaverse in Education Concept

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***Abstract*—During the last decade technological transformation prospered, and digital environments such as Metaverse started to come to life. Metaverse is a hypothesis of the next generation of the Internet, which consists of an online 3D virtual environment and limited physical interaction. Due to the growth of Metaverse technology in various fields and the importance of using it in education, it is being observed that published research related to this topic is also growing. Therefore, the purpose is this study is to review and identify the application areas of this emerging technology for the education field by providing a bibliometric analysis of the literature related to Metaverse. This research contributes to literature as it addresses the status, gaps, and the direction for future research. In the bibliometric analysis, an electronic search was done via a scientific database named Dimensions by combining topic-related keywords for 'metaverse' and 'education' within the time frame of 2004 and 2022. The data gathered by a data extraction table from 5,048 articles retrieved and analysis run by VOSviewer data visualization tool. Of 5,048 articles found through the initial search, most of the studies (48.02%) were published in 2022, and Singapore, Japan, China, and UK are the main countries for the studies and citations appearing dominantly. The main three keywords for 'metaverse' and 'education' articles include: virtual worlds, video and metaverse platforms. The use of metaverse in education has been expanding rapidly in literature during recent years. Yet this study reveals that research is still limited to the main four countries, and studied subtopics are very primitive and vague. Available citations show weak link strength meaning the depth of the studies in the literature is not satisfactory, yet, which is because the metaverse itself is not enough without the supporting technologies. Educators and scientific researchers could rethink what types of technologies belong to the metaverse and how it has the potential to influence the education sector. Policymakers and educators could refer to this study for metaverse learning environment expansion of their future policy and executions.**

Keywords: Metaverse, education, virtual reality, bibliometric analysis, VOSviewer

I. Introduction

A. Metaverse Concept

Both a "new concept in use" and an "idea still under construction" are the terms used to describe the metaverse [1]. It is a compound word derived from two words: "meta" and "universe" [2]. It can be easily interpreted as combination of virtual world and real world [3]. Due to the rapid advancement of technology and changes in consumer preferences, virtual reality in Metaverse is currently a hot topic of discussion [4]. The graphics have improved thanks to technological developments like 3D progress, giving the metaverse a more realistic feel [5]. In the end, it combines a virtual world with a physical reality that has been enhanced to encompass both with a new specific technology known as eXtended Reality (XR), which includes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) [6].

Beginning in 2022, when Facebook's online social media platform changed its name to Meta, the term "metaverse" became widely recognized in the industry [7]. With its new name, Facebook expanded on the "metaverse," a three-dimensional environment [8]. This also brought up the discussions about whether it is a new business innovation or not. There were several business-wise reasons behind this name change. However, the name change also was perceived as an unlocking of a new technological era. The rebranding of Facebook has significantly raised public attention in XR technologies. This progress also was a guidance to the full potential of the metaverse [9]. Critics claimed that the Metaverse was nothing more than hype with no tangible benefits [10]. According to Rana et al. metaverse is an intersection of augmented and virtual reality [11]. Based on this, the metaverse contributes to the structure that shapes and limits user actions [12]. Under the light of these recent evolutions, metaverse became a hot topic for societies. It is still an interesting area to research due to its unmature nature, and that is why it is the focus of this research.

It is also crucial to understand the interest of the consumers in this new era. Worldwide Google searches for the keyword "metaverse" can be reported as below Fig. 1. As it is seen the public interest started by the end of 2020 with a strong jump while it was almost zero before. This is still showing a very fluctuating trend and yet it is not a mature and not a continuous interest about the new concept.

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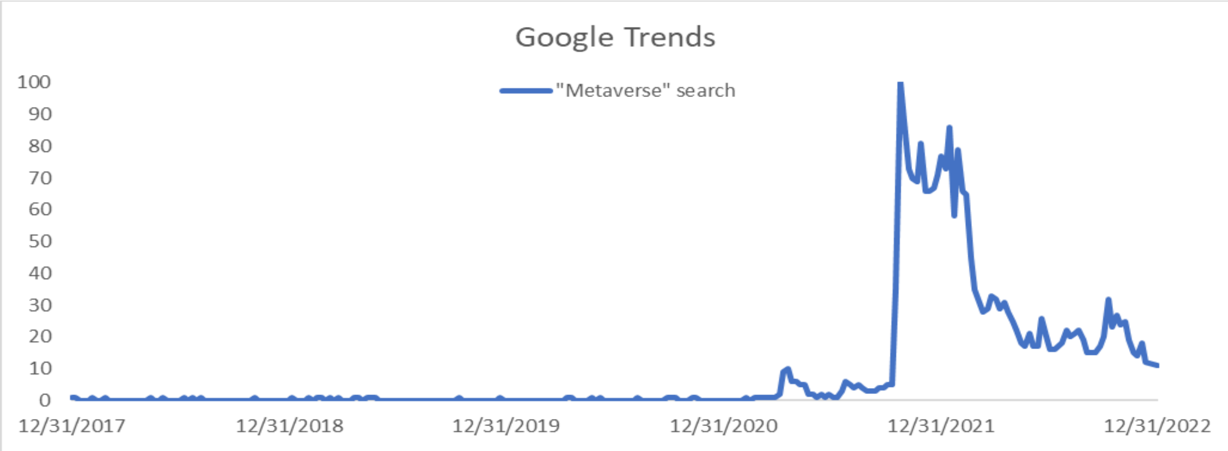

FIG. 1. Worldwide Google searches for 'metaverse'. The maximum popularity during the analyzed period is indicated by an index equal to 100.

The virtual interaction experience is not sufficient alone without a physical component. Thanks in large part to wearable technology, which gives the impression that the experience is as real as a physical interaction, the metaverse has begun to be an intriguing aspect for many industries [13]. Watching movies, working, visiting various locations, or even trying on clothes are virtually all possible activities [14]. Based on immersive interaction, the metaverse expands with a variety of social meanings that go beyond gaming, fashion, and education [15]. But many other possible industries are on the pipeline such as banking, real estate, and so on. To encourage participation in the Metaverse, an economic system is in place [16]. The idea of the Metaverse is still evolving, and no definitive definition has been provided [17]. But many industries are working on solutions that can include virtual space that can lead their industries to the next level. It sounds like a great opportunity and a great angle to work on in terms of product differentiation and experience expansion.

Some fictions give signals to us about the possible future expectations, and they eventually come to life. Many of the features that were predicted in fiction are now possible because the underlying technologies of the metaverse have developed over time [18]. For example, the gaming industry was the only area where the metaverse had a wide-scale application when it first appeared in the early 2000s [19]. Another industry is orthopedic surgery. It has been aided by the technology company Oculus [20]. Beyond these industry examples, some supporting technologies needed to evolve as well. Currently, some platforms provide users with metaverse-like experiences that are combined with virtual economies such as cryptocurrencies. Starting from the world of video games, these supplementary tools are allowing their users to engage in these virtual experiences [21]. Second Life was the first usable VR for many people involved in the field by 2003. It had been released as a social platform. At the time, Second Life or the online game World of Warcraft were the most well-known platforms [22]. People might tend to think of it as a game, but the essence is different because mutual communication is possible [23]. The market's interest in this technology is growing, and several companies, including Microsoft, Nvidia, and Meta, have shared their predictions for the future [24]. In 2021, many industries, including the healthcare sector, have adjusted to the metaverse phenomenon [25]. Medical imaging-guided diagnosis and therapy can be developed, evaluated, and improved with the help of metaverse [26]. The zero-contact business culture has had a significant impact on the medical field [27].

The top highlighted industries for metaverse concept obviously are not limited to virtual social platforms, games, or health industry. Many more are in the pipeline to leverage on the new technologic era. The education sector is one of them. Education has huge potential to benefit from the technological updates due to its nature to make learning more entertaining.

In this research, it is aimed to contribute to the metaverse literature by analyzing the recent performance and dynamics of this innovation, which is tomorrow`s new internet also for education industry like many other industries. The industry focus of this research is the education industry. No bibliometric analysis of publication has been observed till now for metaverse impact in education. Due to the development of software tools and improved capacity for handling massive amounts of data, the bibliometric approach to reviews has recently grown in popularity [28]. This research aims to explore the literature interest on metaverse in education from a bibliometric perspective. The research uncovers further research opportunities related to metaverse in education. In terms of methodology the Dimensions publications will be scanned and search results for the term 'metaverse' and 'education' will be analyzed by conducting keyword frequency method. Then, keyword mapping will be constructed by a viewer tool such as VOSviewer.

B. Research Goal And Research Questions

To ensure that a substantial range of literature was captured relating to the topic of interest, the following initial search questions defined to guide the search:

1. How is the metaverse in education concept covered in literature scope and how has the research progress so far?
2. Which countries, which researchers, which key topics are the focus in the literature for metaverse in education concept?

The following structure is planned for this study, and it is as follows. A literature review related to the metaverse in

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education is presented in Section 2. The methodology used is detailed in Section 3 and the analytical part is presented in Section 4. The insights found in this study are presented in Section 5. Finally, the conclusions, including future research directions are covered in Section 6.

II. Literature Review

The literature was reviewed to understand deeply the studies about metaverse in the education industry. Metaverse workspaces are dimensionless and accessible by simply using VR glasses [29]. Social VR will keep expanding because it gives users a sense of presence in space [30]. Learners rarely have the chance to directly perceive social and linguistic cues through online interactions [31]. The term "Eduverse," which refers to the Metaverse's educational effects, was combined to describe this phenomenon [32]. The COVID-19 outbreak during the pandemic years caused a shift in the type of education from offline to online [33]. The pandemic has forced the closure of in-person classes and adaptation of the knowledge transmission through education [34]. With the lockdown months, it has been experienced that distance learning was not as effective as it used to be in the class. Students may decide to turn off their video camera to play games or watch movies, even though there are reminders to keep cameras on [35]. The Metaverse could be an amazing solution as it enables participants to respond and fully interact. When the decision was made to go back to the classrooms with the masks, the job was easier. But there were still a lot of struggles with breathing with the masks [36]. It could be a way to give the feeling of being with the others in the same room while being tremendously distant. That`s is exactly what was needed. Educators can define a hybrid delivery modality with a VR education environment integrated with existing education [37]. In teaching-related studies, a mix of real and virtual environments such as simulations offer students many benefits. Students can learn about a new subject while being engaged in a more interesting way [38]. Metaverses help to present to their users a high degree of interactivity. The metaverse can be successfully used in subjects such as medical and engineering classes [39]. The game type of experience-based world is expected to have a positive effect on a user's learning motivation [40]. One of the other benefits could be that they can proceed at their own pace [41]. For mathematics, the application of Metaverse may contribute to students' learning outcomes [42]. The modality can help them to use analytical approaches for interactive and attractive for students who don't like numbers. Not to mention the benefit to the industries could be that it may be cheaper to maintain a virtual product and service in the long term as metaverse technology advances [43]. A workable alternative might be to alter the learning materials in a digital textbook using metaverse [44]. Literature researchers are not limited to the given perspectives, obviously there is more to it.

According to the provided background analysis we aim to contribute to literature in several ways by deepening the scope in the selected research area. As it is observed in literature, metaverse affects several industries including education, and education is one of the main industries that can adapt it. When the literature has been analyzed in terms of industry evolution gaming, healthcare and education are the top three industries that have been highlighted. That`s why the topic of this research focuses on education specifically. As literature development also grew up rapidly with the COVID-19 era, literature needs to be analyzed in depth to define the research dimensions and aspects covered so far in terms of countries, institutions, authors, keywords, citation links and so on. Bibliometric analysis helps to understand the trends and effectiveness of bulk research data. It also reveals an overview and a synthesis of the big data which could be more meaningful rather than analysis of each study one by one.

In terms of theoretical framework of this research, literature review highlighted many references to get inspired and guided with. One of the research frameworks that was studied deeply is about model validation for combining the bibliometric and text-mining tool by using bibliometric analysis of the literature [45]. Another bibliometric analysis framework was seen for understanding the studies done for structure international entrepreneurship [46]. One of the most widely used visualization tools was noticed during the literature scanning was VOSviewer. A huge increase for global publications on COVID-19 was studied with bibliometric analysis and visualized by VOSviewer [47].

We identify studies focusing on metaverse in education in literature and perform the analysis of papers in terms of publications and citations trends. Additionally, we identify which countries, institutions, and scholars have been particularly influential and at which fields of research. We also identify the mainstream journals that are leading in publishing bibliometric studies, with results showing that these journals have particularly high-growing scholarly impact. Further, we suggest future research agendas, based on review-based approaches, to further develop the scholarly impact of metaverse in education literature. In conclusion, it can be easily commented that bibliometric studies are crucial for the academic world.

III. Materials And Methods

According to Baker et al. [48] this research follows a bibliometric analysis, incorporating both quantitative and qualitative aspects of literature. Under this approach, we run the following analyses: (1) trends of total publications and citations, (2) bibliometric analysis of keyword/network analysis, (3) bibliometric analysis of citations by countries and (4) bibliographic coupling by authors.

A. Search Plan And Data Sources

In this research, bibliometric review was conducted by searching scientific databases by combining topic-related keywords including “metaverse” and “education”. A common and precise technique for looking over and analyzing sizable amounts of scientific data is bibliometric review, which is a type of systematic review [49]. The time that was considered for this research included all the publications starting from January 1st, 2004, and until December 31st, 2022. As of the end of 2022, 5.048 publications have been retrieved by the database of Dimensions platform by Digital Science [50]. The articles' data that utilized the keywords "metaverse" and "education" were retrieved using the Dimensions platform.

Scientific Procedures and Rationales for Systematic Literature Review (SPAR-4-SLR), one of the review protocols used to evaluate publications, aims to help

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researchers conduct systematic reviews of the literature and defend the choices they make along the way [51]. There are three different stages of SPAR-4-SLR which are assembling, arranging, and assessing (Fig. 2). We assembled and arranged 5.381 publications retrieved from the Dimensions database, having "metaverse" and "education" in the full text, and title of the publication. 333 publications were excluded due to still being in preprinting phase at the time of this research. Eventually 5.048 publications were left to proceed with the bibliometric analysis.

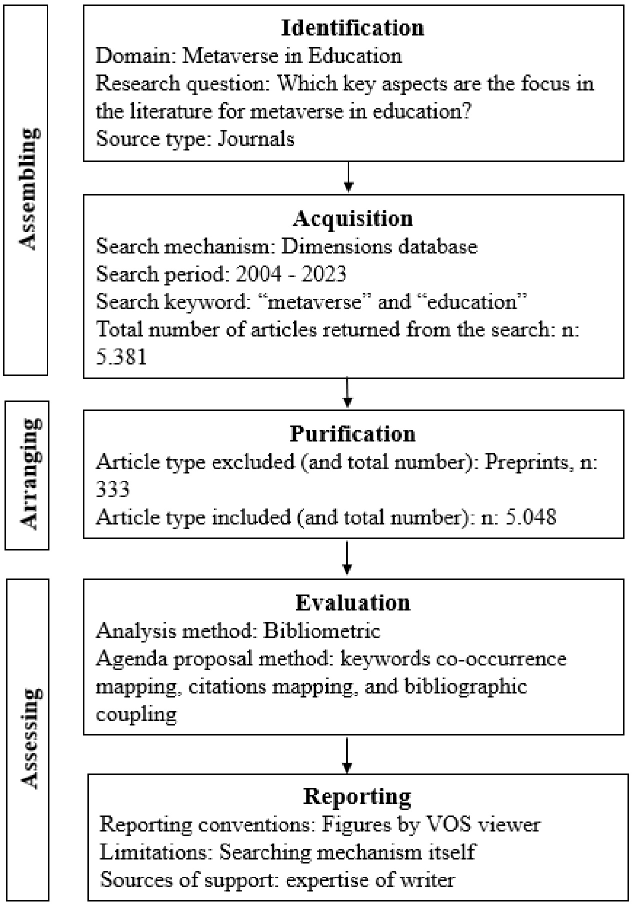

FIG. 2. SPAR-4-SLR review stages

B. Data Analysis

After selecting related studies, data extraction was done on a data extraction table designed in MS Excel 2019 as CSV format. This table has many data filtering items such as year of publication, language, journal, title, author, keywords, and counts of citation. The date of the retrieval was January 21, 2023.

After data extraction, the data was analyzed through the content analysis method, and the results were summarized and reported in related tables and figures. Various software programs and bibliographic mapping techniques that can be used to visualize research on a topic offer the presentation of results [52]. The received results have been downloaded in CSV format to be processed using VOSviewer (version 1.6.18) to visualize and analyze the trends in the bibliometric form. Bibliometric analysis is an accurate method for analyzing large volumes of big data. Growing in popularity in bibliometric research is the visualization of similarities (VOS) viewer, which aims to make the visualization of bibliometric maps simple [53]. This method allows us to effectively collect literature and identify the relationships of the selected publications within the alternatives. In this research the model was framed to analyze literature by open/closed access publications, journals/organizations, network visualization by keywords, citation by countries and bibliographic coupling by authors.

IV. RESULTS

A. Trends of Publications and Citations

As the research period start with 2004, there are not many visible records and citations until 2009. The graph below (Fig. 3) represents the publication and citation trends for literature over the last two decades. After 2016 the research field showed a boost in terms of publications, and it is reflected in citations accordingly between 2017 and 2019. After a slowdown during pandemic years, it is again showing another peak starting from 2021.

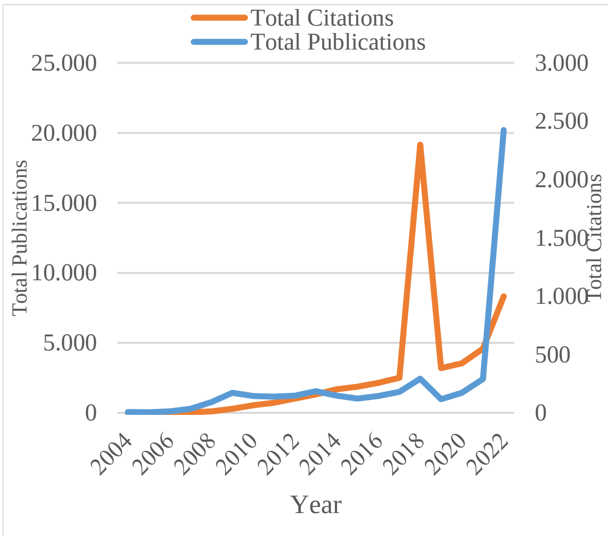

FIG. 3. Total publications and total citations trend

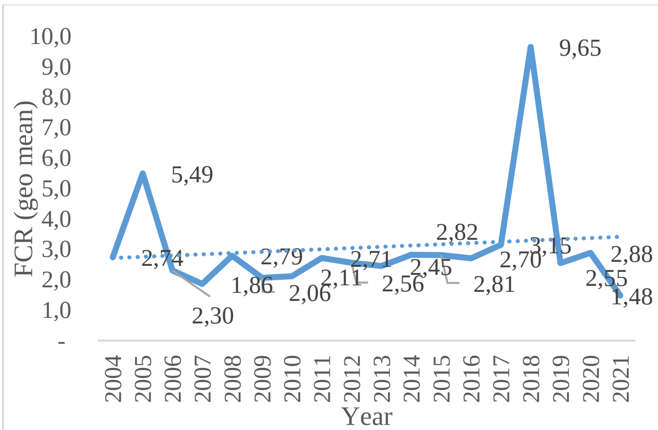

Fig. 4. Trends of total publications with FCR (geo mean)

The Field Citation Ratio (FCR) can be thought of as the average of all journal citation rates in each network. It shows how well a publication performs in terms of citations when compared to similarly aged articles in its field [54]. A value of more than 1.0-1.5 indicates higher than average citation, when defined by publication year. The FCR is calculated for all

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publications in Dimensions which are at least 2 years old and were published in 2004 or later. The highest geo mean score is 9.65 in 2018 (Fig. 4) showing the most impactful period of the research done in this area.

B. Focus on Open and Closed Access Publications

In the scientific literate Open Access (OA) is an important pillar to understand accessibility of the work. Open Access (OA) refers to the free, full-text availability of scholarly journal articles without a subscription, fee, or registration [55]. Compared to closed access articles, open access articles are cited more frequently [56]. The awareness on open access journals became evident in recent years and after 2017 it surpasses the closed article publications continuously (Fig. 5). Starting from 2021 the gap between OA and Closed publications are widening more evident.

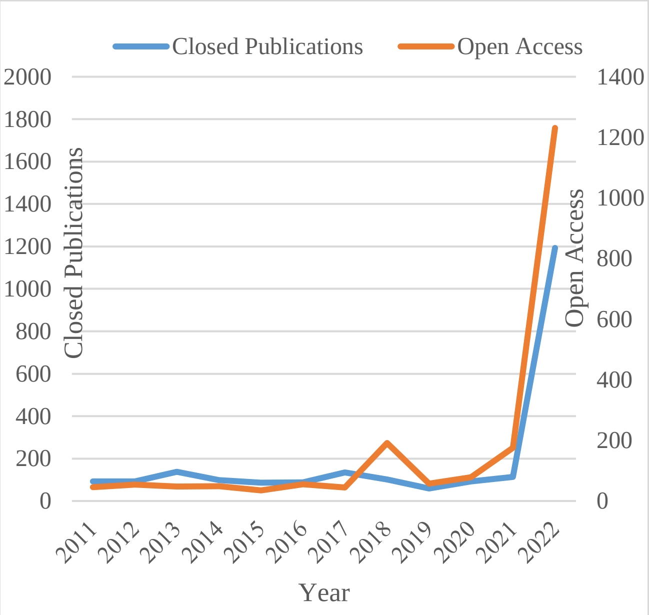

FIG. 5. Closed and open access publications

Overall total publications (TP) for closed publications are higher than open access publications 2,792 versus 2,256. However, total citations (TC) are remarkably higher for open access publications as well as TC/TP is 13.37 for open access while it is 7.51 for closed access journals (Table 1).

TABLE I. Open Access Publications and Citations

Publication Type	TP	TC	TC/TP
Closed	2,792	20,957	7.51
Open	2,256	30,161	13.37

C. Top contributed authors and journals

Top ten contributed authors based on publications are listed in Table 2(a) below. Niyato from Singapore has the highest number of publications with 33 and followed by Xiong again from Singapore with 27 publications. Fukumara from Japan has the highest TC/TP with 8.7 and second is Ogawa from Japan with 7.6 TC/TP indication of highest attendance.

In terms of total citations, Boulos from China is the top author with 552 citations and highest TC/TP of 92.0 as shown in Table 2(b) followed by Papagiannidis from United Kingdom with 364 citations and TC/TP of 52.0.

TABLE II. Top 10 Authors According to The Publications and Citations

Name	Country	Publications	TC/TP
Dusit Tao Niyato	Singapore	33	2.6
Zehui Xiong	Singapore	27	3.5
Hideyuki Kanematsu	Japan	25	6.9
Dana M Barry	USA	21	7.3
Chunyan Y Miao	Singapore	19	3.8
Nobuyuki Ogawa	Japan	18	7.6
Jiawen Kang	China	17	3.9
Xuemin Sherman Shen	Canada	16	3.0
Fei-Yue Wang	China	15	5.9
Yoshimi Fukumura	Japan	15	8.7

Name	Country	Citations	TC/TP
Maged N KBoulos	China	552	92.0
Savvas Papagiannidis	UK	364	52.0
Alan H D Miller	UK	223	31.9
Hideyuki Kanematsu	Japan	207	7.4
Brian E Mennecke	USA	188	31.3
Dana M Barry	USA	187	7.8
Nobuyuki Ogawa	Japan	170	8.1
Yoshimi Fukumura	Japan	154	9.6
Toshiro Kobayashi	Japan	136	10.5
Ko De Ruyter	UK	122	20.3

Another important perspective is understanding the top influential journals as future researchers will be curious to look for those journals. The most top ten influential journals are shown in Table 3 below and top three journal are: UCG Journal Group with 20,993 citations, followed by ERA with 20,535 and in the third place Norwegian Register with 14,581 citations. In terms of TC/TP ratio Norwegian Register is the most effective journal with the highest value of 17.66.

TABLE III. Top Influential Journals

Name	TP	TC	TC/TP
UCG Journal List Group II	2,120	20,993	9.90
ERA 2023	1,970	20,535	10.42
Norwegian Register Lvl I	1,767	14,581	8.25
ERA 2018	1,502	19,233	12.80
VABB-SHW	1,376	16,102	11.70
ERA 2015	1,289	17,428	13.52
DOAJ	642	2,741	4.27
ERIH PLUS	536	7,804	14.56
Pub Med	354	2,414	6.82
Norwegian Register Lvl II	296	5,226	17.66

D. Top field of research topics

We also identified field of research topics to specify the work areas. “Information and Computing Sciences” came up at the first place with 1,905 total publications and 14,837 total citations. It is followed by “Education” with 626 total publications and total citations of 6,372 (Table 4). In terms of TC/TP ration Commerce, Management, Tourism and Services has the highest ranking of 14.17 with 601 TP and 8,519 TC values. These are the leading areas of ‘metaverse’ and

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'education' showing that all aspects of education can be adjusted by the usage of the new concept.

TABLE IV. Top 10 Fields of Research According to Publications and Citations

Field Name	TP	TC	TC/TP
Information & Computing Sciences	1,905	14,837	7.79
Education	626	6,372	10.18
Commerce, Management, Tourism and Services	601	8,519	14.17
Human-Centered Computing	588	5,439	9.25
Creative Arts & Writing	459	2,722	5.93
Language, Communication, and Culture	420	2,892	6.89
Engineering	363	4,419	12.17
Curriculum and Pedagogy	310	2,650	8.55
Education Systems	274	2,954	10.78
Screen and Digital Media	272	2,074	7.63

E. *Bibliometric analysis of the keywords: Co-occurrence mapping*

Keywords given by the authors of the articles and seen more than 10 times in Dimensions database were captured for the analysis done by VOSviewer network visualization with co-occurrence mapping based on text-data. The size of the nodes shows how frequently they occur. Each color represents a group of terms merged into clusters, the clusters representing the relationship between one topic and another, and the curves between the nodes indicate their co-occurrence in the same publication [57].

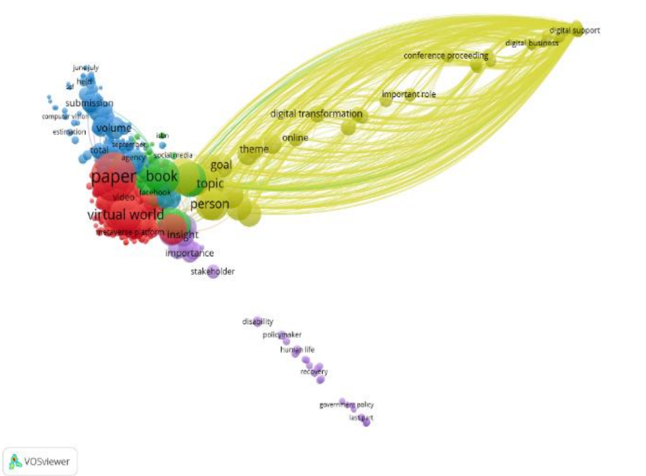

FIG. 6. Bibliometric analysis of the keyword publications of "metaverse" and "education

Five main clusters are yellow, red, green, purple, and blue ones, and are more extensive than the rest. The green cluster's main key items are digital transformation, online, and person. The red area consists of topics related to virtual worlds, video and metaverse platforms (Fig. 6). It is an indication of the research areas are still not specialized but more generic concepts are still being researched and analyzed.

F. *Bibliometric analysis of citations (by countries, authors, and organizations)*

Citations of the studies have been analyzed by counties, authors, and organizations. Different colors indicate different clusters, and the size of circles indicates the counts of citations. The most dominant country which is in purple area is United States with 580 articles, 7,760 total citations with link strength of 1,195 and United States followed by China which is the second biggest cluster in blue (Fig. 7A). China has 449 articles, 2,092 total citations and link strength of 851. United Kingdom is in the third place by 321 articles, 5210 citations and link strength 763.

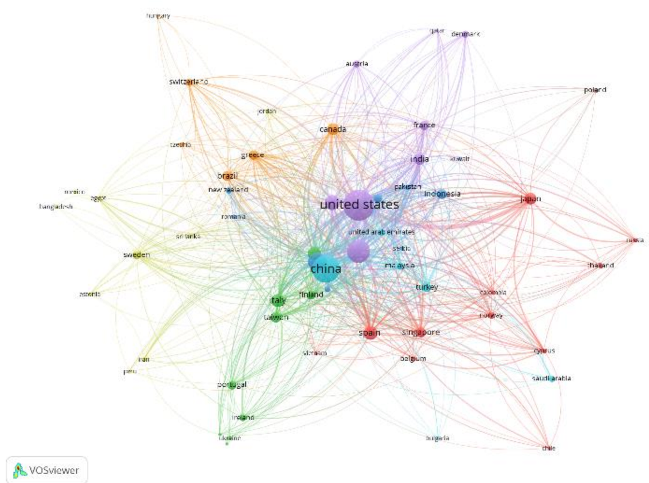

FIG. 7A. Bibliometric analysis of the citations: The citations of countries

In terms of authors perspective of citations, it is observed three main clusters with the colors of green, blue, and red (Fig. 7B). Author Kanematsu, Hideyuki from Japan has the highest number of documents 28 with 207 citations and link strength is 568. Kanematsu is followed by Barry, Dana from United States with 22 documents, 180 citations, and 495 link strength. Ogawa, Nobuyuki from Japan is at the top three of the lists, with 21 documents,170 citations and 484 link strength.

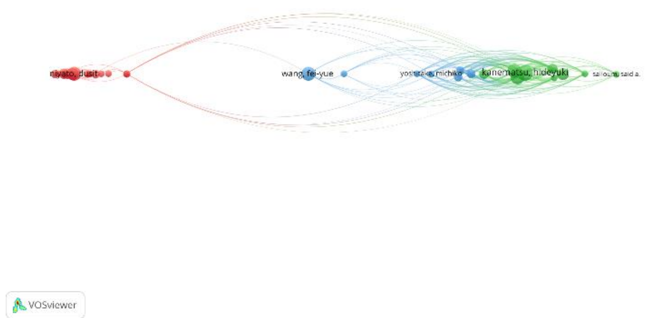

FIG. 7B. Bibliometric analysis of the citations: the citations of authors

Citations by organizations are presented in nine different clusters and colors are red, green, blue, yellow, purple, orange, pink, turquoise and brown (Fig. 7C). Nanyang Technological

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University has the highest number of documents with 40, total citations of 325, and link strength 92 from Singapore. It is followed by Hong Kong Polytechnic University with 29 documents, 389 total citations and 63 link strength. University College London is listed in the third place with 28 documents, 89 total citations and 22 link strength.

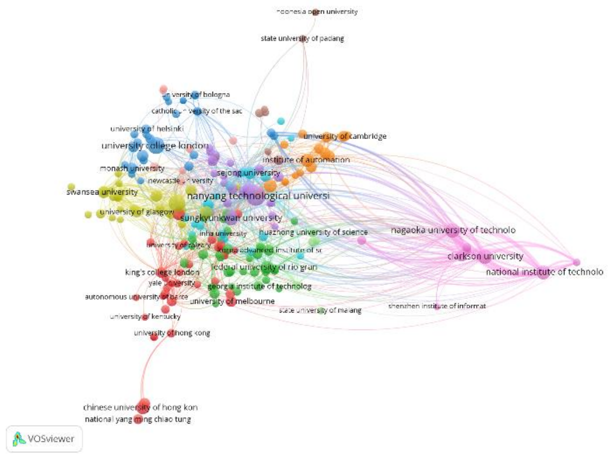

FIG. 7C. Bibliometric analysis of the citations: the citations of organizations

G. Bibliometric analysis of the bibliographic coupling (by authors, sources)

To compare citing articles, bibliographic coupling joins documents that cite the same group of cited sources [58]. The bibliographic coupling map of authors and sources are shown in Fig. 8A and 8B. In terms of authors aspect of the analysis, green, red, blue, and yellow main zone highlighting the dominancy. Green cluster lead by Kanematsu, Hideyuki from Japan with 28 articles, 207 citations and 2,778 link strength (Fig. 8A). Second place is Barry, Dana from United States with 22 articles, 180 citations and 2527 link strength. Ogawa, Nobuyuki from Japan has 21 documents, 170 citations and 2630 link strength. Results are very similar to the bibliometric analysis of citations in terms of authors which is an indication of the concept being still unmature.

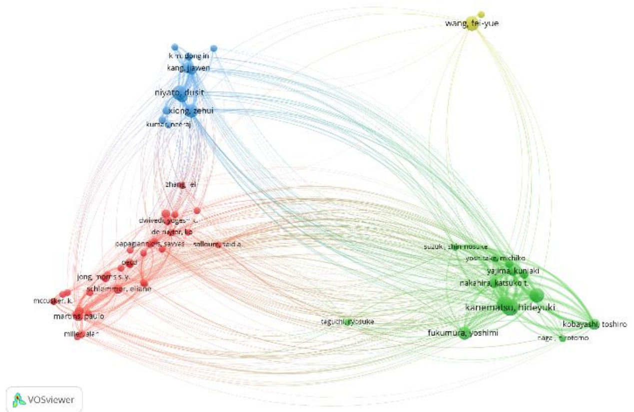

FIG. 8A**.** Bibliometric analysis for bibliographic coupling: bibliographic coupling of authors

In terms of sources analysis, clusters are shown as orange, red, green, blue, yellow, and purple (Fig. 8B). The first source is listed as 'lecture notes in computer science' with the document number of 225, total citations 455, and total link strength 2319. The next source is 'safety and reliability – safe societies in a changing world' with the document number of 155, total citations 16,702 and total link strength 1,720. That also highlights the fact that safety and reliability are the main two concerns for the adoption of new concepts. It is followed by 'communications in computer sciences' with 53 documents, 73 total citations and 804 link strength.

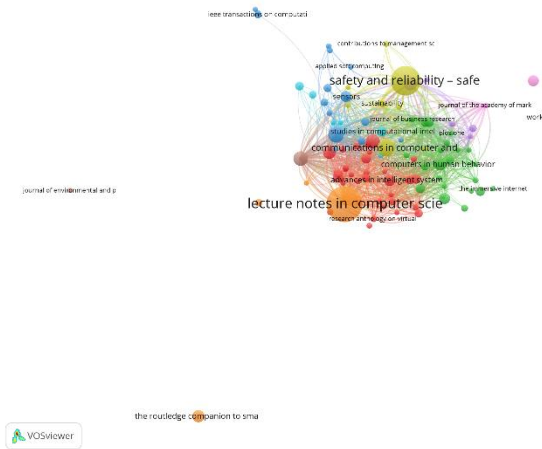

FIG. 8B. Bibliometric analysis for bibliographic coupling: bibliographic coupling of sources

V. DISCUSSION AND FUTURE WORK

According to Deloitte China`s 2022 Global XR industry insight report metaverse is in the early stage of development between 2021 and 2030 [59]. The mature stage will start from 2031 and ecosystem will be shaped as seen in Fig. 8. As is shown in the ecosystem, the education industry has been shown at the top, following the healthcare industry.

Another insights report from McKinsey & Company 'Value Creation in the Metaverse' in 2022 addresses the education is one of the top industries among the others for the future potential [60]. Therefore, the impact of metaverse in education is still being examined and is a hot topic for researchers to understand opportunities and challenges. It will be one of the main industries that need to be investigated further to benefit from the Metaverse concept.

According to the article by Zhang, metaverse universe and its key components have been defined as presented in Fig. 10 [61]. So, ecosystem requires contributions of other industries to evolve such as wearable devices. Technology, technology speed, and equipment developments are still not mature enough. That`s one of the reasons why defined ecosystems are still in the phase of research and not there yet for execution. Another aspect which is still under investigation for the concept and on the radar of the researchers is security, privacy, and ethics. Metaverse will be researched deeply for privacy and security issues, cyberbullying, and other forms of harassment [62].

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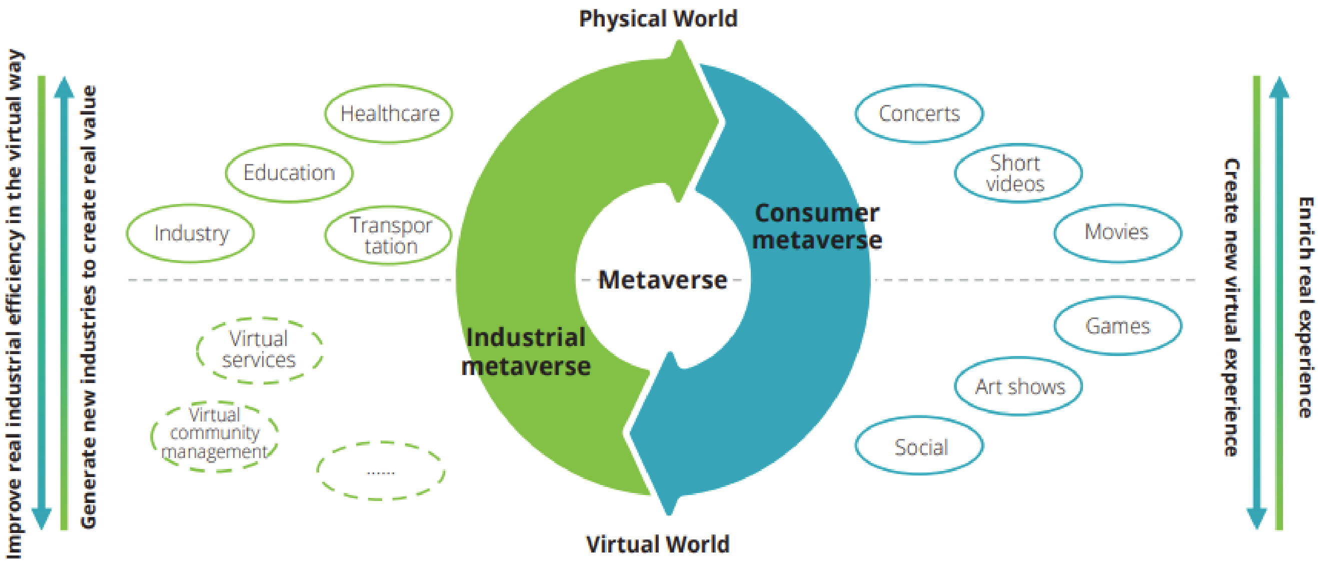

FIG. 9. Ecosystem of the Consumer and Industrial Metaverse [59]

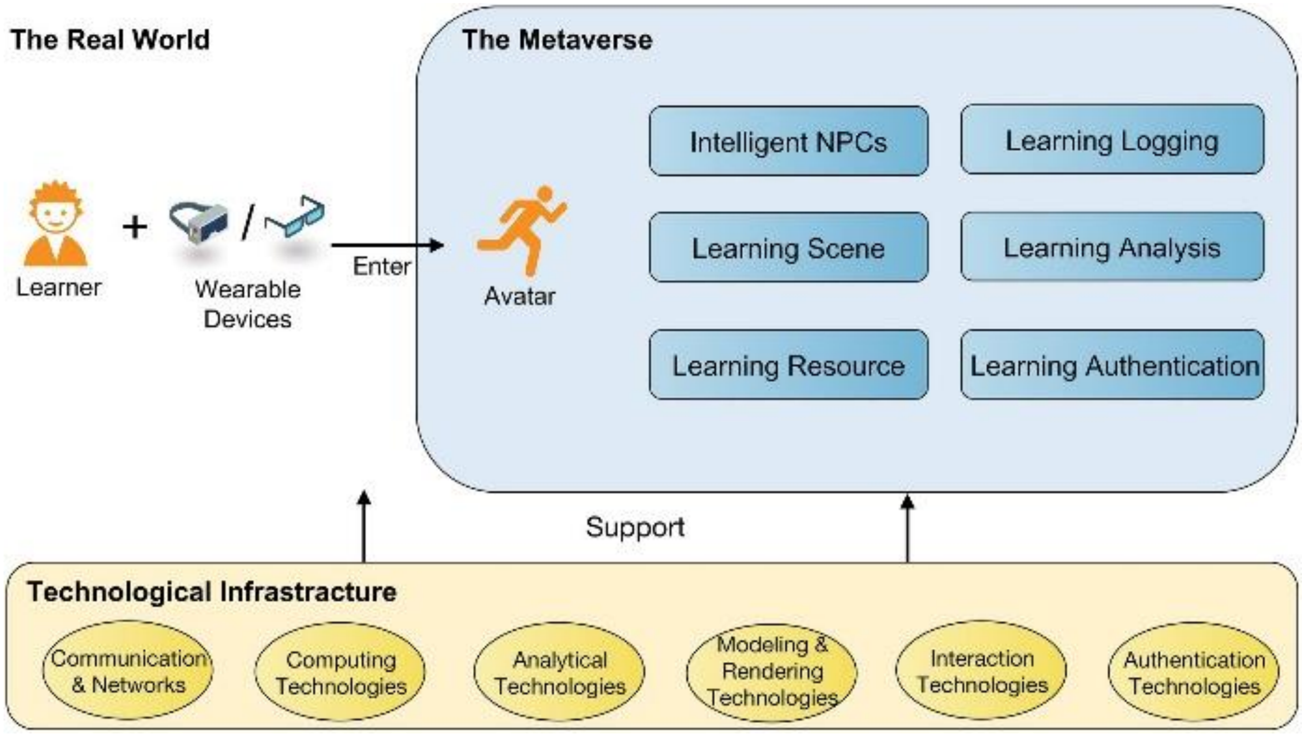

FIG. 10. The framework of metaverse in education [61]

According to our current research, 5,048 publications were indexed in Dimensions database about "metaverse", and "education" were analyzed. The bibliometric analysis performed in terms of country, keyword, author, and citations and explained in detail. However, some limitations are unavoidable. Although a huge set of publications have been analyzed, there are still more that cannot be tracked with a single database. Research papers are being added to the databases every day. Besides, in terms of language, English articles were considered only. That would eliminate a significant number of articles. Besides, preprint articles are also not included which could cover some recent update studies as well.

In terms of future work scope, it would be recommended to extend the study for other article databases such as Web of Science of Scopus databases so that the dataset can be even larger. In terms of keywords, this study guides future research keywords such as 'virtual world' and 'digital transformation'. These words or other similar concept keywords could be the scope for the future research aspects.

VI. CONCLUSION

The metaverse is perceived as an education trend as it merges with new technologies. Through effective communication while also balancing elements from the education sector, the intersection of education and the metaverse will be developed [63]. In his book, Neal

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Stephenson introduced the phrase "metaverse," which he used to describe how people would interact in a virtual world [64]. Although the infrastructure and technology are not yet in place to support the creation of virtual worlds, researchers are increasingly focusing on the metaverse's potential for transformation [65]. Industries are also going slow with the infusion of technology, maybe due to still shortage in know-how and unskilled human workforce. Although education is one of the main industries, research results for bibliometric analysis are also showing evidence of being still 'under developing' concept of metaverse. This research contributes to the scientific community highlighting directions. Top researchers and authors are among five main countries Singapore, Japan, United States, China, and United Kingdom. In terms of growing the economic impact, the emphasis on supporting technologies must be reinforced. This study guides on that scope as well. Scientific work is still limited to a handful of countries and topics are not deepen enough. Concept is still not matured or specialized in terms of research areas.

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AUTHORS` CONTRIBUTIONS

All authors have participated in drafting the manuscript. All authors read and approved the final version of the manuscript. All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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The Impact of Metaverse on Work Life: A Delphi Study

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***Abstract*— The rapidly changing and evolving technology profoundly impacts various aspects of our lives, ranging from our living arrangements and modes of transportation, to the food we consume and clothing we wear, even extending to our relationships with pets, the visions of companies, and the constitutional integrity of countries. The potential of technology to fundamentally transform our living spaces, behaviours, and habits is immense. This study investigates the relationship between working life and the Metaverse, widely regarded as one of the most significant technological advancements of our era. The Delphi technique was used as the research method in this study. Expert opinions were collected to gain insights into the key strengths and weaknesses of the Metaverse in the workplace, as well as the potential threats and opportunities it presents in working life. A total of 52 predictions were analyzed in three rounds of discussions. Although complete consensus could not be reached for six predictions concerning the weaknesses and threats posed by the impact of the Metaverse on working life, experts reached a consensus on 46 predictions.**

***Keywords*— Metaverse, Work Life, Artificial Intelligence, SWOT, Delphi**

I. INTRODUCTION

Human beings are constantly evolving and changing from the moment of birth. In today's world, the primary driving force behind human progress is our collective ability to proficiently harness technology. Efficient utilization of technology brings forth numerous benefits to humanity. However, these advantages are not equally accessible to all. Throughout history, those who have wielded the power of technology have gained significant advantages over other groups by embracing innovation and technology.

Theoretically, the possibility of establishing a connection between a human brain and a computer, generating artificial signals capable of evoking sensations, emotions, and entirely fabricated memories, raises a challenge for humans to distinguish between what is real and what is artificial. Therefore, it can be argued that the starting point of virtual reality studies revolves around the question of whether humans can discern what is genuine from what is artificial. Coined by Jaron Lanier, virtual reality is also referred to as virtual environment, cyberspace, virtual world, and artificial reality [1].

Understanding how the human sensory and perception system functions in the real world is crucial for comprehending the design and operation of virtual environments. The functioning of our sensory system relies on the nerve system within our bodies, stimulating the neurons in our brain through electrical signals, thereby triggering our perception. These signals enable us to perform mechanical movements such as blinking our eyes, lifting our feet, and chewing. All forms of information that reach our senses and nerve system are processed within our brains, enabling the perception mechanism to immerse us in the realities of life. Therefore, if the human brain is stimulated artificially, it becomes possible to experience non-existent sensations such as artificial images, sounds, smells, humidity, temperature, and tactile sensations as if they were real. When the artificially created information possesses the level of detail comparable to the perceptual capacity of human sensory organs, these perceptions can feel extraordinarily realistic.

In virtual reality, users are provide with a visual experience through a display screen. Advanced virtual reality technologies incorporate systems that stimulate multiple senses including hearing, smell, touch, temperature, humidity, and movement. Therefore, it would be incorrect to categorize virtual reality as an unreal perception. Instead, virtual reality is what users generate in their minds, outside of reality, as they interact with real-time simulations through various sensory channels such as sight, touch, hearing, smell, and taste, facilitated by special devices [2].

To grasp the concept of the metaverse, it is important to consider another significant concept known as "Augmented Reality" (AR). AR technology aims to enhance and enrich the environment through information technologies. The main distinction between AR and virtual reality is that AR enriches and diversifies the real world, while virtual reality applications completely detach users from their physical environment. A person using AR technology can witness virtual additions and diversifications within their current physical environment. AR serves as an extension of virtual reality by integrating two and three-dimensional virtual data with human-computer interaction techniques, sensing technologies, and computer and multimedia technologies, into the user's physical environment [3].

The metaverse is recognized as a novel Internet paradigm that allows people to create virtual reality through a head-mounted display, offering an immersive alternative virtual world for play, work and socializing [4]. In this virtual world, users interact through avatars, acting as their second persona, engaging with others and experiencing a real sense of presence in a three-dimensional non-realistic environment [5]. The metaverse is considered a broader concept than virtual reality.

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The term "Metaverse" was first introduced in Neal Stephenson's 1992 science fiction novel, Snow Crash, depicting a computer-generated three-dimensional virtual world where all content is created by its inhabitants. The term "Metaverse" originates from the combination of the Greek prefix "META" and the English word "UNIVERSE." The Greek prefix "META" is similar to the Latin prefix "POST" and means "itself, after, beyond." When paired with the English word "universe", it conveys the concept of "a universe beyond the universe". The Metaverse described in the book envisions a computer-generated three-dimensional virtual world. Recently, we have witnessed the potential of conducting commercial transactions using avatars in the metaverse, including buying and selling digital artworks called NFTs (Non-fungible Tokens), shopping for clothing, and attending virtual concerts and sports events, providing a genuine sense of presence. [6]. On the other hand, there are sociological studies evaluating the opportunities and threats posed by the metaverse [7].

Ball's definition of the metaverse characterizes it as a massively scaled and interoperable network of real-time rendered 3D virtual worlds and environments, offering an effectively unlimited number of users an individual sense of presence and continuity of data, including identity, history, entitlements, objects, communications, and payments [8]. In addition, Edelman defines the metaverse as a constantly existing social cyberspace where people or digital avatars can work, socialize, and hang out. The shift toward online activities, particularly due to the Covid-19 pandemic, has paved the way for the development of the metaverse universe [9].

In order to reveal how the metaverse, as a realm where people can work, will affect work life, attract users' attention and be strategically employed by organizations, it is necessary to examine potential revenue streams. According to the Marabelli and Newell, this situation can be compared to the evolution of business models with the effect of social media. Similar to the evolution of business models with the advent of social media, the relationship between working life and the metaverse exhibits similarities and differences.: (i) social media mostly works asynchronously, in 2D, and is not as immersive as the metaverse (ii) Metaverse works in 3D in real time, enabling users to interact more actively by focusing on the action performed. (iii) While social media platforms are constantly accessible via smart devices, accessing the metaverse requires wearing additional devices such as headphones/glasses, which can limit the time one can spend on the platform. This situation can be seen as a barrier to potential metaverse dependency [10].

In terms of the emergence of new business models, just as social media business models and the metaverse are similar or differentiated, there is a similar relationship between working life and remote work in the metaverse when we look at it from the point of work life. Today, many businesses have adopted remote working, online meeting, and instant messaging tools/applications. In addition, methods such as tracking mouse movements and measuring online time in the system are used to measure employee performance [11]. In the metaverse, there are similar situations in working life. Companies will be able to monitor their employees and collect huge amounts of biometric data through wearable devices [12].

The substantial and detailed data collected from metaverse business models necessiate companies in the information technology field to develop new products and make investments. Examples include providing online space rentals for companies to manage remote work, creating advertising-oriented models for retail businesses, and establishing common access protocols between platforms that allow users to move from one platform to another, encouraging online shopping and delivering immersive experiences [10].

In the study conducted by Wang et al. on remote working during the pandemic period, the main challenges faced were work-home interference, ineffective communication, procrastination, and loneliness [13]. Furthermore, working in the metaverse has the potential to create a dynamic, 3D simulation of the workplace environment, transcending the mere routine of checking mailboxes or attending meetings on online platforms.

This study aims to examine the potential effects of technological changes and the emerging new world order, particularly the metaverse, on people's work life. It investigates the root causes of negative outcomes such as increasing unemployment rates, widening social class disparities, income reductions, and decreased happiness. It seeks to answer the popular and frequently debated question of "What kind of work life can humanity expect in the metaverse?"

II. Research Method

The Delphi technique was used as the research model. The Delphi technique, which is evaluated within the scope of qualitative research method and helps to determine future predictions with specific systematic processes, aims to collect creative and reliable information from individuals by examining their decision-making processes. The Delphi technique aims to collect information from expert panelists in a structured process and shape this information [14]. The Delphi technique is a method that allows experts in a specific field to make final decisions systematically and without bias, without influencing each other, while maintaining confidentiality and anonymity during a specific process. [15]

In the first round of the Delphi study, a SWOT analysis was conducted to identify the challenges and opportunities that organizations' human resources might encounter in the workplace with the emergence of new technologies, particularly virtual reality solutions and metaverse universes. Four main questions were addressed in the SWOT analysis to determine the challenges and opportunities of using metaverse in the workplace:

- Strengths: What are the key strengths of metaverse in the workplace?
- Weaknesses: What are the key weaknesses of metaverse in the workplace?
- Opportunities: In what ways can organizations/individuals benefit from metaverse in the workplace?

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- Threats: What potential threats does metaverse pose for organizations/individuals in the workplace?

After the panelists were identified, in the first Delphi survey, they were given information about the purpose and scope of the study by one-on-one interviews and then the panelists were asked to provide open-ended responses to the four questions in the SWOT analysis.

In the second Delphi survey, the findings from the first survey were analyzed and prioritized. The participants were then asked to complete a newly created and structured five-point Likert-type measurement tool and to provide comments and explanations regarding their level of agreement with the relevant items. [16] In the third Delphi stage, the analysis of the previous outputs was conducted and the same survey as in the second stage was sent with the addition of first quartile (Q1), third quartile (Q3), median (Md), and range (R) values. The R value was obtained by subtracting the Q1 value from the Q3 value. With the answers provided by the panelists and this information, it was determined whether there were any changes or not, and the final stage was completed [17].

It is expected that the experts in the study have the knowledge and competence to contribute to the researched topic [18]. The experts involved in the research were selected by the snowball/ sampling method, one of the purposeful sampling methods. The selection of the experts to be included in the study in the snowball sample started by taking the suggestions of the Artificial Intelligence NGO management and advisory board members. The minimum number of panelists in the Delphi method is 7, and the ideal number is expected to be between 10 and 20 [16]. In the context of this study, considering the scope of the research, 15 expert panelists were selected, however, due to the intensity of their work, the study was completed with 11 expert panelists. Another important issue after determining the number of participants to apply the Delphi method was to identify the expertise and criteria of the participants. The expertise criteria sought in the participants who participated in the study were as follows:

- Having participated in virtual reality, augmented reality, or mixed reality projects.
- Being an entrepreneur or manager in the technology ecosystem.

At least one of these criteria was sought, but limited access to experts in this emerging field of Metaverse posed a constraint on this study.

The demographic data of the technology ecosystem professionals who participated in the SWOT analysis and Delphi survey evaluating the impact of the metaverse on business life are presented in Table 1.

However, panelists work in institutions operating in Istanbul, Ankara, and Kayseri. There are 4 white-collar workers and 7 entrepreneurs among the participants. Information was gathered through one-on-one interviews with individuals during the first round of Delphi, which was the SWOT analysis.

Triangulation method is used as a qualitative research strategy that tests validity by combining information from different sources. In the study, the Researcher / Investigator Triangulation method was applied while creating the questions directed to the experts and to ensure the reliability of the answers received.

TABLE I. DEMOGRAPHIC DATA OF PANELISTS

Panelist No	Age	Education Level	Occupation	Institution	Job Position
1	40	Master's degree	Economist - Financial Technologies Specialist	Bank	Manager
2	45	Master's degree	Computer Engineer	IT Firm	Chairman of the Board
3	34	Master's degree	Project Manager	IT Firm	Project Manager
4	37	Bachelor's degree	Computer Engineer	IT Firm	Founding Chairman
5	33	Master's degree	Civil Engineer	NFT Game Firm	Co-Founder
6	40	Bachelor's degree	Academician	Digital Monitoring and IT	Founding Chairman
7	33	Bachelor's degree	Civil Engineer	NFT Game Firm	Co-Founder
8	42	Bachelor's degree	Statistician	Research Firm	Founding Chairman
9	45	Doctorate	Data Analyst and Solution Specialist	TOBB	Founder/General Manager
10	33	Master's degree	Economics - IT Manager	IT Firm	Sales Manager
11	34	Doctorate	Academician / Entrepreneur	Public/IT Firm	Founding Chairman

A. Delphi Round 1

Upon evaluation of the interviews conducted with the panelists in the initial round of the Delphi method, the following key themes and strengths emerged:

Strengths

1. Quick and effective customer reach for individuals and businesses
2. Easy accessibility
3. Limitlessness
4. Enhanced communication
5. Triggering the new economy and technology
6. Efficient use of time
7. Elimination of time and space constraints
8. Accelaration of processes
9. Time-saving
10. Connecting the world together
11. Increased collaboration

Weaknesses

1. Lack of trust due to malicious individuals
2. Not everyone can adapt to digital maturity level.
3. Vulnerability in security

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4. Laziness
5. Reduced physical interaction
6. Diminished sense of belonging due to remote work
7. Elimination of regional competitive advantage
8. Absence of legal and commercial regulations
9. Performance loss due to remote work
10. High costs
11. Absence of real emotions, conscience, and feelings
12. Failure to establish ethical codes

Opportunities

1. New channel for sales and marketing
2. Effective human resources management
3. Reaching more participants with lower costs through online fairs
4. Opportunity to catch up with technology and gain a competitive edge quickly
5. Opportunity to do business on a global scale without time and location constraints
6. Providing strong communication opportunities
7. Opportunity to effectively handle any type of work from any location
8. Creating new business opportunities
9. Decrease in general expenses
10. Opportunity to pursue dreams and aspirations
11. Emergence of new business opportunities with stakeholder ecosystem
12. Formation of new business models with company mergers

Threats

1. Reputation loss due to cyber security vulnerabilities
2. Increased ease of theft, fraud, and exploitation, especially involving children
3. Traditional businesses that cannot transform losing customers
4. Unequal competition
5. Ease of manipulating society
6. The many and varied benefits of the new ecosystem will cause confusion
7. Threats to personal data protection
8. Future loneliness caused by virtual socialization
9. Social problems arising from the gap between one's true self and desired identity
10. Increased income inequality
11. Job loss for individuals
12. Potential loss of identity for children and young people.
13. Lack of authority to appeal to in case of lost or stolen decentralized wallets
14. Significant job losses due to reduced performance in remote work
15. Unhappiness stemming from excessive work without overtime pay
16. Sociological damage
17. Significant time consumption

The characteristics identified above are the expressions obtained from the SWOT analysis conducted by experts in the first Round of Delphi.

B. Delphi Round 2

In the first part of the analysis conducted using the Delphi technique, the key words that emerged from the SWOT analysis were sent to the experts as a 52-question survey in the second round of the Delphi (11 questions for strengths, 12 questions for weaknesses, 12 questions for opportunities, and 17 questions for threats).

As known, the First Quartile (Q1) is the point that separates the lowest 25% of the responses on the left and the highest 75% on the right. The Third Quartile (Q3) is the point that separates the lowest 75% of the responses on the left and the highest 25% on the right. The range (R) value is the difference between the Third Quartile and the First Quartile (R=Q3-Q1) [16]. According to [19], when the R value is greater than 1.2, it is assumed that there is no consensus among experts. The questions that had a value higher than 1.2 and on which the experts did not reach a consensus were resubmitted in the third round.

When the survey results were evaluated, it was observed that there was a consensus among the experts on the strengths of the metaverse that are thought to impact the business world, and agreement was reached. The item that received the highest number of "strongly agree" responses in the business world was the Metaverse's role in triggering new economy and technology. The most striking result in this section is the consensus that the metaverse will create a brand new economy and lead to new technological developments.

However, among experts, there is no consensus regarding the weaknesses of the Metaverse that are believed to impact the business world, as 7 questions showed no agreement. The item that received the highest number of "strongly agree" responses was the notion that the Metaverse will "reduce physical interaction". This evaluation suggests an anticipation of decreased physical interaction in the new world order introduced by the Metaverse. The most significant finding in this section is the strong consensus indicating that the Metaverse will lead to a reduction in physical interaction. The key words on which the panelists could not reach a consensus are as follows:

- Lack of trust due to malicious individuals (R=1.5)
- Diminished sense of belonging due to remote work (R=1.5)

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- Elimination of regional competitive advantage (R=2.0)
- Absence of legal and commercial regulations (R=1.5)
- Performance loss due to remote work (R=1.5)
- High costs (R=1.5)
- Absence of real emotions, conscience, and feelings (R=2.0)

There is no consensus among experts on three questions regarding the potential opportunities of the metaverse in working life. When the opinions are evaluated, there is a high level of agreement on the following points: the opportunity to conduct business globally without the constraints of time and location, the ability to effectively perform any kind of work from wherever they are located, and the generation of new job opportunities. These evaluations indicate that the metaverse will create many new industries and income streams. Furthermore, it becomes evident that there will be no limitations in terms of place and time when it comes to creating these opportunities. The questions on which experts could not reach a consensus are as follows:

- Reaching more participants with lower costs through online fairs (R=1.5)
- Decrease in general expenses (R=1.5)
- Opportunity to pursue dreams and aspirations (R=2.0)

There is no consensus among the experts on five questions regarding the perceived threats of the metaverse in working life. Upon evaluating the opinions, a substantial level of agreement is observed regarding the following views: unequal competition, feelings of isolation arising from virtual environments, and the risk of people losing their jobs. According to the experts' opinions, it is evident that, similar to opportunities, threats will also emerge in the world of the Metaverse.

- Reputation loss resulting from cyber security vulnerabilities (R=1.5)
- Ease of manipulating society (R=1.5)
- Potential loss of identity for children and young people (R=1.5)
- Unhappiness stemming from excessive work without overtime pay (R=2.0)
- Significant time consumption (R=1.5)

C. *Delphi Round 3*

In the final round of Delphi analysis, there was still no consensus among the experts on six questions out of the previous 15 questions on which consensus could not be reached. These unresolved topics consist of the weaknesses and threats of the Metaverse in working life.

- Lack of trust due to malicious individuals (R=1.5)
- Diminished sense of belonging due to remote work (R=1.5)
- Performance loss due to remote work (R=1.5)
- High costs (R=1.5)
- Unhappiness stemming from excessive work without overtime pay (R=1.5)
- Significant time consumption (R=2.0)

III. Discussion and Conclusion

The world is in a perpetual state of evolution and transformation, mirroring its history. The emergence of new technologies acts as a catalyst for this ongoing process of development. Within this context, Metaverse technology stands out as a prominent driving force that will shape the future world. The aim of this study is to unveil the impact of the Metaverse on people's working lives by utilizing a methodology rooted in expert predictions regarding the future of work within the Metaverse paradigm.

Based on the study findings, several significant aspects are believed to profoundly impact working life through the Metaverse. Based on expert predictions, the Metaverse will enable individuals and businesses to reach their customers quickly and efficiently, benefit from easy accessibility, experience boundless possibilities, strengthen communication, trigger new economy and technology, facilitate efficient time management, eliminate time and space constraints, accelerate processes, save time, connect the world together, and foster collaborations. Experts have reached a consensus on these influential aspects, which is a noteworthy outcome. The most striking result regarding these strong aspects is the consensus that the Metaverse will create a whole new economy and drive new technological advancements. These expert opinions align with existing studies in the literature, emphasizing the innovative potential of the metaverse in terms of hardware, software, and business models [10, 20, 21].

The study also identifies the weak aspects believed to impact the working life through the Metaverse. Based on the predictions put forth by the experts, the metaverse will lead to distrust due to malicious individuals, cause difficulties in adapting for everyone due to digital maturity levels, result in security vulnerabilities, promote laziness, reduce physical interaction, eliminate the sense of belonging created by remote work, diminish regional competitive advantages of companies, create problems due to the absence of legal and commercial regulations, cause performance decline due to remote work, generate high costs, result in the absence of real emotions, conscience, and feelings, and fail to establish ethical codes. The most significant result concerning the weak aspects is the prevalence of opinions stating that the metaverse will reduce physical interactions. The studies reveal that job descriptions unsuitable for working in the Metaverse vary, particularly based on individuals' digital maturity levels [10].

When assessing the opportunities, the study emphasizes that the Metaverse will serve as a novel avenue for sales and marketing, enable effective management of human resources, offer the potential to reach a larger audience through cost-effective online fairs, provide an opportunity to catch up with technology and gain a competitive advantage, remove limitations of time and space, facilitate global business operations, enable robust communication within the Metaverse, empower individuals to efficiently manage various

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tasks remotely, create fresh business prospects, reduce overall expenses, allow individuals to pursue their aspirations, unlock new business opportunities through stakeholder ecosystems, and foster the emergence of innovative business models through company mergers. Furthermore, high levels of consensus exist among the experts regarding the opportunities such as the ability to conduct global business operations without time and space constraints, the effective management of tasks from any location, and the generation of new business opportunities. It is evident from the expert evaluations that the Metaverse will create numerous new job sectors and sources of income while eliminating constraints such as time and location.

The threats believed to affect the working life in the metaverse include reputational damage due to cyber security vulnerabilities, increased risks of theft, fraud, and exploitation, particularly concerning activities involving children, traditional businesses unable to adapt losing customers, unequal competition, manipulation of society, confusion arising from the diverse benefits of the new ecosystem, threats to personal data protection and privacy, feelings of loneliness resulting from virtual socialization, societal issues stemming from the discrepancy between one's true identity and desired self-presentation, increased income inequality, job losses for individuals, loss of identity for children and young people, lack of recourse in case of loss or theft of decentralized wallets, significant job losses due to performance decline in remote work, dissatisfaction among individuals who work excessively without receiving overtime pay, social disruption, and significant time consumption within the Metaverse. Additionally, there is a high level of consensus on issues such as unequal competition, feelings of loneliness due to virtual environments, and job losses for individuals. As evident from expert opinions, similar to the opportunities presented in the real world, the metaverse will also bring forth potential threats to individuals.

Some of the points that experts agree on as a threat are inconsistent with recent studies. For example, in a study of Young Metaverse users in Korea, it was concluded that emotional touch through avatars in Metaverse would enhance the sense of social presence, encourage supportive interactions, and thus improve social connections between users. Also, similar studies reported the benefits of using the virtual environment to reduce feelings of loneliness [22][23][24].

The study concludes with six unresolved questions related to the weak aspects and threats of the Metaverse's impact on the working life. These issues are as follows: lack of trust due to malicious individuals, loss of sense of belonging due to remote work, performance decline due to remote work, possibility of high costs, unhappiness stemming from excessive work without overtime pay, and significant time consumption. The presence of unresolved issues reflects a significant divergence of opinions among experts. While some experts fully agree with these points, others hold contrasting viewpoints.

When analyzing these specific concerns, the lack of trust resulting from malicious individuals emerges as a current challenge during the early stages of the Metaverse, primarily due to the incomplete implementation of certain security measures.

The view that remote work may lead to a decline in performance is another unresolved issue. However, some businesses, particularly during the pandemic, have demonstrated that workers' productivity has increased. The productivity increase observed in these studies encompasses the period of the pandemic and subsequent years. Although average productivity when working from home remains lower than in-office work, it shows a gradual incremental improvement over time. This phenomenon is attributed to employees' growing familiarity with digital platforms [25][26]. Consequently, this circumstance has led to a lack of consensus among experts regarding the extent to which metaverse business models will impact productivity. The Metaverse incurs certain investment costs due to being a new technology, but it also eliminates the physical cost of gathering people from different parts of the world in one place. Climate change presents another scenario where physical gatherings come at a cost. Recent research indicates that wider adoption of the metaverse could potentially contribute to a reduction of up to 0.02 °C in global surface temperature by the end of this century and lead to a decrease of up to 10 Gt of CO_2 in greenhouse gas emissions [27]. Since it can increase costs in some areas while reducing them in others, there is no consensus among the experts regarding this view.

In remote work systems, the concept of working hours can be more flexible. People typically perform their tasks within specific time intervals at their workplaces and resume their work from where they left off on the next workday. However, in remote work systems, especially for individuals who do not change their working environment at home, the notion of working hours can sometimes change. Dissatisfaction arises when individuals who work longer and at different hours compared to their traditional office hours do not receive overtime pay. There is a divergence of views from the employer's perspective. People experience some discomfort in adapting to the new system. This topic is also an unresolved issue among experts.

The unresolved viewpoint on "significant time consumption" hinges on the nature of the activities or work individuals undertake in the Metaverse, determining whether they are productive or unproductive. If individuals utilize their time in the Metaverse for skill development, work-related tasks, or creative endeavours, it may not be perceived as wasteful. Generally, people tend to worry about the unknown. The present world provides people with ample opportunities to access information, enabling them to gain new skills. People, just as they have done in the past, adapt to challenges, problems, and changes that arise with the passing of time. New professions and sectors emerge. Especially with the accelerated growth of the creative economy, particularly after the pandemic, individuals can be both employees and entrepreneurs. For instance, the concept of gaming has gained more recognition with the Metaverse. While gaming used to be associated with activities that people, especially children, engaged in when they were bored, it has now transformed into a trillion-dollar industry. Businesses have started incorporating gamification into their marketing, production, and advertising activities.

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Based on extensive discussions with experts, the findings strongly suggest a widespread belief in the Metaverse's potential to generate new economic and job opportunities. Just as previous technological advancements have rendered certain jobs obsolete, the advent of "Metaverse technology" is expected to have a similar effect. However, it is anticipated that this technology will also give rise to a multitude of new fields and employment opportunities. In this context, the study examines the relationship between the Metaverse and working life from various perspectives.

When evaluating the unresolved issues in the final round, differences in perspectives become apparent. While there is currently a lack of sufficient research in the field, it is important to note that the topics of Metaverse governance, ethics, safety and security, acceptable behaviors, and privacy are essential areas that warrant exploration in future studies [28]. This study aimed to identify and prioritize agreed-upon topic headings related to the impact of the Metaverse on working life using the Delphi method. These topics were then opened up for further discussion within the framework of working life. Future studies could expand the scope of participants involved in the Delphi analysis by including professionals in decision-making or stakeholder positions from the public sector, civil society organizations, and the private sector, thus diversifying the findings. Furthermore, it is recommended to apply the Delphi method to explore more specific topics such as "future new professions with Metaverse technologies".

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CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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The 4 Epochs of the Metaverse

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Abstract — ***The concept of the Metaverse has attracted considerable attention since 2021, primarily due to the rebranding of "Fakebook" to "Meta" and its promise of delivering a more immersive online experience. However, the origins of this term can be traced back to Neal Stephenson's sci-fi novel, "Snow Crash", published in 1992. In the current study, an extensive articles review has been conducted, including academic sources, technology blogs, business reports, and social media posts. The main goal is to create a comprehensive timeline of the Metaverse and its underlying technologies. By categorizing 26 significant milestones into four distinct periods, the study introduces a framework called "4 Epochs of the Metaverse." The suggested framework challenges previously established linear timelines found in literature by identifying time periods that are based on content, rather than on chronological order. The findings emphasize that the Metaverse is not a new phenomenon, but, rather, a concept that has evolved over time since 1905 and can be classified under 4 dynamic periods, which are named Epochs. The study provides an in-depth description of the origins and evolution of the Metaverse, serving a dual purpose for researchers and practitioners: it provides insights into the transformative potential and future possibilities of the metaverse, while it lays the groundwork for further exploration and innovation in this phygital (physical + digital) environment.***

***Keywords** — Metaverse, blockchain, NFTs, timeline, digital twin*

I. INTRODUCTION

Over the past few years, there has been a notable explosion in interest surrounding the metaverse, especially following the rebranding of the social media giant "Facebook" to "Meta" [2], [8], [25], [45], [98], [112]. The company has made claims that the new platform will offer an even more immersive internet experience, where users will be able to actively participate in the virtual environment rather than simply observe it [75]. Following this announcement, a great number of people related the term "metaverse" with the social media company "Meta" and due to their lack of previous knowledge, it is widely believed, until the time of writing this study, that the metaverse is a new social medium. For this, it is important to note at this point that the term "metaverse" did not suddenly appear in 2021, nor should be associated with any particular company or platform. The origins of metaverse can be traced back to the year 1992 in Neal Stephenson's science fiction novel, ''Snow Crash'' [11],]27], [63], [78], [82]. In fact, the notion of metaverse extends even further into the past, as revealed by the current research. According to Stephenson, the metaverse is a virtual world that coexists alongside the physical realm. In his book, individuals interact with metaverse through digital representations called "avatars" [97]. Within the metaverse, people can engage in work, generate income, perform daily tasks, access information, socialize, join leisure activities, interact with others, and explore diverse locations, as if they were in the physical world. Direct linkage and collaboration between the world of metaverse and the real-life world is of major importance, involving avatars controlled by human users and Artificial Intelligence (AI)-powered agents. These agents are avatars guided by lines of code, rather than human operators. They offer various services, such as information search and provision.

Stephenson's depiction of the metaverse in 1992 aligns with recent plans proposed by big corporations regarding its characteristics, way of use and potential benefits for its users. Nevertheless, there is a notable difference between the initial portrayal of the metaverse and how it is currently envisioned by developers, academics, and entrepreneurs. The difference lies in the technological advancements that have taken place from 1992 to the present day. These advancements involve the development of blockchain technology and its associated applications, such as smart contracts, decentralized applications (Dapps), cryptocurrencies, oracles, lifelogging, and Non-Fungible Tokens (NFTs), among others [56]. Apart from blockchain, other technologies including high-speed (5G-6G) connectivity, digital twins, mirror world, avatars, virtual reality (VR), augmented reality (AR), mixed reality (MR), and numerous others have furtherly fueled optimism among experts regarding metaverse's future capabilities and its widespread adoption [56], [57]. Some of the above technologies, such as VR, avatars, AI, high-speed connectivity, and fog computing to name some, were implied or directly mentioned in the initial concept of the metaverse by Neal Stephenson, while others have been later explored and incorporated, and now serve as essential components of it. An excellent illustration is the birth of NFTs: Although the first description of the metaverse in 1992 did not include any reference to NFTs or any assets with similar characteristics, nowadays, it is almost impossible to engage in discussions about the metaverse without acknowledging the significant role of NFTs in providing ownership rights. On the other hand, the collaboration between humans and AI-powered agents for rapid and accurate information access and critical discussions, as depicted in "Snow Crash", has only recently appeared in the real world. It is more than characteristic the scene where *H. Protagonist* (the protagonist figure in the book) has long discussions with the *Librarian*. The latter is an AI entity that assists *H. Protagonist* in his research [58]. In fact, *Librarian* is a vast digital repository, while he possesses the ability to navigate through oceans of information within seconds [58], [97]. The emergence of human-AI collaboration today coincides with the boom of generative AI applications in late 2022 and the onset of 2023, with the widely known application "ChatGPT" playing the role of *Librarian*.

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At present, the metaverse is predominantly a conceptual advancement or, better, a theoretical leap forward rather than a reality. Despite this, the gaming industry has enthusiastically embraced the idea of evolving multiplayer virtual worlds into metaverse environments. Moreover, gamers appear more than eager to follow this shift and immerse themselves in a novel experience. A study conducted by Ernst & Young indicates that the metaverse has the potential to revolutionize the gaming industry and introduce new business models to the real world [33], [61], [96]. Examples of such models are already emerging, such as Play-to-Earn (P2E) games or Run-to-Earn (R2E) mobile applications. P2E games or R2E applications use blockchain technology and reward users' performance with cryptocurrencies (tokens) that can be traded for other cryptocurrencies or exchanged for national currencies, in other words, they are games that can be a source of income for the user. Another potential of the metaverse lies in enabling hyper-realistic virtual conversations, experiences, and transactions. As the COVID-19 pandemic unveiled the benefits of digitization, with people having to meet [34], learn, have fun, socialize, seek consultation, and engage in online interactions [4], it is evident that the metaverse appears as a clear answer to how the future will look like.

To gain a deeper understanding of the ever-evolving concept of the metaverse and its ongoing development, it is imperative for researchers and practitioners to explore its origins, the historical progression of its components and the overall development of the metaverse as a cohesive entity up to the present. Understanding its roots and the path it has traversed over time is essential for harnessing its full potential and addressing the challenges it may present. In this regard, the current research makes a significant two-fold contribution. Firstly, it aims to uncover the roots of the metaverse by presenting a comprehensive and detailed timeline, shedding light on the milestones and key developments that shaped its evolution. This historical context not only highlights the metaverse's journey but, also, reveal the factors that have propelled its emergence. Secondly, this paper builds a dynamic framework that categorizes significant milestones of the metaverse's evolution into four distinct periods, referred to as ''Epochs''. By organizing the history of metaverse into these Epochs, researchers, developers, and enthusiasts can gain a clearer perspective on its continuous evolution.

II. METHODOLOGY

In addition to academic literature, the authors of the current study conducted an extensive articles review encompassing various sources such as technology blogs, business reports, social media posts, and webpages of tech corporations, all relevant to metaverse. For this purpose, two academic databases, namely "Research Gate" and "Google Scholar" were employed. From these two sources a sum of academic articles was collected, which were later screened for their relevance to the topic of metaverse. Irrelevant papers, along with duplications were excluded. Similarly, internet scraping was employed to gather business reports, social media posts and blog articles related to metaverse. For all the searches, the following keywords were utilized: "metaverse", "metaverse" AND "history", "history of metaverse", "metaverse" AND "timeline", "metaverse timeline", "metaverse" AND "evolution", "metaverse evolution", "metaverse" AND "milestones'' and "metaverse" AND "events".

Building upon the findings of previous researchers who identified VR, AR, blockchain (including cryptocurrencies, smart contracts, and NFTs), digital twins, mirror worlds, and edge computing as key underlying technologies of the metaverse [16], [25], [30], [57], the current research aims to examine the historical development of all these elements and their integration in shaping the concept of the metaverse. The collection of both academic and non-academic articles played a vital role in identifying events and inventions of great importance for the history of metaverse. Additionally, this approach not only aided in confirming and triangulating the inclusion of these milestones in the timeline of metaverse, but, also, enhanced our understanding of these events and their influence on the metaverse. Finally, the articles review method with academic and non-academic literature sufficiently facilitated the categorization of each event within the corresponding Epoch.

III. BUILDING THE METAVERSE TIMELINE

A. *The History of Metaverse (1905-2000)*

Although the concept of the metaverse was initially introduced in 1992, the idea of creating a virtual world that exists alongside and / or replaces the reality has roots that go long further back. The history of the metaverse can be traced back to the early 20th century, specifically in the science fiction short story "The Machine Stops" by E.M. Forster, published in 1909 [45], [70]. The story depicts a dystopian future, in which people live underground in cells, and rely on a machine (the ''Machine'') to fulfill their every need. "The Machine" allows them to control the temperature and lighting of their rooms, to virtually travel, to communicate with each other, to work, or search for information. However, this universal virtuality and dependence on technology ultimately influence the psychology and behavior of people in Forster's world. For example, a character all surprisingly expresses a desire for face-to-face interaction, complaining about the limitations of technology in truly connecting people [39] (p.2). It is worth noting that this story was written in response to E.G. Wells's work, "A Modern Utopia" [37], [48], [55], [90], which was published four years prior to "The Machine Stops", in 1905. Wells presented a parallel world, a second Earth, that was an idealized version of the real world, free from the flaws and limitations of reality. Wells aimed to describe an utopian society through his writing, focusing on designing an improved and desirable way of life [107] (p.8). E.M. Forster, in turn, sought to respond to Wells's vision by presenting his own version of a parallel virtual world, with technology leading to a dystopian future. In essence, Forster attempted to demonstrate how the machine-centered society, envisioned by Wells, would exacerbate pain, fear, and anxiety instead of alleviating them [37]. Thus, according to the current extensive articles review, the origins of the metaverse as a concept can be traced back to the science fiction literature of 1905 and 1909, where the ideas of a parallel world are presented in both utopian and dystopian forms, expressing expectations and fears for a world where technology defines reality. However, some researchers argued that the terms

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"dystopian" and "utopian" cannot be used separately for these two works, as *"...the effectiveness of dystopian fiction depends upon its invocation of utopia as its mirror image*" [90] (p.56).

The next milestone in the realization of the metaverse can be found in the science fiction short story "Pygmalion's Spectacles" by S.G. Weinbaum, published in 1935. The story depicts virtual reality for the first time [89] and explores the idea of users escaping from the physical world to such an extent, that they question the nature of reality itself. The protagonist experiences a story with all senses engaged, where he becomes part of the narrative and interacts with the virtual environment to such a degree that he is left in doubt whether his encounter was a mere illusion or a real event [106] (p.3). According to [59], "Pygmalion's Spectacles" is considered the starting point of the metaverse. It not only presents the concept of virtual reality technology and user's full immersion, as it was imagined by S.G. Weinbaum, but, also, describes the impact of such an experience on the protagonist, who begins to question the boundaries between truth and illusion, between dreaming and reality [106]. Related to virtual reality, in 1939, the first non-digital virtual reality device, known as the "View-Master" [47], was introduced at the *New York World's Fair*. This device aimed to "travel" users far from their physical surroundings. It consisted of a pair of eyepieces that displayed a series of color images mounted on a rotating circular cardboard base. This invention marked an early attempt to create an immersive experience for users. Two decades later in the history of the metaverse, another notable advancement emerged in the technology industry. In 1962, Morton Heilig developed the simulator "Sensorama" [35], [53], [78], [94]. Users were offered a groundbreaking simulation of a motorbike ride through the streets of New York City, with 3D graphics, a vibrating seat, realistic sounds, and authentic odors. "Sensorama" could even create the feeling of wind on the rider's face, rendering it an immersive experience [10], [59], [78]. Later, in 1968, Ivan Sutherland developed the "Sword of Damocles", the first portable virtual reality device that resembled today's VR headsets. The name of the device was inspired by the mythological *Sword of Damocles*, as it was large, heavy, and hung from the ceiling before connecting to the user's head [78], [105]. The "Sword of Damocles" integrated the latest virtual reality advancements of its time, introducing the novel feature of portability.

In the 1970s, the gaming industry introduced the idea of users exploring and joining adventures in virtual worlds and presented the concept of self-representation within those environments to the public. This began with the popular tabletop role-playing game "Dungeons & Dragons", which was created by the American game designers E.G. Gyrax and D. Arneson in 1974 [27], [67]. This idea brought the world one step closer to metaverse, as it introduced the concept that fantasy worlds not only exist and can be visited (as it happened in the 1960s) but one can live and perform tasks and activities in there, same as in the real world. A few years later, proto-digital virtual worlds called "MUDs" (Multi-User Dungeons) and "MUSHs" (Multi-User Shared Hallucinations) emerged, with "MUD1" being the first digital virtual world in 1978 [26], [32], [72]. In the same year, the *Massachusetts Institute of Technology* (MIT) presented the "Aspen Movie Map", a virtual navigation program that allowed users to explore the city of Aspen in Colorado [59], [71], [103]. This marked the first successful attempt of virtual reality transporting users to a real place. Conversely, the video game "MUD1" immersed users in non-real locations by presenting text-based scenarios and commands on a computer screen [27]. In the years to follow, several video games capable of hosting larger numbers of players followed "MUD1", including "AberMUD" in 1987, "tinyMUD" in 1988, "LPMUD" in 1989, and "DikuMUD" in 1990 [27].

Three years after the release of "MUD1", the publication of "Simulacra and Simulation" by the French sociologist and philosopher Jean Baudrillard, in 1981 [59], represents another significant milestone in the evolution history of the metaverse. Baudrillard identified and described the state where simulation replaces reality rather than merely reflecting it. In this way, simulation is perceived as reality [21]. This body of work by Baudrillard can be seen as the foundation of immersive experiences, a core characteristic of the metaverse. The author states, "*The territory no longer precedes the map, nor does it survive it. It is nevertheless the map that precedes the territory... it is no longer a question of imitation, nor duplication, nor even parody. It is a question of substituting the signs of the real for the real*" [36]. At the same time, in the film industry, "Tron" was released in 1982 and introduced viewers to the concept of becoming completely immersed in virtual reality [19], [35]. In essence, "Tron" visualized the work of J. Baudrillard and furtherly familiarized the audience with the idea that virtual worlds can entirely replace and define reality through full immersion. Two years later, in 1984, the science fiction novel "Neuromancer" by William Gibson introduced the term *cyberspace* for the first time. *Cyberspace* refers to any online digital environment directly linked to the real world, highly resembling metaverse [13], [26], [35], [100]. W. Gibson defines cyberspace as "*a consensual hallucination experienced daily by billions of legitimate operators, in every nation, by children being taught mathematical concepts... A graphic representation of data abstracted from banks of every computer in the human system*" [42] (p.56). This quote can perfectly describe the metaverse, as described so far, from a rather technical aspect. It is worth noting that three years prior, in 1981, Vernor Vinge's novel "True Names" had influenced both W. Gibson in writing "Neuromancer" and later Neal Stephenson in the creation of "Snow Crash" [13], [27]. "True Names" and "Neuromancer" introduced readers to the use of electronic computers for accessing virtual realms that were as real as the physical world. These virtual realms maintained a direct connection to the physical world, meaning that actions taken by users in the virtual environments had real-life consequences. It cannot be ignored the description of "Neuromancer" from [44] as "*a conceptual world where words, human relationships, data, wealth, and power are manifested by people using computer-mediated communication technology*" (p.313). The final milestone of the 1980s took place in 1986, with the release of the videogame "Habitat". The game built upon the concept of existing and acting within a virtual world enabling users to interact in real-time. It was the first multiplayer role-playing game with a graphical environment (not solely text-based like "MUDs") for Commodore 64 (8-bit) computer models. The

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novel element brought by "Habitat" was the introduction of the term "avatar" [26]. The game made its users familiar for the first time with the idea of visually represent themselves in a virtual environment, a fundamental necessity for the metaverse.

The 1990s can be recognized as the pivotal decade in the timeline building of the metaverse, since the very term was established by the creator of “Snow Crash” in 1992. However, a year earlier, Dr. D. Gelernter, a computer science professor at Yale University, presented the theory of *Mirror Worlds* in his book of the same name [52]. The concept of *Mirror Worlds* revolves around creating accurate digital replicas of systems, whether they are small entities such as companies or larger entities such as cities or, even, destinations. Mirror Worlds, according to their creator, serve simulation, testing, and information gathering purposes [41]. The significance of this milestone is paramount for the evolution of metaverse, given that every physical destination can potentially be replicated as a Mirror World in the metaverse, granting users the ability to virtually visit it with their avatars. Apart from Mirror Worlds, during the same year, the internet took shape in its present form, offering users the ability to create content and engage in secure online transactions [26]. This evolution paved the way for the emergence of various virtual worlds in the form of websites. Some of these include “Cityspace” in 1993, “CyberTown”, “Worlds”, and “ActiveWorlds” in 1995, “Online Traveler” in 1996, and “There” in 1998 [3], [27], [60], [67], [80]. These platforms not only delivered gameplay experiences similar to multiplayer video games, but, also, offered opportunities for online socialization and interaction among users. Players of these games had the chance to interact with fellow internet users within the same virtual environment, initiating a new trend: socializing and making connections with both familiar and unfamiliar individuals in virtual worlds, mirroring real-world interactions. During the 1990s, strangers could build friendships in virtual realms through their avatars and meet as friends in the real world.

In 1996, the interconnection between real and virtual worlds was further illustrated in the sci-fi book series "Otherland" by Tad Williams [73], [88], [102]. This series of books insisted on the idea that actions taken in a virtual world could have irreversible consequences in the real life, which is a fact for the metaverse, as described by N. Stephenson. One year later, in 1997, following the trend of the time, the first social network on the Internet, called “Sixdegrees”, was established [59]. This platform encouraged users to build online friendships and reconnect with old schoolmates, based on the idea that each person's group of friends could be utilized by others to find common acquaintances [91]. Online socialization has emerged as the predominant trend of this decade, encouraging individuals to make use of technology for their interactions, either for business or recreational purposes. Finally, 1999 the movies "The Matrix" and "The Thirteenth Floor" succeeded in popularizing the notion of virtual worlds to the extent of mainstream. These films reached a much broader audience beyond merely video game enthusiasts, challenging the imagination of viewers. In the same year, internet users experienced live voice chats within a virtual environment. It was achieved by the creators of the video game “SissyFight2000”. Overall, the 1990s undeniably shaped the vision of metaverse through the realm of gaming, the film industry, and the literature. The last decade of the previous century effectively acquainted the public with the fundamental essence of the metaverse: interactions through digital representation in real time, even with sound, which can have direct impact on real life. Consequently, it comes with no surprise that 1990’s established all the core characteristics of the metaverse, as it is currently envisioned.

B. The History of Metaverse (2000-2023)

In the new millennium, the development of various platforms in the logic of metaverse took place, such as “Habbo Hotel” in 2002 [32], [92]. Two highly important platforms followed, “The Sims” [2], [12] and “Second Life” in 2003 [3], [11], [27], [64], [68], [80], [92], [105], with the latter being widely considered as the closest and most popular representation of the metaverse up to that date. Of course, myriads of online games with remarkable graphics and the ability to accommodate a great number of users are emerging at the same decade, such as such as “Lineage II”, “World of Warcraft” [12], [15], or “League of Legends” [84]. What sets “Habbo Hotel”, “The Sims” and “Second Life” apart from multiplayer online games of the same decade, is that the primary goal of online games focuses on accomplishing missions and following predefined storylines [17], [57]. In contrast, in the cases of “Habbo Hotel”, “The Sims”, and “Second Life”, users were invited to live a parallel life in a virtual world, alongside their real one, without being confined to any predetermined scenario. "*The distinction lies in the focus on the social nature of virtual worlds, without the inclusion of 'game' elements as the primary defining rules of the space*" [95] (p.4). As a result, the present study delineates a substantial differentiation between online games and the metaverse. Due to this distinction, famous multiplayer online games that researchers may refer to as “metaverses” are omitted from the current metaverse timeline. It is important to emphasize that labeling a platform as a “metaverse” is based not only on its technical attributes but also on its intended purpose of use.

In search for more milestones in the new millennium, the current paper highlights the introduction of the concept of “Digital Twins” by Dr. M. Grieves in 2002. By 2003, the *University of Michigan* began offering lessons on this topic [9], [43], [49], [86]. The term “Digital Twin” refers to a precise digital representation of a physical object. Since the notion of “Digital Twin” closely aligns with that of “Mirror World” a further explanation is needed at this point: The concept of “Digital Twin” describes a single entity that can be digitally represented, while the latter refers to a group of digital twins operating as a system and collectively represented. For instance, the accurate depiction of a hotel in a virtual world can be termed as the digital twin of that specific hotel. The collective assembly of digital twins of every hotel or other infrastructure of the destination in the same platform, forms the Mirror World of the destination. As of the writing of this paper, digital twin technology has not yet been fully integrated into any metaverse platform, due to increased technological requirements, although it is considered a fundamental characteristic of the metaverse. With "fully integrated" the current research refers to seamless flow of information between the physical and digital

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counterparts beyond just the graphical representation of the physical part. Therefore, in the previous example, if a user visits the physical hotel and makes a room reservation, the digital twin of the hotel will display that specific room as booked for users on the platform. The same applies to the Mirror World, but on a larger scale.

In 2006 "ABN AMRO" becomes the first European bank to appear on the metaverse-oriented platform "Second Life", following the digital twin concept [85]. This move initiates the metamorphosis of the metaverse from a space primarily for gaming and social interaction to a space where users can discover a wider range of possibilities, closely related to their everyday lives. In that same year, the launch of the virtual space "Roblox" took place [51], [67], [69], [76], [111], allowing users not only to build a variety of games accessible to other users, but also to organize events, such as parties and concerts. Up to the present day, during these events, users have the opportunity, for instance, to attend real-time concerts of their favorite bands alongside their friends. For the first time "Roblox" fulfilled a major expectation about the metaverse, that it should have a dynamic nature. This means that users could interact not only with one another, but also with the virtual environment they immerse themselves in. It is noteworthy that the first concert in the metaverse was held in 2020 featuring the artist Travis Scott on the "Fortnite" platform, followed by pop singer Ariana Grande in 2021, also hosted on "Fortnite" [11], [27], [32], [84].

In addition, "Roblox" contributed to the use of metaverse as a means for users to generate income, thereby reinforcing the direction, initially introduced by "ABN AMRO", that the metaverse should serve a variety of purposes beyond mere entertainment. At this point it is important to note that users' earliest attempts to generate income through virtual worlds dates as far back as 1993, with the game "Cybercity". In that game users could trade items in-game with other users. However, a great difference exists between the early attempts, such as "Cybercity", and the modern approach of to income generation by "Roblox": In the former case, virtual world did not organically support income generation; it was rather users' ingenuity that allowed them to trade in-game items for real money. On the contrary, "Roblox" not only officially allows but, even, encourages its users to generate income by building applications within the platform. Following "Roblox", similar virtual spaces emerged, such as "Sandbox" in 2011 [11], [27], "Decentraland" in 2015 [11], [100] and "Fortnite" in 2017 [2], [12], [32]. These platforms provided users with various ways to generate income, including cryptocurrency trading, digital assets trading, advertising products or services, earning rewards by participating in games or activities within the platforms, and numerous other avenues. In more detail, by adopting blockchain technology, "Decentraland" and "Sandbox" allow users to connect their digital wallets to their platforms and engage in transactions using the platform tokens ("MANA" and "Sand," respectively). They also allow them to buy and sell pieces of digital land in the form of NFTs. This signifies the essential contribution of blockchain as an underlying technology of the metaverse. Beyond providing users with opportunities for income generation, "Second Life", "Roblox", "Sandbox", and "Decentraland" have fostered a real-world economic ecosystem: These platforms attracted the interest of well-known commercial firms, which have established a presence and initiated operations, focusing on addressing the needs of avatars rather than their operators. As a result, users can purchase accessories in the metaverse for their avatars [7], [12], [30], [62], [81], [87], on the base that avatars in a virtual world have the same needs as humans in the real world. The new norm introduced by these four pioneer platforms has, essentially, created a parallel economic sphere alongside the physical world, illustrating the ontology of the metaverse as a parallel reality, consistently with its original vision.

Regarding blockchain technology and its role as an underlying technology, it is important to recognize that a series of innovations in the field were utilized to expand the potentiality of the metaverse. The creation of *Bitcoin* in 2009 by Satoshi Nakamoto [6], [14], [23], the establishment of the *Ethereum* network in 2014 by Vitalik Buterin [23], the development of smart contracts on the blockchain by Vitalik Buterin in 2014 [50], and the creation of NFTs in 2015 [6] facilitated the realization of agreements, transactions and items trading within the metaverse. It needs to be clarified that smart contracts were initially conceptualized by cryptographer N. Szabo in 1994. Nonetheless, in the timeline presented in the current paper, smart contracts are chronologically positioned in 2014, refering to the initial practical implementation of this application on the blockchain. Adding to the diverse range of roles that the metaverse is anticipated to play, in 2007, the platform "Second Life" hosted the first university lecture, delivered by Dr. Rob Bloomfield, a renowned accounting professor from *Cornell University*. The lecture focused on *Economics in the Metaverse* [20], [29], [110]. Up to that time, "Second Life" was the first platform to showcase the ability of metaverse to revolutionize education, however, in the following years a variety of universities and colleges were represented on "Second Life" or other similar platforms for either educational or promotional reasons.

In 2009, the concept of "avatar", the visual representation of a user in a virtual world, was introduced to the public through the widely popular movie "Avatar" [35], [88]. Before that movie, the term "avatar" was familiar only within gaming circles or among tech-savvy communities. Two years later, in 2011, Ernest Cline's sci-fi novel "Ready Player One" further popularized the idea of interacting through avatars in a metaverse environment. This idea was later brought to the big screen by Steven Spielberg in 2018, when the novel adapted into a film under the same title [11], [22], [100]. The storyline portrays users living and interacting in the metaverse through their avatars, using computers and portable devices [105]. In fact, "Ready Player One" was the visualization of how N. Stephenson described the metaverse in "Snow Crash".

Another significant milestone in the metaverse timeline is the creation of the first NFT in 2014, named *Quantum* by artists Jennifer and Kevin McCoy. Since then, NFTs became a prominent feature of the metaverse [46], primarily due to their tradeability in combination with their ability to grant ownership rights to their holders. "Sotheby's" auctioned *Quantum* in June 2021 for $1.472 billion, describing it as "*universally regarded as the first NFT ever created*" [104]. According to "Sotheby's" website: "*these prime movers*

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occupy a singular position in art history. They came first. Kevin McCoy's Quantum is such a work" [93]. Continuing with milestones that shaped our vision of metaverse, the speech of the President of France within a metaverse environment cannot be overlooked. In October 2022, *Emmanuel Macron*, delivered a real-time speech to an audience of avatars on the virtual world platform ''Decentraland'' [24]. Thus, the range of purposes that metaverse can cover expands even to nation-wide communication and delivery of political messages. In the same year, three reputable universities, namely *University of Nicosia* in Cyprus, *University of Nanjing*, and the *Hong Kong Polytechnic* in China—incorporated the concept of the metaverse into their curriculum, by offering master's programs focused on this subject. The recognition of the metaverse as a research-worthy topic was further evidenced in 2021 through the establishment of the *Journal of Metaverse*, the first academic journal dedicated to this field and the "AIRSI2022" scientific conference in 2022. "AIRSI2022" was the first academic conference to take place within a metaverse environment, where participants utilized avatars to present their research and interact with one another.

Finalizing the collection of milestones that shaped the metaverse to the present day, the year of writing this paper, 2023, includes two pivotal events: Firstly, AI-empowered avatars made their debut for public use, with the company "DeepBrainAI" creating *Prof. AI Human*, a digital twin of a university professor equipped with deep learning abilities. This allowed the digital replica of Prof. Kim to deliver lectures and respond to stimuli much like a real person. Secondly, the first court hearing on the metaverse occurred at the "Magdalena Administrative Court" in Colombia, where everyone involved was represented by their avatars. These two milestones expand even further the diverse range of applications of metaverse platforms. As already mentioned, since 2006 that metaverse has proved its capability of extending beyond its conventional use in gaming and socialization. The latest milestones reveal the almost limitless potential of applications in everyday life, on the condition that technology can efficiently support new ideas. In addition, the milestones presented in this paper emphatically confirm for once more that the metaverse can constitute a digital reflection of real life, in every aspect of it.

C. The Metaverse Timeline

The timeline proposed within the current research is illustrated in Figure 1. The *Metaverse Timeline* has included 26 milestones with great impact on bringing the metaverse closer to the envisioned concept of the past. The milestones are chronologically presented in Figure 1 as following: "A Modern Utopia" in 1905, "The Machine Stops" in 1909, "Pygmalion's Spectacles" in 1935, "Sensorama" in 1962, "Tron" in 1982, "Neuromancer" in 1984, "Habitat" in 1985, "Mirror Worlds" and "Snow Crash" in 1992, "Otherland" in 1996, "The Matrix" in 1999, "Habbo Hotel" and the theory of *Digital Twins* in 2002, the launch of "Second Life" in 2003, the launch of "Roblox" in 2006, the movie "Avatar" in 2009, the sci-fi novel "Ready Player One" in 2011, the first NFT in 2014, and the use of smart contracts in Ethereum network in 2015.

Furthermore, the timeline incorporates significant events, as the first ever concert on a metaverse-oriented platform and the launch of "Decentraland", both occurring in 2020. In the subsequent year, 2021, entries refer to the rebranding of "Facebook" to "Meta" and the establishment of the first academic journal *Journal of Metaverse*. In 2022, the timeline includes the first national leader's speech, the initiation of university masters' classes on the metaverse, and the hosting of "AIRSI2022". In the same year, the first attempt of a mirror world is highlighted: The digital representation of the entire city of Seoul. Finally, the year 2023 includes the first court hearing on the metaverse and the emergence of a virtual human professor. This AI-empowered avatar has been trained using the knowledge and personality traits of a human professor and is employed for educational purposes, effectively replacing the human professor.

IV. An Overview Of Metaverse Timelines

Despite its relatively recent emergence in academic literature, the metaverse has already become a subject of interest with researchers aiming to identify crucial milestones and establish robust timelines. The metaverse timeline suggested in this paper sheds light on the metaverse journey over the past 118 years, commencing with its initial conceptualization in 1905 and progressing to the present day. The significance of every milestone included in this timeline has been extensively discussed in the previous chapter. It is worth noting that, at the time of writing this paper, the metaverse has not been fully realized as envisioned by N. Stephenson, nor has it fully met modern expectations [27], [31], [38], [109], [111]. "*However, although there is no perfect example that meets all of the requirements of an ideal metaverse, various existing works possess several features that are worthy of summary*" [27] (p.157). The root of this inconsistency primarily stems from existing technological constraints in integrating the underlying technologies into a unified system. Moreover, each of these technologies is still separately advancing to reach the requisite level of advancement to fully support the metaverse in its final form [5]. Wiederhold states characteristically on this issue that "*Right now, there are several obstacles standing in the way of this fully immersive vision, and even metaverse supporters are not expecting it to be fully realized any time soon. For the metaverse to truly replicate the real world, there will need to be significant upgrades to existing computer systems and technology*" [108] (p.1). In summary, the metaverse's evolution is a complex narrative spanning over a century, which makes imperative the need for a systematic examination. To this end, the *4 Epochs of the Metaverse* framework is proposed after the analysis of all the existing timelines sourced in literature.

A. Previous metaverse timelines

- The American digital marketing agency "Jack Morton" in its *metaverse timeline project*, classifies the historical trajectory of the metaverse into 4 periods: the fantasy period (1935-1978), the foundation period (1978-2009), the experimentation period (2011-2019), and the adoption period (2019-present) [59].

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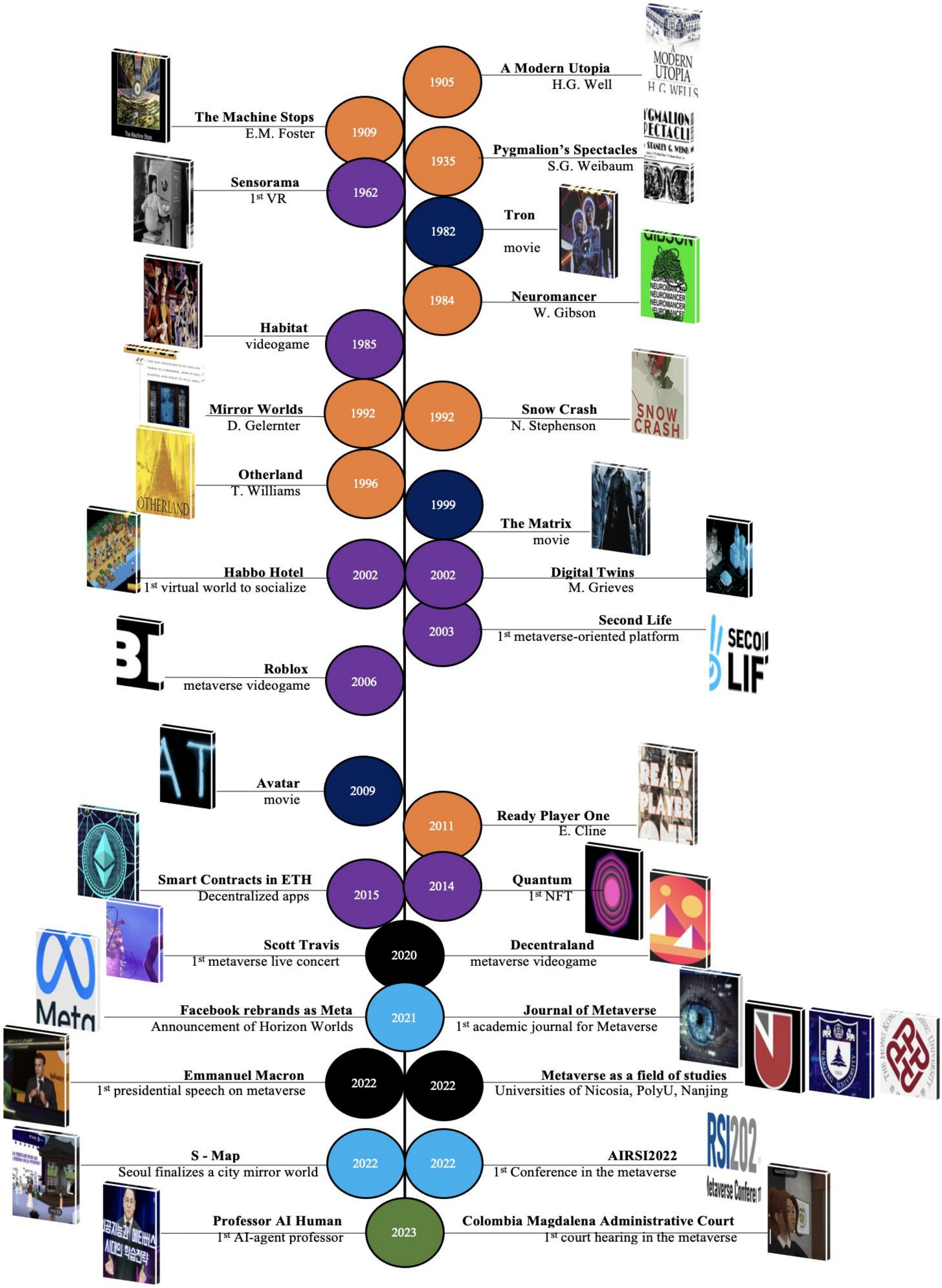

FIGURE I. The Metaverse and its components timeline (1905 – 2023)

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- [27] attempt a similar demonstration of the underlying technologies of the metaverse by defining 4 periods: first period, called *Text-based Interactive Game* period spans from 1974 to mid-1990s and can be divided into two categories, *Prehistory* (before the web) and the *Main Period*. The second period, from 1994 until the early 2000s, belongs to the *Open Virtual Worlds*. The third period starts from 2003 with "Second Life" until 2018 and belongs to Massively Multiplayer Online Games, while the fourth period commences from 2018 and the incorporation of Blockchain into virtual worlds until today.

- According to [54] there are specific events related to the components of the metaverse, from its presentation in literature as an idea, to the involvement of giant companies, such as "Meta" and "Microsoft". The authors present 20 significant events in their timeline, starting from the birth of the internet in 1991 and reaching to "Facebook"s renaming to "Meta" in 2021.

- The American investment bank "JP Morgan" entered the metaverse through its blockchain platform, "Onyx", and released a report in 2022 including a metaverse timeline exclusively focused on gaming. The report highlights 13 key events in the history of the metaverse, stating that "*The metaverse is evolving from two decades of gaming and will be built upon gaming infrastructure*" [84] (p.6). The report's historical overview starts from 2003 with the release of "Second Life" and ends with Microsoft's announcement in January 2022 of its intention to acquire the company "Activision Blizzard", a company that is one of the pioneers in producing video games and virtual worlds.

- An interesting approach is presented by [81], who view the metaverse as an evolution of people's communication, creating a different perspective from that of other researchers. This overview starts with the discovery of speech and language as a means of communication 300,000 years ago and presents 13 events until 2021, where it ends with the rebrand of "Facebook" to "Meta".

- [67] based on the review and classification from [27], present a similar historical trajectory of the metaverse grouped into 5 periods, namely the period of *Literature* (1974-1984), the period of *Interactive Text-Based Games* (1984-1992), the period of *Virtual Worlds* and *Multi-User Online Games* (1995-2011), the period of *Mobile-based Virtual Environments* (2015-2017), and finally, the *New Era of the Metaverse* (2017-2020). The authors showcase 21 events starting from the year 1974 and the release of the tabletop role-playing game *Dungeon & Dragons*, up to the year 2020 and the release of the virtual world-game *Alien Worlds*, which is a P2E game. The authors categorize the events into 3 categories: events related to the evolution of the metaverse, representative narratives of science fiction, and technological discoveries in the market.

- [26] are the only researchers who choose not to employ the term "metaverse" in their article "3D Virtual Worlds and the Metaverse: Current status and Future Possibilities", published in 2013. Instead, they opt for the term "virtual worlds". Their article provides a detailed historical overview of virtual worlds through five periods: the first period, in the 1970s, is characterized by virtual worlds based on tabletop role-playing games, such as *Dungeons & Dragons*. The second period begins in 1984 with the video game "Habitat" and includes virtual worlds with two-dimensional or three-dimensional graphics. The third period is placed in the mid-1990s and is characterized by progress in graphics and computing power. The fourth period begins in the dawn of the new millennium and includes the use of virtual reality for commercial and advertising purposes, and its adoption by institutional players. The authors mention "Second Life" in 2003 as a great example of the fourth period. Finally, the fifth period begins in 2007 and includes open-source and decentralized architecture in the creation of virtual worlds.

- [66] in his historical retrospective on the website *Tech Target Network*, in November 2022, recognizes the ongoing evolution of the metaverse, while pointing out that it has not reached its full potential. His timeline is composed of milestones related to the metaverse's underlying technologies. He presents 24 events, spanning from 1938, with the coining of the term "virtual reality", to 2022 where it culminates with the collaboration between "Siemens" and "Nvidia". That collaboration signified the entry of the German technology giant into the metaverse.

- [8] based on *CNBC*'s timeline [18], choose to start their historical overview with the inception of the internet, in 1989. They present 12 events up to 2021, where the renaming of "Facebook" to "Meta" took place. There are no distinct periods in their overview, while they emphasize on the creation of the *Mesh* platform by "Microsoft" in 2021.

- [83] commence their historical review in 1992 with the release of "Snow Crash" and mention 12 events up to 2021, including the development of "Horizon Worlds" in pilot form from "Meta". The authors describe three eras in the evolution of the metaverse: 1) the era of *science fiction* works, the *gradual implementation of the metaverse* 2) through virtual worlds and then 3) through online interactive video games.

B. The proposed framework

A strong commonality among all the historical trajectories presented above is the association of the metaverse with the gaming industry. Except for the timeline presented by "Jack Morton", all the previous attempts to build a metaverse timeline were closely related to gaming. The timelines presented highlight the existence of several Web3 gaming platforms and acknowledge their significance as milestones for the metaverse. Another common point among previous works is that most of the researchers label their timelines as *history of the metaverse*, implying that all these gaming platforms can be characterized as metaverses. On the contrary, [26] provides a historical retrospective using the term "virtual worlds" instead of "metaverse". The current research paper after having reviewed in detail all previous

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works, introduces a novel approach of examining the evolution of the metaverse. It traces the metaverse journey from the roots of its component parts to its full fruition in the future. The proposed framework, as illustrated in **Table 1**, consists of 4 time periods, referred to as *Epochs*. The *4 Epochs of the Metaverse* effectively covers the metaverse's journey from 1905 to its eventual full realization in the future. The proposed framework not only allows for the inclusion of more milestones in the future, but also offers a better understanding of each milestone's impact on the metaverse's evolution by categorizing them in the corresponding epoch. The *4 Epochs of the Metaverse* is described below in detail:

The first period, known as the *Epoch of Ideas*, spans from the initial idea of a parallel world to the release of the movie "Avatar" in 2009. It begins with the publication of "A Modern Utopia" in 1905 and is characterized by science fiction narratives. Those works introduced the public to the concept of parallel worlds, virtual worlds, and the interconnectedness of virtual with real world. During the *Epoch of Ideas* the technologies required to create such worlds were envisioned and illustrated in the novels and movies of that Epoch. These visions may have cast light on different facets of the metaverse, yet without providing a complete description of it. The *Epoch of Ideas* include the novels "A Modern Utopia", "The Machine Stops", "Pygamalion's Spectacles" and "Otherland". It also involves the publication of "Mirror Worlds", and the theory of "Digital Twins". The early videogame "Habitat" and the movie "Avatar" complete the list of the milestones that introduced all the fundamental components constituting a metaverse.

TABLE I. The 4 Epochs of The Metaverse Framework

The 4 Epochs of the Metaverse		
Epochs' Order	**Epochs' Names**	**Chronological Period**
1st Epoch	*Epoch of Ideas*	1905 - 2009
2nd Epoch	*Epoch of Definitions*	1982 - 2011
3rd Epoch	*Epoch of Foundation & Experimentation*	1962 - present
Sub-Epoch 3.1	*Epoch of Foundation*	1962 - present
Sub-Epoch 3.2	*Epoch of Experimentation*	1993 - present
4th Epoch	*Metaverse Epoch*	Undefined

The second period is called the *Epoch of Definition* and ranges from 1982 to 2011. It is characterized by pieces of literature that showcase fully integrated metaverses and describe in detail their capabilities and benefits for users. Throughout this period, the public becomes familiar with the idea and the characteristics of a fully integrated metaverse, in contrast to the first period, where the focus was on peoples' familiarization with the underlying technologies and the notion of virtual worlds. The Epoch begins with the movie "Tron" in 1982 and continues with the publication of "Neuromancer" in 1984. "Snow Crash" and "The Matrix" are undoubtedly included in the *Epoch of Definition*. The Epoch extends until 2011 when ''Ready Player One'' portrayed a modern, vibrant, and complete metaverse. In all these pieces of work, fully realized metaverse worlds are presented, making use of all the elements unveiled during the *Epoch of Ideas*.

The third period, the *Epoch of Foundation & Experimentation* signals the practical implementation of the previous two Epochs, by realizing the ideas of the 1st Epoch and the launch of platforms, as described in the 2nd Epoch. The *Epoch of Foundation and Experimentation* succeeds in bringing to life the underlying technologies of the metaverse, while progressively leans towards the realization of a full metaverse, as described in the works of the *Epoch of Definition*. Since a complete metaverse has not been fully realized yet, the 3rd period is an ongoing Epoch that continues to the present day and will reach its conclusion when a fully integrated metaverse becomes accessible. This Epoch is further divided into two sub-Epochs: The *Epoch of Foundation* and the *Epoch of Experimentation*.

- The former includes all the significant achievements that succeeded in making real and available to people the ideas expressed in 1st Epoch. *The Epoch of Foundation* began in 1962 with the creation of the first simulator called "Sensorama" and continues to the present day, including the game "Habbo Hotel", the genesis of the first NFT "Quantum", the implementation of smart contracts, the launch of cryptocurrencies and blockchain networks, the progress in reaching 5G speed and the widespread adoption of avatars for both gaming and social interactions. The recent advancements in AI applications have made this technology readily available and user-friendly, and led to its widespread popularity, having as starting point the launch of generative AI application "ChatGPT" in November 2022. The progress in AI research can be also classified within the *Epoch of Foundation*.
- The *Epoch of Experimentation* combines different underlying technologies from the *Epoch of Foundation,* in an effort to reach to a fully developed metaverse. This period began in 1993 with the launch of metaverse-oriented videogames, such as "CitySpace", "CyberTown", "Worlds" and "Active Worlds". These games constituted innovations in the field of multiplayer virtual worlds, as they seamlessly combined 3D graphics, internet connectivity, user communication, VR elements, avatars, in-platform monetary systems and the potential for users to generate income with real life value. It becomes evident that that the *Epoch of Experimentation* not only synthesizes the achievements of the *Epoch of Foundation*, but also realizes the interconnection of virtual worlds with the real world. Users can establish relationships through virtual worlds that extend into the real world. Additionally, they have the capacity to generate in-game income with value in the real world, by converting in-platform earnings into real-world currencies, such as USD or EUR. The *Epoch of Experimentation* and the continuous effort to combine and incorporate advanced technologies is still ongoing and will persist until the arrival of *Metaverse Epoch*.

The 4th period, known as the *Metaverse Epoch*, lies in the future and has not been reached as of the time of writing this

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paper in 2023. This period will inaugurate the implementation of a complete, practical, and user-friendly metaverse that is accessible to the public. The term "user-friendly" refers to the size and the ease of use of portable devices required for accessing the metaverse. The term "complete" encompasses the integration of all underlying technologies to support the use of metaverse for every aspect of our daily life. The term “practical” refers to a fully functional space designed to provide users with an easy, flawless, and enjoyable experience while navigating in it. The *Metaverse Epoch* differs from the *Epoch of Foundation & Experimentation* on several aspects: Firstly, the 4th Epoch is expected to offer fully operational and mature metaverses, all incorporating the elements described in the *Epoch of Definition*. On the contrary, in the 3rd Epoch, only some of the underlying technologies are present in the current platforms, limiting down the potential of these platforms. In the *Metaverse Epoch* interoperability will become a reality, allowing users for rapid and seamless navigation among metaverses owned by different companies, similarly to the case today where users can easily navigate across different webpages. Currently, interoperability remains a major and rather unsolved problem for metaverse platforms.

Moreover, metaverses of the 4th Epoch will serve a greater multitude of purposes than today. This includes innovative approaches to generating income, emergence of novel professions, new methods of work attendance or task execution, super realistic representation of users through their avatars, capturing even facial expressions, and a myriad of other applications beyond recreational purposes that is the common case today. It needs to be clarified that previous attempts have already proved metaverse capable of serving this wide spectrum of purposes, as already mentioned in this paper. However, what differentiates the *Metaverse Epoch* from today is the comprehensive integration of these features across all metaverse platforms, accompanied by improvements in user friendliness and reduced access costs. For instance, users would no longer need to create a new avatar upon entering a new metaverse (similarly to modern internet users do not need to sign up a new account every time they navigate across various webpages) or connect their e-wallet every time they jump from one metaverse to another, since the wallet will be linked with their avatar. Thus, users of the *Metaverse Epoch* will be able to make use of their money or NFTs across all metaverse platforms in a convenient way. Most importantly, people will find strong reasons to use metaverse for every aspect of their daily life. The absence of these features in current metaverse-oriented platforms is a result of technological limitations, which serves as a strong signal that the *Metaverse Epoch* is not here yet. Based on this, the present paper characterizes as ‘’metaverse-oriented’’ all the current platforms, diverging from the dominant characterization “metaverse”, used by most members in academia and the business community.

V. Discussion

The 4 Epochs framework offers a fresh perspective on studying the development of the metaverse, diverging from the traditional linear timelines used in previous studies. Instead of defining the Epochs as strict sequential phases based on chronological order, this framework focuses on content. It treats Epochs as overlapping and dynamic periods of time, which include events of similar impact on metaverse’s evolution. As a result, the *4 Epochs of the Metaverse* effectively manages the complexity of metaverse development: From opaque theoretical concepts to well-shaped ideas and, finally, the launch of metaverse-oriented platforms today, the history of metaverse is a multifaceted and complex journey. This journey could be hardly understood and analyzed if it was approached only on a temporal basis. The analysis based on the content of the events assisted by the dynamic and overlapping nature of the Epochs can efficiently tackle this challenge.

According to the present study, since 1905 emerging ideas and approaches have continuously surfaced, forming the basis for defining the metaverse and its societal benefits. As these definitions evolved, new approaches and conceptual frameworks emerged, underscoring the need for an overlapping categorization, as the two first Epochs were ongoing in parallel. Meanwhile, developers and entrepreneurs began experimenting on the content of the first two epochs, leading to the realization of metaverse-oriented platforms, The creators of these platforms capitalized on technological advancements and managed to integrate several elements that aligned with the metaverse envisioned characteristics, as described by the ideas and definitions available by that time. Due to those creators and their works, the 3rd epoch of the metaverse has been already a reality since 1962, while, not surprisingly, new ideas and new definitions of the metaverse continued to emerge, concurrently with experimentation. This overlapping series of events, as addressed in the current research, cannot be adequately depicted by chronological based timelines, and constitutes the main gap that the 4 Epochs framework aims to fill. Considering the dynamic nature of the framework, at first it categorizes milestones into three groups: i) initial and raw visions and ideas of particular elements related to virtual worlds, ii) complete and well-shaped descriptions of the metaverse, and iii) technological realizations of all the above. It further allows for new entries of events in the future, as new technological advancements and ideas continuously emerge. The dynamic nature of the *4 Epochs of the Metaverse* enables the temporal adjustment of the boundaries for each Epoch. The current temporal boundaries, as presented in this paper are based on the events up to the time of writing this study. With the evolution of the technological landscape, the framework exhibits flexibility to accommodate shifts and future progress within the metaverse realm.

The forthcoming 4th Epoch is anticipated to become a reality when technological progress enables smooth integration of all distinct components of the metaverse onto a unified platform. This will ensure seamless flow of information and interconnection among different metaverses, enhanced user experience, usefulness, and ease of use. Creators will persist in combining different elements and technologies, as they currently do, until we reach the point of achieving a fully integrated metaverse. This will mark the transition from the 3rd Epoch to the *Metaverse Epoch*. Of course, it would not be a surprise if novel ideas or theoretical concepts emerge and reshape the current vision of metaverse. In fact, this seems to be the most likely scenario. Such a case

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will eventually prolong the duration of the first three Epochs in the framework. Shifts or alterations in human needs and the emergence of fresh ideas or perspectives in future societies might lead to new approaches on how the metaverse should cater people’s needs.

Although this paper extensively discusses the technological struggles and the journey to efficiently support a complete metaverse, it must be noted that its realization, and consequently the *Metaverse Epoch*, is not solely dependent on the technological development. The overall usefulness is an equally major condition for the initiation of the last Epoch. At present, most individuals miss to find significant value in the existing metaverse-oriented platforms, which are mainly visited by young users out of curiosity or for gaming. This is partially related to technology limitations, as the use of these platforms for purposes other than gaming exceeds our current technological capabilities. Furthermore, existing tools for social interaction (such as social media websites), online shopping (e-shops platforms) or attending meetings and performing tasks (online meeting platforms) are more user-friendly and effective. Current metaverse-oriented platforms are struggling to provide added value in comparison to the already established tools, leading people to reject metaverse as a means to simplify their lives.

A fully integrated metaverse could add value in areas such as work, social life, and entertainment, as well as a more user-friendly nature. In the *Metaverse Epoch* people will not only use these platforms for playing games or socializing but for everyday tasks. In this frame, the *4 Epochs of the Metaverse* can also be applied across diverse sectors that recently began embracing metaverse technology, including but not limited to, tourism [30], [45], [63], [81], education [1], [3], [22], [77], healthcare [9], [27], [40], [54], [65], [74], [77], [79], [99], [101], [109], construction [1], [9], [77], entertainment and gaming [3], [22], [77], [79], real estate [27], [30], [77], [84], [112], and the banking sector [28], [85], [92]. The implementation of the 4 Epochs framework to any economic sector that has adopted a metaverse focus will offer a better understanding of the sector’s evolution in the future.

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CONFLICT OF INTEREST

The authors declare that they have no actual or potential conflict of interest as it concerns the publication of this paper.

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Path To Gain Functional Transparency In Artificial Intelligence With Meaningful Explainability

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Abstract—*Artificial Intelligence (AI) is rapidly integrating into various aspects of our daily lives, influencing decision-making processes in areas such as targeted advertising and matchmaking algorithms. As AI systems become increasingly sophisticated, ensuring their transparency and explainability becomes crucial. Functional transparency is a fundamental aspect of algorithmic decision-making systems, allowing stakeholders to comprehend the inner workings of these systems and enabling them to evaluate their fairness and accuracy. However, achieving functional transparency poses significant challenges that need to be addressed. In this paper, we propose a design for user-centered compliant-by-design transparency in transparent systems. We emphasize that the development of transparent and explainable AI systems is a complex and multidisciplinary endeavor, necessitating collaboration among researchers from diverse fields such as computer science, artificial intelligence, ethics, law, and social science. By providing a comprehensive understanding of the challenges associated with transparency in AI systems and proposing a user-centered design framework, we aim to facilitate the development of AI systems that are accountable, trustworthy, and aligned with societal values.*

Keywords—*Explainable Artificial Intelligence (XAI), Explainability, Interpretability, Transparency, Accountability, Fairness*

I. INTRODUCTION

The concept of transparency has been a topic of interest, often approached from a technological perspective, in the quest to enhance various aspects of decision-making processes [5]. Previous research has predominantly focused on developing computer-based methods to facilitate transparency. Transparency is seen to empower stakeholders to assess the potential impact of algorithmic decision-making systems and make informed choices about their utilization [3]. However, transparency is often framed in terms of the desired outcomes it aims to achieve, rather than the specific procedures employed to achieve those outcomes.

Algorithmic transparency is essential for stakeholders to comprehend, improve, and question the predictions made by machine learning models. Explainability aims to provide stakeholders with explanations for the actions of such models. However, stakeholders may not be able to determine the accuracy of a model or recognize when it lacks sufficient information for a given task solely by examining its behavior [2]. Explainable machine learning techniques, such as feature significance scores, counterfactual explanations, or analysis of influential training data, can offer insights into model behavior and aid stakeholders in understanding its decision-making process. Nonetheless, the practical implementation of these strategies in businesses remains relatively unexplored [4].

As we move forward, autonomous AI systems are expected to coexist with humans in various domains, providing valuable services. To gain acceptance and trust from users, it is crucial for these systems to be transparent, enabling humans to comprehend their underlying logic. Transparency allows humans to generate meaningful justifications for the decisions and actions of AI systems. Developing algorithms that humans perceive as fair, and embrace is of utmost importance as algorithms increasingly assume greater management and governance responsibilities.

In this paper, our overall contributions are-

1. Firstly, we explain the theoretical concepts related to ensuring transparency. We show the difference of the state of between and in-between. We also outline some traditional problems that arise covering transparency, while blasting the misconceptions of transparency.
2. Secondly, we show different ML factors related to algorithmic transparency, their internal dependencies among each other.

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3. Thirdly, we study a case where we showed the dependency between confidence and decision parameter in AI systems while disclosing functional transparency.

4. After that, we show the state of the art of transparency. Finally, provide our design of user-centered compliant-by-design transparency for transparent systems by using empirical approaches to better understand user responses to transparent systems.

II. Explainable Artificial Intelligence

Explainable Artificial Intelligence (XAI) is a set of procedures and techniques that enable human users to understand and trust the output and outcomes of machine learning algorithms [27]. XAI aims to describe an AI model, its anticipated effects, and potential biases in a way that is understandable and transparent to humans. It helps define model correctness, fairness, transparency, and decision-making outcomes supported by AI. By adopting AI explainability, businesses can establish trust and confidence in the development and deployment of AI systems [28].

As AI develops, it becomes challenging for humans to understand and trace the steps taken by algorithms. The calculation process is often treated as a "black box," making it difficult to comprehend [29]. These black box models are generated using data, but even the engineers and data scientists who created the algorithm may not fully understand or describe what happens inside them, including how the AI algorithm reaches specific conclusions.

The goal of an explainable AI (XAI) system is to make its actions more understandable to people by providing justifications. Designing AI systems that are efficient and comprehensible to humans can be guided by the following general principles: the XAI system should be able to describe its capabilities, understandings, and actions, as well as provide insights into the information it acts upon. However, explanations are context-dependent, influenced by the work, user skills, and expectations of the AI system. Thus, interpretability and explainability cannot be defined independently of the domain and are domain specific. Explanations can be complete or partial, with fully interpretable models providing transparent, comprehensive explanations and partially interpretable models shedding light on key aspects of their decision-making process. Interpretable models adhere to "interpretability restrictions" specific to the domain. Examples of partial explanations include variable importance measurements, local models resembling global models in certain instances, and saliency maps.

Understanding how an AI-enabled system produces a specific result offers several benefits. Explainability helps developers ensure that the system operates as intended, may be necessary to meet regulatory standards, and can be crucial in enabling affected individuals to contest or modify decisions [30].

To avoid blindly relying on AI decision-making processes, enterprises must fully comprehend them through model monitoring and accountability. Explainable AI assists humans in better understanding and explaining machine learning (ML), deep learning, and neural networks. ML models are often perceived as opaque "black boxes" that are challenging to understand, particularly when employing neural networks [31]. Addressing bias, often based on race, gender, age, or region, has long been a concern in AI model development. Additionally, AI model performance can drift or deteriorate due to discrepancies between production and training data. Consequently, it is crucial for companies to regularly manage models to enhance AI explainability and assess the impact of deploying such algorithms on their bottom line [26]. Explainable AI also supports end-user trust, model auditability, and effective utilization of AI, while reducing compliance, legal, security, and reputational concerns in production AI. It forms an integral part of responsible AI, providing a framework for the ethical application of AI techniques in real-world businesses with considerations for fairness, model explainability, and accountability [32].

III. Artificial Intelligence In Between With Or Without Explanation

Many companies market simple analytics tools as artificial intelligence, claiming that they can replace human intelligence and provide superior results. However, these tools often involve human labor disguised as artificial intelligence. The use of metaphors and simplifications obscures the fact that human analysts are performing the data analysis behind the scenes. This metaphorical portrayal of mechanical automation may be an inaccurate or exaggerated representation, but it effectively serves as a precise image of the overall concept. This misleading and evolving idea of artificial intelligence forms the basis of marketing gimmicks employed by technology companies. They rely on abstract and oversimplified representations to present a ready-to-use concept of their product, while omitting its true composition and distorting its essence to satisfy the curiosity of end users.

On the other hand, certain systems covertly employ complex data processing and machine learning intentionally. These systems aim to make their influence on decision-making impenetrable, while businesses employ deceptive strategies to contain the action within their own realm. Although these systems could theoretically be designed to be more understandable, the lack of transparency in this era of unprecedented technical complexity cannot be solely attributed to poor communication.

Ultimately, the opacity of machine learning algorithms stems from both institutional self-protection and concealment, as well as the mismatch between the high-dimensional mathematical optimization inherent in machine learning and the requirements of human-scale reasoning and interpretation. The lack of transparency in systems incorporating artificial intelligence solutions is intertwined with the emergence of a new form of automation in cognitive tasks. This fundamental issue goes beyond convoluted storytelling devised by marketing teams or deceptive interfaces and user experience design.

IV. Questions Arise in Explanation

We have quality assurance and testing techniques, tools, and technologies that can swiftly identify any problems or departures from accepted programming conventions in a

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normal application development project. We have techniques to continually test our capabilities as we combine them with ever-more complicated systems and application functionality. We can run our apps through regression tests to ensure that new patches and fixes do not cause further problems. However, here is where issues with machine learning models arise. They are not code since we cannot just look at the code to see the faults.

We wouldn't need to train it with data if we were aware of how learning was intended to operate in the first place. We would just start from scratch when coding the model. But that isn't how machine learning models operate. The model's functionality is derived from the data, and we do this by using In a typical application development project, we have established quality assurance and testing techniques, tools, and technologies that can quickly identify any issues or deviations from accepted programming conventions. These methods allow us to continuously test and validate our capabilities as we integrate them into increasingly complex systems and application functionalities. We can run regression tests on our applications to ensure that new patches and fixes do not introduce further problems. However, when it comes to machine learning models, we encounter different challenges.

TABLE I. TRADITIONAL QUESTIONS ON TRANSPARENCY

Question
What if we are the model's user or consumer?
What if the model we are employing isn't working out too well?
Was the data used to train it bad?
Did the data scientists choose a biased or selected collection of data that doesn't reflect your reality?
Should we believe the cloud service provider's model?
What about the model that is integrated within the tool we use?
What knowledge do we have about the model's construction and iteration process?
Do we understand the model's purpose and the use case that the model's creators had in mind?
Are we employing the model in the manner that the designers intended?
Was a study conducted on the potential effects the model may have on various users?
Where did the training data come from?
What distinct performance measures are there for various sorts of input data?
How does this model fare in real-world testing using different metrics?
How can we apply transfer learning to the model?
How have measures for model performance evolved over time?
Does anybody else use the model?

Machine learning models are not like traditional code where we can easily identify faults by examining the code itself. Unlike conventional programming, where we start from scratch and write explicit instructions, machine learning models derive their functionality from data. We use algorithms to create the most accurate model possible, given that we need to make generalizations about unseen data. Since we are estimating and generalizing, precision is not guaranteed. Therefore, fixing bugs alone will not lead us to the perfect model. Instead, we iterate and improve by utilizing better data, fine-tuning hyperparameters, employing advanced algorithms, and increasing computational power. These tools are available to us for improving the model we have created. However, rebuilding the entire model is more challenging and less under our control. Moreover, we may not fully understand why the existing model is not performing well, as it might have been developed with hyperparameter values that worked well for the developers but not for us. As consumers of the model, we have limited options: either use the model as it is or create our own. To establish trust in the models developed by others, there is a need for greater visibility and openness. Model users should carefully consider relying on a model for critical applications due to various concerns regarding model transparency. The lack of answers to these questions is the underlying issue, as there is a lack of openness. Table 1 highlights some of the transparency-related questions that need to be addressed. Addressing these questions will contribute to a more transparent model, addressing real and significant concerns.

V. CONTRASTIVE EXPLANATION: TRANSPARENCY

Transparency can be described in various ways [35]. Related terms such as "explainability" or "XAI," "interpretability," "understandability," and "black box" are sometimes used interchangeably with transparency. Essentially, transparency is a property of an application, indicating the extent to which the inner workings of a system can be theoretically understood. It can also refer to the process of providing user-friendly explanations of algorithmic models and decisions, which contributes to public perception and comprehension of AI. Another perspective on transparency is as a broader socio-technical and normative ideal of "openness" [36].

Transparency refers to the quality of providing access to specific information about how a system operates. However, the relevance of such information from an ethical standpoint depends on the ethical question at hand. Transparency itself is morally neutral; it serves as an ideal. It can take various forms and offer solutions to underlying moral dilemmas.

Some modern machine learning techniques are considered "black box" because users cannot directly observe their inner workings [33]. When these algorithms are used to make decisions that impact individuals, the lack of transparency can be problematic. People have the right to understand how important decisions are made [34]. Consequently, there has been a growing demand for "more transparent AI."

Non-arbitrariness in decision-making is crucial for effective governance in both public and commercial sectors. This principle applies to decisions that significantly affect people in ethical or legal ways. Justifications for why a particular choice was made and the grounds on which it stands indicate non-arbitrariness. Additionally, the ability to challenge and appeal decisions is important, particularly in public governance, as it allows for rectifying any wrongs.

Individuals have the right to access information about the decision-making process to safeguard their agency, freedom, and privacy as per human rights. Freedom encompasses the

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right to know how one's activities are monitored, what conclusions are being drawn about them, and how those conclusions were reached.

Societal accountability entails managing risks as a collective. There is a moral responsibility to comprehend and anticipate the effects of the technology one develops up to a certain extent. Releasing a harmful system without understanding its potential consequences is not a justifiable course of action. Instead, it is our moral obligation to consider the risks involved.

All these issues can be summarized as requests for sufficient information. Do we know if an algorithmic decision is justifiable, and to what extent? Do individuals understand how assumptions about them are made? To what degree are individuals responsible for the system's actions, and how much knowledge of the system is necessary to assume that responsibility?

The definition of openness or explainability, the level of transparency required for different stakeholders, and other related issues are still topics of debate. The exact definition of "transparency" may vary depending on the context. Whether there are multiple degrees of transparency is still a subject of scientific discussion. Furthermore, the term transparency may be used in different contexts, whether examining the legal implications of unfair biases or discussing characteristics of machine learning systems.

VI. Problems Arise In Transparency: Why A System Considered AS A "Black Box"?

It is quite improbable that we would be able to construct deep learning systems that are entirely transparent because many of the most effective models available now are black box models [38]. As a result, establishing the right amount of openness is the main topic of discussion. Would it be sufficient if algorithms provided the smallest change that could be made to produce a desired result as well as a disclosure of how they arrived at their decision? For instance, if an algorithm rejects someone's request for a social benefit, it should explain why as well as what the person can do to appeal the decision. Transparency also serves a variety of additional purposes in current discussions of machine learning models [39].

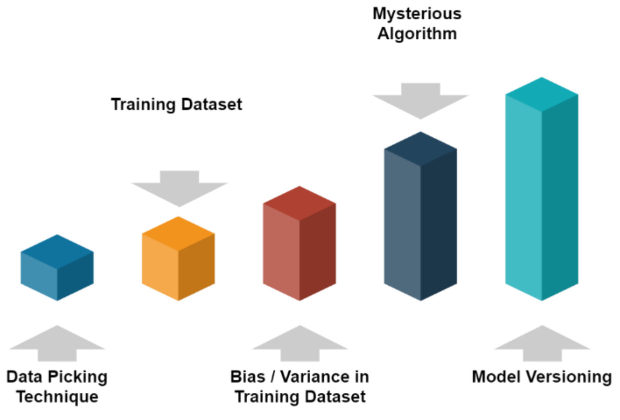

FIG. I. Lackings of Producing a Shadowy Model

It may be crucial for creating legislation or maintaining public confidence in AI. The idea of transparency in AI has given a larger connotation in terms of "comprehensibility" to address these problems. For an algorithm to be comprehensible, or intelligible, it must be possible to explain to individuals who may be impacted by the model how an AI model came to a certain conclusion [40]. One should be able to clearly understand the reasoning behind a decision made using inputs. Fig. 1 shows some possible lackings producing a non-transparent model. After that, the answer for what reason a system is considered a "black-box".

A. Complexity

The activity of a neural network is stored in dozens or even millions of numerical coefficients in modern AI systems. In most cases, the system picks up these data during the training phase. Even when all the parameters are known, it is almost hard to grasp how the neural network operates since its performance depends on the intricate relationships between these variables.

B. Developing Difficulties

Even though the AI models that are currently being employed allow explainability to some extent. It could be challenging to design an interface that allows users to receive thorough yet simple explanations.

C. Risk Concerns

If an attacker carefully constructs an input that breaks the system, they can trick many AI systems. In a system with great transparency, it could be simpler to manipulate the system to produce odd or undesirable consequences. As a result, systems are occasionally purposefully created as black boxes [37].

However, converting notions from algorithms into concepts that people can grasp is notoriously challenging. Legislators in certain nations have debated whether public agencies should reveal the programming codes for the algorithms they employ for automated decision-making. However, most individuals are unable to understand programming codes. Thus, it is difficult to see how publishing codes would increase transparency. Would publishing precise algorithms be more beneficial? Even when the actual techniques are published, there is often little openness, particularly if you do not have access to the model's data.

Today, cognitive and computer scientists create explanations of how and why programs act that are understandable to humans [41]. The creation of tools for data visualization, interactive user interfaces, vocal explanations, or meta-level descriptions of model aspects are a few examples of approaches. These technologies can be of great assistance in increasing the usability of AI applications. There is, however, still a tremendous ton of work being done. This is further complicated by the fact that comprehensibility is reliant on subject- and culture-dependent factors [42]. For instance, diverse cultures use different reasoning when interpreting visuals or drawing conclusions from them. Therefore, it is important for tech developers to have a thorough comprehension of the visual language they employ. Additionally, a lot depends on one's level of algorithmic or

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data literacy, such one's familiarity with modern technology. The terms used in modern technology are more common in certain cultures than others, and they may be utterly alien to others. There is obviously a need for considerable educational initiatives to improve algorithmic literacy, such as those on "computational thinking," to boost understandability. This user literacy will directly impact how transparent AI systems are in terms of the common users' fundamental knowledge of them. For many people, it could really be the most effective and useful technique to lighten the color of the boxes.

VII. Precondition Of Algorithmic Transparency: Data Transparency

Machine learning is opaque, and this applies to both supervised and unsupervised models. Algorithms may significantly increase the efficiency of current business and governance procedures. Every day, algorithms get more intelligent and train themselves to decide quickly and effectively without consulting people.

TABLE II. Answer to some Traditional Myths on Algorithmic Transparency

Myth	Disclosure
As organizations are capable of self-regulation, Artificial Intelligence transparency is not required.	Transparency in Artificial Intelligence promotes uniform and predictable regulation.
Artificial Intelligence is a machine that lacks emotion, but humans are driven by emotion.	It is possible to encode emotions into an Artificial Intelligence system.
That model can’t be prejudiced if protected class data isn’t used in its construction.	Practitioners of Machine Learning can better understand where to identify biases by having access to protected class data.
Humans are known to mess up and make mistakes, but Artificial Intelligence is a computer that can repeat endlessly and consistently.	In any logical sense, Artificial Intelligence is not a machine that can repeat actions endlessly and consistently.
Artificial Intelligence transparency puts intellectual property at risk of theft.	Intellectual property disclosure is not necessary for transparency.
If Machine Leaning models are seen to act unfairly or biasedly, we will immediately lose the trust of our customers.	Building trust with customers and the public through responsible AI practices.
Humans are prejudiced and discriminating, but Artificial Intelligence is a machine that is impartial and neutral.	Computational biases can be introduced into Machine Learning etc. and cause it to behave discriminatorily.
While humans have ulterior motives, Artificial Intelligence is a computer devoid of motivation.	Artificial Intelligence has a secret objective that will exploit their human-fueled motivating desires.
Humans are capricious and prone to whims, but Artificial Intelligence is a computer that is reliable and will carry out instructions.	Artificial Intelligence is a computer that is not always reliable.

Information (Data) transparency is "the certainty that data being provided are true and are coming from the official source" as well as "the capability to freely access and operate with data regardless of where they are located or what application developed them". Data transparency gathers reliable information from various sources and presents it in an understandable and practical style [47]. It provides you with a bird's-eye view of the situation. Nothing stays hidden in the dark.

The technological barriers to data sharing are vanishing with time, however this is offset by the growth in the amount of data being produced [48]. Researchers are no longer required to send CD copies of the material they are sharing by mail. Instead, data may be transferred with a single mouse click, in real time, and at a rate of speed that, if it was not so ordinary, would be astounding. In Table 2. clarifications of misconceptions of known algorithmic transparency are shown.

Technology is not a barrier when it comes to medical data [49] [50]. It is important to respect privacy and confidentiality concerns, which are valid concerns [51]. Understanding that behind the data are actual individuals who have the potential to be seriously hurt if their data are mistreated is a key component of Patterns' ethos [52].

Because of this, sensitive data must be subject to protections and limitations, and only those with a "need to know" should have access to it [53].

The use of closed and proprietary databases has been advocated for and the foundation of a great deal of worthwhile scientific study, this is not the problem. Due to selective accessibility, or the fact that professional peer reviewers were given access to the data to verify it, the results based on closed data are still valid. In these situations, the reviewers take on the role of the community, offering quality control checks and reassurances that the data support the results.

Nobody is an expert in every field. Data gathering, annotation, and validation are intricate and time-consuming processes that frequently go unrecognized by the systems in place for academic acknowledgment [54]. To make the usage and creation of research materials like datasets and code more visible and clearer and now the journals now give the option to write descriptor articles on them.

The community that is most likely to utilize the data, including those who are most likely to be peer reviewing it, must be able to reuse it. Creating documentation, annotating data, identifying, and addressing issues with a dataset—all these tasks require time and effort but are required and significant [55].

Data scientists have the expertise and aptitude to swiftly evaluate data and detect the outliers that can suggest issues with the dataset, so researchers serving as peer reviewers don't have to conduct the quality control effort of examining the data in isolation [56]. Collaboration between researchers and data scientists is necessary [57]. An illustration of how a domain expert and a data scientist might collaborate to validate data is as follows: A data scientist would be able to find the negative numbers in a colossally long time series, but the domain expert would know that negative numbers in this stream are a sign that the data are corrupt because negative numbers for this quantity are physically impossible.

Data is better understood when common standards are used [58]. Data is made more useable through common tools

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and services [59]. By making these things open, others may build on them without having to reinvent the wheel, by modularly linking data and services.

VIII. Algorithmic Transparency

The idea behind algorithmic transparency is that individuals who use, oversee, and are impacted by the systems that use these algorithms should be able to see the elements that drive those decisions. Although the phrase was first used in 2016 to discuss how algorithms are used to determine the content of digital journalism services, the basic idea dates to the 1970s and the emergence of automated systems for calculating consumer credit. In significant ways, algorithms are supplanting or enhancing human decision-making. The use of algorithms to propose anything from goods to buy to music to listen to social network connections has become commonplace. Algorithms, however, are used to make important choices about people's lives, including who receives loans, whose resumes are assessed by humans for potential employment, and the length of prison sentences. Although speed, economy, and even fairness might be advantages of algorithmic decision making, it is a frequent fallacy that algorithms always provide objective judgments. In fact, opaque algorithms have the potential to incorrectly restrict freedom and limit opportunities as well as services [25].

More focus is being paid to algorithmic transparency as significant tasks and procedures are entrusted in algorithmic decision-making systems. Greater openness is recommended by researchers and policymakers as a means of recognizing and preventing several potential harmful consequences of these systems. Experiencing non-obvious knowledge about how and why a system functions as it does and what this means for the system's outputs information that is challenging for a person to understand or personally experience—is a requirement for transparency [3]. Transparency methods offer users the chance to become familiar with features of a system that are often hidden, which has the potential to alter people's perceptions of the system and their interactions with it [43].

A. Algorithmic Transparency Mechanism

There are numerous various kinds of strategies that have been found to increase algorithmic decision-making transparency. Through regular use of a system, users may become aware of an algorithm [44]. Users occasionally come across surprising or perplexing data that deviates from expectations and suggests algorithmic bias [45]. In other cases, users are encouraged to learn more about the computational outputs so they can develop workarounds to try to prevent undesirable results. Such "organic" awareness, meanwhile, is not systematic nor evenly distributed across users. Algorithm audits, which look at how an algorithmic decision-making system functions and its effects, are another sort of transparency tool propose several levels, each of which might provide a different amount of responsibility and visibility for algorithm audits. However, as system providers frequently exclude the use of auditing techniques in their terms of service, audits must typically be conducted without their assistance. Some claim that platforms deliberately hide information about how they function to protect themselves from rivals or others who try to "game" the system [46].

There are some dependencies for making algorithms transparent, precise, and useful. Precise data, learning about computational output and awareness of the data are the significant factors which can control or manipulate the outcome of an algorithm. Those factors can control undesirable result percentage, expected outcome, algorithmic biasing (Algorithm is biased somehow by the internal or external factors massively).

Mathematically, if the precise data, knowledge on computational output, awareness are proportional to prevent the undesirable data and possible expected outcome, but inversely proportional to the algorithmic biasing.

Table 3 shows Algorithmic decision-making accuracy relationship based on external dependency factors according to the percentage. (↑) Means the percentage increment and (↓) means the decrement of the percentage of input and output factors. So, it can be easily clarified that precise data, knowledge on computational outcome and flawless data entry can enhance the accuracy of the expected outcome, prevent undesired data, and reduce algorithmic biasness.

TABLE III. Algorithmic Decision-Making Dependencies

Output / Input	Preventing Non-Desirable Output	Expecting Output	Biasing Algorithm
Precising Data (↑)	(↑)	(↑)	(↓)
Learning about Computational Output (↑)	(↑)	(↑)	(↓)
Awareness of Data Entry (↑)	(↑)	(↑)	(↓)

B. Factors of Algorithmic Transparency Mechanism

Making a system knowable or transparent is referred to as algorithmic transparency often [60]. In this conception, user behavior or system governance changes are brought about via a transparent method or process [61]. Transparency is, however, occasionally viewed as a condition that results from a process [62]. For instance, as a method of increasing system transparency, the Association for Computing Machinery has included justifications in its list of "Principles for Algorithmic Transparency and Accountability."

Whether "transparency" refers to the method or the result, the cause, or the impact, might be unclear in the literature. In this essay, transparency is the mechanism, and the consequences of transparency are defined in terms of the many sorts of tasks that transparency methods are supposed to be able to do [63]. This enables us to start figuring out what information and justifications explanations may offer to influence specific knowledge and attitudes about systems that use algorithmic decision-making.

Transparency serves the fundamental purpose of making it visible that choices are being made by an algorithm, which raises awareness that interactions with the system are mediated by an algorithm. By explaining what the system is doing, users may notice and understand parts of its behavior

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that might not be obvious or observable [63]. Users who may not be aware of an algorithm's operations can be especially well-informed by a description alerting them to it.

Transparency techniques also aid users in understanding how the system operates so they may assess the accuracy of the outputs they encounter and recognize inaccurate outputs [3]. Correctness assessments are a result of transparency in that a person cannot independently assess "whether a system is performing as intended and what modifications are required" without a mechanism that can assist an understanding of how the inputs create the outputs. Users should be able to grasp the system's intended outputs and spot flaws or omissions with the aid of a description of how it operates [64].

Transparency can enable judgements about the outputs' sense and indicate that the system's behavior is neither random nor arbitrary in addition to supporting judgments about accuracy [3]. Users are more at ease acting on the outputs when they can understand why a system behaves the way it does and can assess if the system is behaving in accordance with those reasons [65]. This makes the behavior of the system understandable. Users would be better able to comprehend the system's behavior based on perceiving the "truth and intentions" or reasons behind the system's activities, and to recognize when the system is not operating in support of those motives, with the aid of an explanation that supports interpretability [66].

The aim of regulating a system via accountability is emphasized in most of the literature on transparency [67]. Mechanisms for transparency might imply iterative control or individual users believing they are accountable for the outputs of the algorithm [3]. To be effective, a system must be directly answerable to consumers, a justification would present details that support their belief and comprehension that they have direct control over the system's outputs. Ideally, Users are also able to recognize biases because of transparency methods that might have unfavorable effects and empower users can criticize the system and ask questions, presenting evidence for requesting correction [68]. The purpose of this experiment was to determine how user views in an algorithmic decision-making system were affected by four different explanation types (What, How, Why, and Objective), as assessed by the tasks that transparency mechanisms carry out (awareness, correctness, interpretability, accountability). Each transparency function represents a qualitatively distinct view of the system, and certain transparency functions may be more helpful than others in reducing possible adverse impacts of algorithmic decision-making. This experiment is a crucial first step in figuring out how various kinds of information about a system could cause changes in certain user views about transparency.

For advertisements, suggestions, and judgments nowadays, many firms employ algorithms and personal data. Some people are worried that this usage violates people's privacy and endangers both individuals and society. Many people have responded by calling for increased algorithmic openness, or for businesses to be more transparent and open about how they utilize algorithms and personal data [60].

IX. Factors Of Explanation-Probability With Risk

In Machine Learning, we use the term uncertainty to describe our ignorance about a particular result of interest. To understand and measure uncertainty, we employ probability-based reasoning techniques. Probability is seen by the Bayesian school of thinking as individual levels of conviction that a desired result will materialize [16] [2].

Fig. 2 and Fig. 3 show our result of probabilistic confidence and decision graph of while tackling risk. It shows how confidence and decision are co-related with each other while working on transparency risk related to some intelligent system. The probabilistic confidence which we have used as *C* and the observed data as D. The probabilistic confidence function *C(D)* can be expressed using Bayesian probability as follows:

$$C(D) = P\ (Model \mid D) \quad (1)$$

Here, *P (Model | D)* is the posterior probability of the model given the observed data *D*. It represents the confidence in the model's parameters (weights) after considering the data. On the other hand, the decision as *Dec* and the model parameters (weights) as *W*. The decision function *Dec(W)* can be expressed as a threshold-based decision using Bayesian probability as follows:

$$Dec(W) = \{1, \text{ if } P\ (Class=1 \mid W) > Threshold\ 0, \text{ if } P\ (Class=1|W) <= Threshold\} \quad (2)$$

Here, *P (Class=1 | W)* is the probability of the positive class (class 1) given the model parameters *W*. Threshold is a predefined value used to make the binary decision. If the probability of the positive class is higher than the threshold, the decision is *1* (positive), otherwise, it is *0* (negative). As we work for this taking observation of some traditional algorithm in Artificial Intelligence transparency; it is a big concern that the two function shows that the confidence vs decision is inversely proportional. We have got the relationship between functions as follows:

$$Dec(D) = k / C(D) \quad (3)$$

Here, *k* is a constant representing the strength of the inverse relationship. The constant *k* can be adjusted to control the strength of the inverse relationship between confidence and decision. A higher value of *k* will result in a stronger inverse relationship, while a lower value of *k* will result in a weaker inverse relationship. Bayesian approaches clearly specify a hypothesis space of plausible models a prior then apply deductive logic to update these priors given the actual data. This is often accomplished in parametric models, such as Bayesian Neural Networks [2] [20] [21], by considering model weights as random variables rather than single values and assigning them a prior distribution. The conditional probability informs us how well each weight setting explains our observations given certain observed data. The prior is updated using the likelihood, which results in the posterior distribution over the weights. Through the process of marginalization, a prediction for a test point is created. For each configuration of weights, the prediction is weighed according to the posterior density of that weight. Model uncertainty arises from the discrepancy between predictions made using several reasonable weight choices. Both epistemic

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and aleatoric uncertainty are captured by the predicted posterior distribution. Due to their adaptability and scalability to massive volumes of data, Neural Network have recently gained respect among the Machine Learning community. According to frequentists, probabilities represent how frequently we would see the result if we repeated our observation repeatedly [17] [2] [18]. For the benefit of end users, uncertainty resulting from frequentist and Bayesian approaches conveys identical information in practice [2] [19] and is frequently addressed equally in subsequent tasks. Research communities and application areas utilize different measures to convey uncertainty. Although a comprehensive predictive distribution has a lot of information, it may not always be desired. To provide information concerning uncertainty, summary statistics of the predictive distribution are frequently utilized. The class probabilities make up the predictive distribution for classification. These innately convey our level of confidence as a result. Predictive entropy, on the other hand, separates our predictions from their uncertainty and only informs us of the latter. A predicted mean and error bar is frequently used to summarize the predictive distribution for regression. These frequently represent the predictive distribution's standard deviation or a few percentiles.

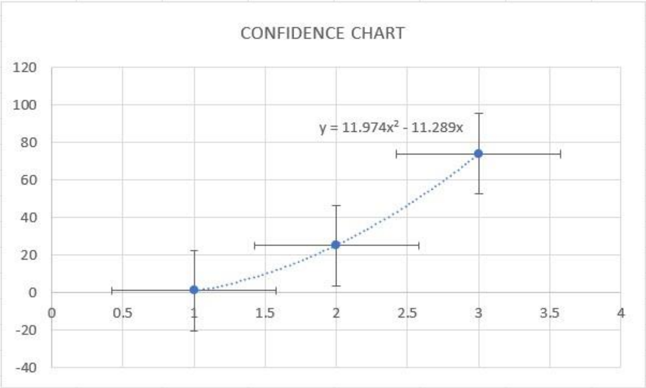

FIG. 2. Probabilistic Confidence Graph

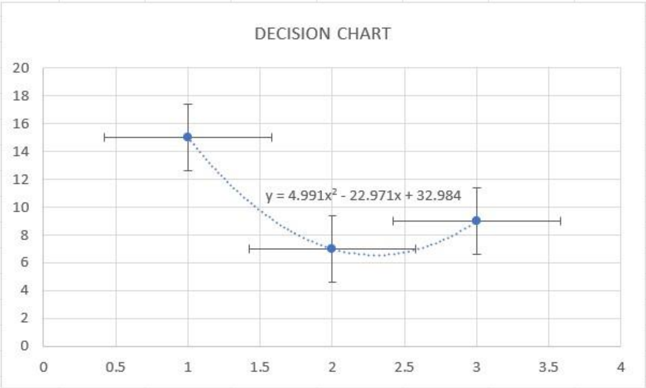

FIG. 3. Probabilistic Decision Graph

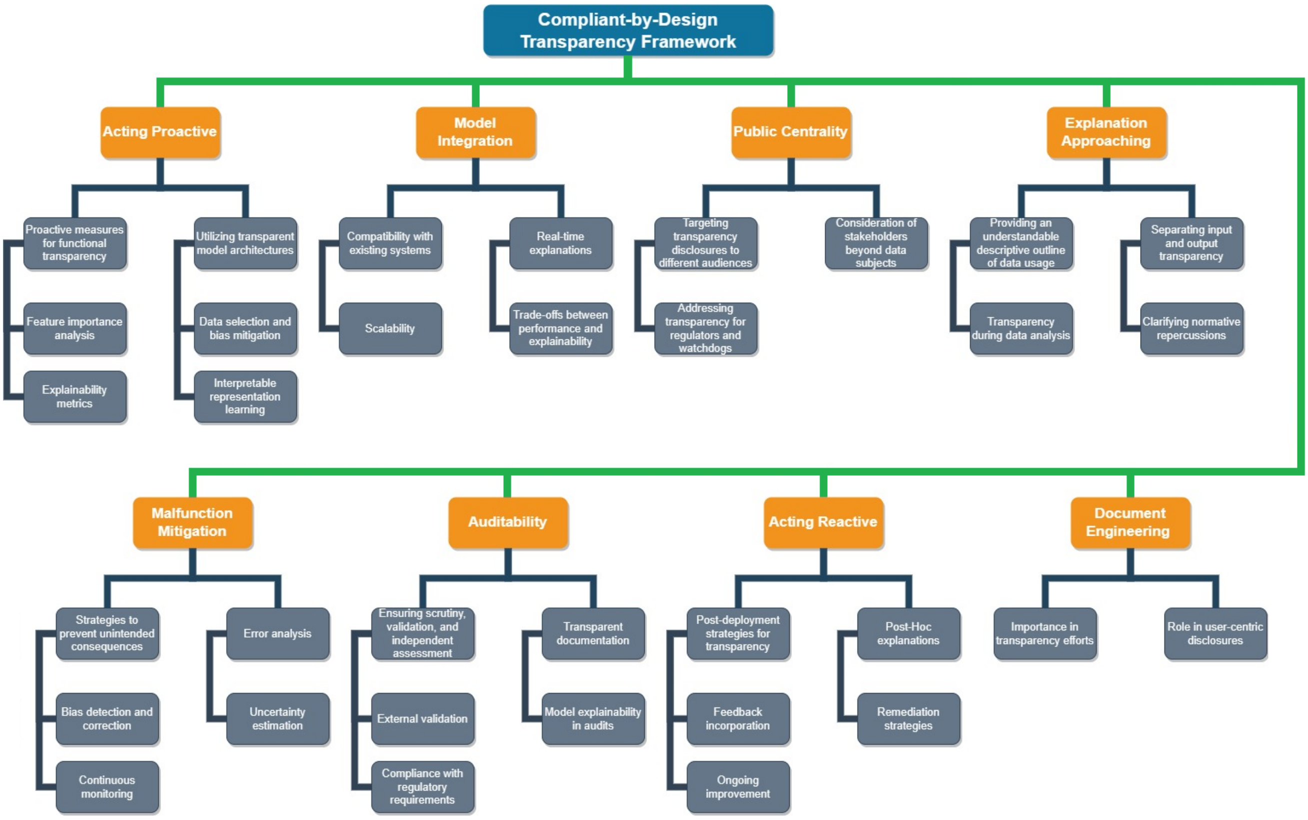

FIG. 4. Functional Transparency Model

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X. Toward State Of The Art Of Functional Transparency

Organizations have long struggled with the transparency dilemma in several contexts, including security and privacy. The inner workings of artificial intelligence models should be more transparent, have been argued by academics and practitioners in recent years, and for many excellent reasons. Fairness, prejudice, and trust are concerns that may all be lessened through transparency. These issues have all gotten more attention recently. It's a common belief in the field of data analytics that more data is always better. However, data itself is frequently a source of liability in risk management. The same is starting to be true with artificial intelligence. Organizations have long struggled with the transparency dilemma in several contexts, including security and privacy. All they must do is modernize their processes for AI. Companies aiming to use artificial intelligence need to understand that openness comes at a price. This is not to indicate that transparency is not desirable; rather, it is to point out that it also has drawbacks that must be properly appreciated. These expenses ought to be considered by a larger risk model that determines how to interact with explainable models and how much of the model's details are made public. Additionally, businesses need to understand that security is a growing risk in the AI industry. As my colleagues and I recently discussed at the Future of Privacy Forum, as AI becomes more extensively used, more security flaws and bugs will undoubtedly be found. In fact, one of the largest long-term obstacles to the adoption of AI may be security [24].

XI. Compliant-By-Design Adhering Functional Transparency

Calling for AI system transparency alone has little practical benefit. Transparency standards must be turned into actionable activities. To offer such useful advice, the compliant-by-design transparency principles were created. As a result, our approach concentrates on basic design criteria, user-oriented system information providing, and the organizational management of system transparency. The Compliant-by-Design Openness Framework's ultimate objective is to promote the advantages of transparency while simultaneously minimizing its drawbacks. When including the transparency requirement in the creation of AI systems, system designers, particularly engineers, and organizational stakeholders are held to these standards. Design-side requirements line up with other stakeholders' rights to openness and inspection, particularly users and third parties. The transparency principles' primary intended audience is engineers. Fig. 4 shows our design model of functional transparency.

A. Acting Proactive

Acting proactive refers to the proactive measures taken to ensure functional transparency and meaningful explainability in artificial intelligence (AI) systems. This subsection focuses on preemptive strategies that can be employed during the design, development, and deployment stages of AI models. The aim is to integrate interpretability and transparency features from the inception of the AI system, rather than trying to retrofit explanations after the model has been deployed. Key components of acting proactive include:

1. Transparent Model Architectures: Utilizing model architectures that inherently promote interpretability, such as decision trees, rule-based models, or explainable neural networks.
2. Feature Importance Analysis: Identifying and analyzing the most influential features in the model's decision-making process, providing insights into its behavior.
3. Data Selection and Bias Mitigation: Ensuring that the training data used for the AI model is diverse, representative, and free from biases that could lead to unfair or unethical decisions.
4. Explainability Metrics: Defining quantitative metrics to assess the level of explainability of the AI system and continuously improving it based on these metrics.
5. Interpretable Representation Learning: Exploring techniques that learn feature representations that are easier to understand and interpret.

B. Model Integration

Model integration refers to the process of seamlessly incorporating explainable AI models into real-world applications and systems. This addresses the challenges and opportunities of deploying interpretable AI models in complex environments where transparency is crucial. Key considerations in model integration include:

1. Compatibility with Existing Systems: Ensuring that the explainable AI models can be easily integrated with existing infrastructures, APIs, and frameworks without causing significant disruptions.
2. Real-time Explanations: Enabling the AI system to provide meaningful explanations in real-time to users, facilitating better trust and understanding.
3. Scalability: Designing interpretable models that can scale to handle large volumes of data and users without compromising on their transparency.
4. Trade-offs: Addressing trade-offs between model performance and explainability, as more complex models may offer higher accuracy but lower interpretability.

C. Public Centrality

The relational character of transparency communications must be respected by AI system developers. Therefore, it is not enough to simply provide information; one must also consider who is most likely to receive and understand it. The transparency obligation will change based on who the anticipated information recipient is, as is noted. Although the primary recipients of personal information processing are the individuals whose data is being used, it is important to be aware that other stakeholders must also be considered. These stakeholders may include distinct categories of system users, regulators, watchdogs, or the public, depending on the nature and function of the system in question. The information offered to the affected individual, where specific information needs for decision-making on the individual will be the key focus, will need to differ from information intended at the

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wider public, where queries about general functioning would be prevalent. Unlike the public, government agencies, regulators, and independent watchdogs would receive information that was not only specific to their needs but also possibly more technical in nature. This is because it can be assumed that these institutions, unlike the public, have relevant specialized expertise at their disposal. If transparency disclosures are targeted at regulators or trained third parties that represent the public interest rather than data subjects themselves, they may have a greater impact. The need to make decisions understandable to affected people, the public, regulatory bodies, or watchdogs is also closely related to avoiding public mistrust and suspicion.

D. Explanation Approaching

This principle calls for the provision of an understandable descriptive outline of the data being used by the system and the ways in which it is being used, including information on what stages of data processing are inspectable and where human discretion, intervention, or oversight occurs in the system. This is necessary considering the potential technical limitations on the explainability of decision-making of complex AI systems. The system can use data for several purposes.

The system's operation and any biases are defined by the previous stages, even if the stakeholders' main transparency objectives pertain to the consumption stage. Therefore, one could argue that to fully comply with the transparency requirements at this time, access should be given to the working protocol analysts use for these preliminary parts of the prediction tasks, such as the display of the data that was utilized for analysis. Transparency in input and output can be separated. Input openness often comes at an excessive cost and offers little benefits, in part because of the potentially enormous volume. Technical transparency during data analysis might imply that the program used to make automated choices should be made public. If specialized software is employed, this gets increasingly difficult since requiring such openness can violate people's legal rights to their intellectual property. Systems with characteristics that may be examined by relevant parties without disclosing the code or input data can help with these problems. This might aid in the design of systems that are open about the characteristics that matter for a certain automated judgment while safeguarding personal information and keeping trade secrets hidden. A need for transparency might be the revelation of the real methods and procedures used to use the data. The precision that the Fairness, Accountability and Transparency in Machine Learning [22] principles define should be part of this. Depending on whether such openness is intended for professionals or laypeople whose information demands are more general and less technical, the criteria for delivering such information may seem different. Making information about a system intelligible for the broader public is regarded to be the definition of explainability. Where there is human judgment, control, or supervision, transparency information must also be disclosed.

The practice of explainability to ensure transparency begins through properly explaining the process of processing data with meaningful insights. The data processing process is iterative and may involve multiple rounds of analysis and refinement to improve the quality of insights obtained from the data. Additionally, data processing can also include data cleaning and preprocessing steps to ensure the data's accuracy, completeness, and consistency before performing analysis and extraction.

1. Data Collection: Data collection is the first step in the process of data processing. In this step, raw data is gathered from various sources, such as databases, sensors, logs, surveys, social media, or any other relevant data sources. The collected data can be structured, semi-structured, or unstructured.
2. Data Aggregation: Once the data is collected, the next step is data aggregation. In this step, data is organized and combined to form a larger dataset. Aggregation may involve summarizing or grouping the data based on specific attributes or criteria. The purpose of aggregation is to reduce data volume and to provide a more concise and manageable dataset for analysis.
3. Data Analysis: After data aggregation, the data is analyzed to derive meaningful insights and draw conclusions. Data analysis involves various techniques and methods, such as statistical analysis, machine learning, data mining, or any other domain-specific analysis approaches. The goal is to uncover patterns, trends, correlations, or anomalies within the data.
4. Data Extraction: Data extraction is the final step in the process. In this step, the relevant insights and information obtained from data analysis are extracted and presented in a usable format. This can involve generating reports, visualizations, or data summaries that provide actionable insights to support decision-making processes.

Transparency is required when it comes to the influence of human decision-making, which may be prone to biases, such as when it comes to the development and selection of training data. A right to be exempt from automated decision-making that might have a significant impact on one's life legally or in other ways is specifically included in the General Data Protection Regulation [23]. Therefore, disclosures about when and how such human interaction occurs must be included in transparency standards. Along with disclosure of the descriptive aspects of data processing, the variables that influence decision-making should be considered. These normative norms carry implicit meanings in them. Clarifying normative repercussions is necessary for the implicit decision-making criterion to be transparent. They discuss the limitations of various explanation approaches before settling on an interpretation of explanation that is intricately linked to the idea of interpersonal justifiability rather than aiming for a precise descriptive representation. The following crucial aspects of justifiability must be addressed why certain data are a normatively acceptable basis for drawing inferences and why these inferences are normatively acceptable and relevant for the chosen explanation. When evaluating data processing, it is important to look both ahead, at the data sources that are connected to the desired outputs, and backward, at the underlying assumptions that influence how we, as data subjects, are seen and assessed by outside parties. It is

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important to closely consider how data sources and conclusions relate to one another. The level of privacy invasion caused by processing, the counter intuitiveness of the inferences, the specific intentions driving the processing, the use of potentially discriminatory features, the potential repercussions of deriving sensitive information from non-sensitive information, the acceptability of doing so according to norms, and the racial and ethnic composition of the source data could all be relevant issues to discuss in the context of justification.

E. *Malfunction Mitigation*

Malfunction mitigation deals with strategies to prevent or minimize unintended and harmful consequences of AI systems due to misunderstandings, biases, or errors in the decision-making process. This subsection emphasizes the need to identify and address potential issues before they lead to negative outcomes. Important components of malfunction mitigation include:

1. Error Analysis: Conducting thorough error analysis to understand the types of mistakes the AI model is prone to make and developing targeted solutions to rectify them.
2. Bias Detection and Correction: Implementing mechanisms to detect and correct biases in the model's predictions, ensuring fairness and ethical decision-making.
3. Uncertainty Estimation: Incorporating uncertainty estimation techniques to communicate the confidence levels of the AI system's predictions, especially in critical scenarios.
4. Continuous Monitoring: Setting up continuous monitoring and auditing processes to identify and rectify malfunctioning AI models in real-time.

F. *Auditability*

Auditability focuses on ensuring that AI systems are subject to scrutiny, validation, and independent assessment of their performance and behavior. This subsection highlights the importance of third-party audits and evaluations to gain trust and confidence in AI applications. Key aspects of auditability include:

1. Transparent Documentation: Providing comprehensive documentation of the AI model, including its architecture, training data, hyperparameters, and explainability mechanisms.
2. External Validation: Allowing external auditors and evaluators to assess the AI system's performance and transparency, promoting accountability and reducing bias.
3. Model Explainability in Audits: Ensuring that explanations provided by the AI model are understandable and meaningful for auditors to assess the system's decision-making process.
4. Compliance and Regulatory Requirements: Aligning with relevant regulations and guidelines for AI transparency, explainability, and auditability.

G. *Acting Reactive*

Acting reactive refers to measures taken in response to unforeseen issues, ethical concerns, or legal requirements regarding AI transparency and explainability. This subsection deals with post-deployment strategies to address challenges and continuously improve AI systems' transparency. Key components of acting reactive include:

1. Post-Hoc Explanations: Developing techniques to explain AI model decisions retrospectively, even for black-box models, to understand the factors influencing predictions.
2. Feedback Incorporation: Integrating user feedback and input into the AI model to improve its transparency and correct potential misconceptions or biases.
3. Remediation Strategies: Implementing strategies to rectify issues related to transparency and explainability discovered after the AI system is deployed in real-world scenarios.
4. Ongoing Improvement: Establishing a feedback loop for continuous improvement of the AI model's transparency and explainability over time.

H. *Document Engineering*

Both academia and business are paying more and more attention to the problem of transparency in machine learning models and datasets [9] [15]. The objective has frequently been to increase visibility into ML models and datasets through source code disclosure [15] [10], contribution histories [11] [15], the introduction of ML-driven data analysis techniques, and the introduction of varied supervision [15] [12]. In terms of regulation from government entities throughout the world, transparency and explainability of model outputs via the lens of datasets has become a major problem. However, in research and industrial contexts, efforts to develop standardized, real-world, and long-lasting methods for transparency that provide value at scale encounter little success. This reflects the limitations imposed by the diversity of aims, processes, and backgrounds of the various stakeholders involved in the dataset and artificial intelligence system life cycles [1] [13] [14].

Engineering must also pick up new abilities. The ability to style papers according to specifications in the forms needed by the contract, professional society, or internal norms is now just as important as the ability to write effectively and concisely. Engineering owes readers an additional duty. It must recognize that it is an essential part of the new cost-competitive emphasis that is changing the way engineering companies conduct business: If it doesn't increase the bottom line, change it so that it does, or get rid of it. It must also understand the standard writing skills of audience identification and writing clearly to those audiences.

The process of defining, creating, and implementing the information models that support document-centric applications is known as document engineering [6] [7]. To create documents that are more generic and resilient, it is necessary to describe various information and data sources using new document models. A key paradigm in the shift from people-oriented documents to technical schemas, document

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engineering is supposed to help make information flows more uniform, organized, compatible, and visible across stakeholders.

To simplify and automate document sharing inside and across organizations, Document Engineering looks for commonality in forms and transaction documentation. Relationships inside organizations are thought of as a series of document exchanges where the parties are aware of one another's papers. Documents are seen in this sense as disclosing the inputs and outputs of business operations, where they act as the organization's public face [6] [7]. Document Engineering technique is based on the needs of the stakeholders and involves the breakdown of current information sources into the reconstruction of associated documents.

Because Document Engineering seeks to make document interchange more organized, consistent, and intelligible, it stands to reason that the technique may be used to produce disclosures that are user focused. Since disclosures are essentially documents, we may examine instances of present disclosure procedures and then reconstruct them as user-facing documents with interfaces that are more logical and better suit the needs of their receivers. Therefore, after the content of those papers is defined, Document Engineering works in conjunction with design techniques, documentation approaches, or any number of other viable methods to develop and adapt the look of those disclosures. although the usage context varies.

Once more, Document Engineering is only one method for producing disclosures that are more relevant. Our goal in describing how we may use this technique is not to make the case that this is how disclosures need to be made or that Document Engineering will be appropriate in every circumstance. Instead, we highlight one-way interfaces offer a fresh approach to information disclosures that are tailored to receivers' requirements.

TABLE IV. Process Of Document Engineering

Organization Level	Analyzing Business Process	Analyzing Context of Service	
Process Level	Applying Pattern on Process Models	Implementing Process and Documents Models	
	Assembling Document Models		
Information Level	Assembling Document Components	Analyzing Document Components	Analyzing Documents
	Conceptual Models	Physical Models	Implementation Models

1. Process of Document Engineering: Understanding multi-modal datasets that provide models nuance rapidly becomes more difficult as research and business progress toward large-scale models capable of many downstream functions. The responsible and informed deployment of models, especially those in human-facing contexts and high-risk domains, requires a clear and full knowledge of a dataset's origins, development, intent, ethical issues, and evolution. However, the documentation's clarity, succinctness, and thoroughness frequently bear the weight of this knowledge. All the dataset's documentation must be consistent and comparable, and as a result, documentation must be seen as a standalone user-centric product. The Document Engineering process, which is crucial because disclosure interfaces require an iterative approach to be refined and adjusted as systems, usage contexts, and requirements change and as the overall landscape of transparency regimes continue to change. This is like how the applications themselves are developed. In Table 4, we can see that effective documentation can be maintained through its 4x4 matrix requirements.

Processes in document engineering [6] [7], which we now described being applied to a disclosure context.

1. Conceptual Analysis: Analyzing the settings in which the process' output, in this case the disclosure, will be utilized is a component of document engineering. When discussing disclosures, this entails figuring out who the possible stakeholders are and what they would hope to gain from the disclosure, which serves as the basis for the subsequent analysis. It is crucial to consider the legal restrictions that the disclosure must adhere to. The results of it are frequently universally relevant across a variety of disclosures, and as a result, the settings of applications may be comparable across a variety of organizations and industries. As was previously said, a common need for revealed information is that it should be contextually suitable and provide information that is accurate, relevant, proportionate, and understandable [7] [8]. The way disclosure data is presented will inevitably have an influence on each of these areas, and it can help determine how disclosure interfaces might better enable stakeholders to participate in the processing of their personal data. Afterward, investigating present business procedures Here, we considered the kinds of data supplied as well as how this data is categorized, structured, and portrayed within existing disclosures using the variety of disclosures we acquired. With the help of these patterns, we were able to begin developing a suggestive model of the kinds of data that our model disclosure should probably include as well as how this data should be arranged and presented to create a more contextually relevant disclosure. Afterward, analyze the documents. This required analyzing the information in the disclosures we acquired, including their structure to determine how relevant material is categorized and whether visualizations or other modalities could be more appropriate given the context of the recipient's needs. To determine where the disclosures may more closely match user experiences.
2. Implementation: Begin developing component prototypes. This entails looking at several presentation options for disclosure data that have been reassembled

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into more relevant forms. The components are then put together to create a document model, which helps to fully grasp how the final document should be organized and how relevant components should be grouped. The new interface must then be operationalized and put into use. This requires the organization to implement the designed disclosure.

XII. LIMITATIONS

Every area of research, business, and government is still being transformed by the data revolution. We are becoming more conscious of the need to utilize data and algorithms responsibly in line with laws and ethical standards due to the enormous influence that data-driven technology has on society. There is a significant drive for organizations to increase their accountability and transparency. To this end, several transparency laws compel businesses to provide specific information to interested parties. With the use of this information, organizational activities are meant to be monitored, overseen, scrutinized, and challenged. However, it is important to note that these disclosures are only useful to the extent that their recipients find them valuable. However, the disclosures of tech/data-driven organizations are frequently extremely specialized, scattered, and hence of little use to anybody outside experts. This lessens the impact of a revelation, disempowers people, and thwarts larger transparency goals.

After conducting the research on explainable AI and the transparency of AI some fundamental outcomes have been founded like the importance of the transparency of AI, data and Algorithmic transparency mechanisms and the designs of the transparency techniques. But some major and minor areas are untouched in the research. The limitations of the research are:

1. Cons of the over transparency of AI and algorithm.
2. Transparency controlling mechanisms are also a limitation of the research.
3. Uncertainty accuracy for the algorithmic prediction.
4. Trustworthiness of the automation and advanced algorithms for artificial intelligence.

XIII. FUTURE RESEARCH OPPORTUNITIES

Though lots of studies are done and new studies are running to provide more transparency in Artificial Intelligent systems, there are still work to be done. Some of the future working sectors for transparency are listed below:

1. Researching how people feel about privacy and openness- How do people see privacy and transparency in regards to learning and control? When do individual actions align or deviate from the declared value?
2. Peer transparency vs hierarchical openness as a method of control- How do peer relationships differ from hierarchical ones in terms of the behavioral impacts of transparency/privacy? Do the outcomes alter depending on whether the witness and the witnessed are part of a stable structure or the general public?
3. Examining the value of trust and openness in society- How do trust and culture affect learning and control when it comes to openness and privacy?
4. Using different degrees of analysis to produce effective methods for balancing transparency and privacy- How does the observation of a person, organization, region, or entire company affect the perceived dangers and advantages of openness vs privacy? Is there a relationship between an institution's fundamental ambidexterity and how privacy is constructed?
5. Observed characteristics and their influence on how transparency and privacy affect behaviors- Do various characteristics affect how transparency and privacy work? Do different nations experience privacy and transparency differently? Do millennials behave differently in terms of openness and privacy?
6. Looking into the causes and processes of behavioral reactions to privacy and transparency- Does privacy serve an instinctive or strategic requirement in humans? How might neuroscience aid our understanding of how people behave when faced with openness or privacy?
7. Researching the effects of different types of transparency- Does the operation of physical such as open offices and digital such as open data transparency differ? How do process transparency and result transparency varies from one another? How do transparencies that are only momentary and persistent function differently? How do delayed transparency and rapid transparency differ from one another? How do mandatory and voluntary transparency differ from one another? How do anonymous and personally identifiable transparency vary from one another?
8. Methodological possibilities and difficulties- Mixed-method studies that blend privacy and transparency research approaches. Real-time field experiments that record information on both observer and observed viewpoints as organizations expand openness.

XIV. CONCLUSION

In this research paper, we have highlighted the significance of transparency and explainability in artificial intelligence (AI) systems. As AI becomes an integral part of our lives, understanding how these systems make decisions is crucial for ensuring fairness and accuracy. Achieving transparency, however, poses numerous challenges that must be addressed. We have proposed a user-centered, compliant-by-design approach for transparent systems. Our argument is that developing transparent and explainable AI systems is a complex endeavor that necessitates collaboration across multiple disciplines, including computer science, artificial intelligence, ethics, law, and social science. By emphasizing the need for transparency, we underscore the importance of enabling stakeholders to comprehend and trust AI systems. This research contributes to the growing body of knowledge surrounding transparency in AI and provides a foundation for future studies in this area. Moving forward, it is imperative that researchers, policymakers, and industry professionals work together to develop robust frameworks and guidelines for transparency and explainability. Only through

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interdisciplinary collaboration and ongoing research efforts can we ensure that AI systems are accountable, fair, and trustworthy, promoting their responsible and ethical deployment in society.

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CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Towards an Ethics for the Healthcare Metaverse

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***Abstract*—Harnessing the metaverse for medical and healthcare purposes is currently heralded as the "next frontier in healthcare." However, to ensure the "amazing possibilities" of the so-called "healthcare metaverse" can be fully realized, it's vital to proactively identify and address potential challenges, especially those of an ethical nature. This paper aims to spotlight these ethical challenges within the healthcare metaverse and chart a course for confronting these issues and cultivating an ethics framework for this emerging field. We will demonstrate that the ethical quandaries within the healthcare metaverse bear striking similarities to those seen in digital medicine, an arena that grapples with vast quantities of data and the application of artificial intelligence. Reflecting on these parallels, we explore how six central ethical challenges in digital medicine – 1) *accessibility*, 2) *fairness*, 3) *discrimination and bias*, 4) *responsibility*, 5) *privacy, data safety and security, and data ownership*, as well as 6) *environmental issues* – unfold within the healthcare metaverse's virtual boundaries and show that the metaverse's immersive nature further intensifies these ethical challenges. In view of this, we advocate that the next phase in forging ethics for the healthcare metaverse involves a nuanced reconsideration of current ethical methods and principles in digital medicine, with an emphasis on the immersive element of the metaverse. We foresee the concept of embodiment within virtual settings to be at the heart of this immersion-focused reassessment.**

Keywords*—*Virtual Reality, Medicine, Bioethics, Artificial Intelligence, Challenges

I. INTRODUCTION

For a long time, the possibilities of the metaverse were primarily explored in fiction, through novels like William Gibson's *Neuromancer* or Vasili Mahanenko's *Survival Quest* series, movies like *Ready Player One* or series like *Black Mirror*. Nowadays, the utilization of the metaverse for educational, advertising, commercial, and other purposes is gaining increased attention in real life. Its potential for healthcare is estimated to be particularly great [1] – with the metaverse already heralded as the "next technological step in the healthcare sector" [2] and the "next frontier in healthcare" [3]. Numerous researchers discuss the "amazing possibilities" [4] of the so-called "healthcare metaverse" and promise that it will make healthcare smarter, more accessible, and more efficient [5], contributing to a "revolution of the healthcare sector" [6] or, even more sensationally, a "revolution in health" [7].

Yet, beyond mere euphemistic statements, a rich tapestry of research has emerged surrounding the metaverse for healthcare purposes. On the technological front, researchers are probing the technical capabilities, striving to weave health data more seamlessly into the metaverse, and actively working to transform the metaverse into a full-fledged healthcare environment [8-10]. From the medical angle, the multifaceted applications of the metaverse are under exploration for diagnostic utility, treatment of a wide array of mental [11, 12] and physical conditions, preventative measures, and continuous patient monitoring [1, 13]. These applications span various developmental stages, encompassing everything from initial conceptual designs to practical trials [1]. Viewing from a social science lens, studies are being conducted to gauge how individuals perceive the potentials of a healthcare metaverse and their attitudes towards it. Similarly, educational initiatives are emerging that delve into the metaverse's capabilities for training medical practitioners [14, 15] or as a tool for public health communication and education [16, 17].

From an ethical standpoint, various studies have engaged with the ethics of immersive environments or the metaverse more broadly [18-20]. However, specific research focusing on the ethics of a healthcare metaverse remains notably scant. Aside from a few tentative approaches to the topic [21-23], there has been minimal exploration explicitly targeting the ethics of a healthcare metaverse. To ensure that the healthcare metaverse can fully realize its potential, a focused examination of this subject is not only necessary but essential. Investigating these ethical challenges and proactively addressing them will lay a strong foundation. This proactive approach can create safeguards that ensure the metaverse operates within the healthcare community in a manner that is both responsible and ethically sound, ultimately optimizing its efficacy and impact.

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We will pinpoint and address this existing gap by exploring the ethical challenges that the healthcare metaverse presents. In doing this, we will adhere to the conceptual framework laid out by Caitlin Curtis and Claire E. Brolan [24]. They portray the healthcare metaverse as an extension of the increasingly data-driven and AI-centric field of digital medicine. The healthcare metaverse not only builds upon but also broadens the trends and technologies of digital medicine by infusing the aspect of immersion [1]. In view of this context, we argue that the ethical challenges faced in the healthcare metaverse are comparable to those of "digital medicine", i.e., medicine that utilizes data and AI. However, the immersive nature of the metaverse magnifies several of these challenges, increasing the urgency to address them. Hence, to effectively address the ethical issues of the healthcare metaverse, we argue that it is crucial to reconsider or extend previous approaches to the ethics of digital medicine, taking into account the aspect of immersion.

II. Methods

To bolster our argument, we employ a mixed-methods approach that pragmatically combines conceptual analyses, comparative methods, and ethical reflections. First, we elucidate the concept of the "metaverse" and explore the opportunities it offers within healthcare. Second, in a comparative depiction, we demonstrate the benefits the healthcare metaverse has over other forms of telemedicine. These elucidations are rooted in an intensive examination and thorough literature review on the subject of the metaverse and healthcare, deepening the insights into the current research landscape on the subject of the metaverse in healthcare that were given above.

Against this conceptual background and building on the similarities between digital medicine and the immersive healthcare environments presented above [24], we proceed to identify and delineate the principal ethical challenges specific to the healthcare metaverse. We identify the key ethical challenges of the healthcare metaverse by considering scientific reviews that pinpoint the core ethical issues of digital medicine [25-27]. Among the many issues these three papers indicate, we select those that are particularly relevant to the context of the healthcare metaverse by critically assessing which of the challenges highlighted in the reviews are of particular significance in the context of immersive healthcare environments. This leads us to identify six core ethical issues: 1) *accessibility*, 2) *fairness*, 3) *discrimination and bias*, 4) *responsibility*, and 5) *privacy, data safety and security, and data ownership*, as well as 6) *environmental issues*. We then engage in conceptual ethical reasoning to illustrate how these ethical issues manifest themselves within the immersive environment of a healthcare metaverse.

In the *Discussion* chapter, we critically reflect on these insights. We initially conclude that the path towards an ethics of the healthcare metaverse starts with reimagining the ethics of digital medicine, aligning approaches and motives with the perspective of immersivity. In this context, we argue that embodiment is central for an ethics of the healthcare metaverse and propose a preliminary framework for further exploration in this direction. Then, we address the limitations of our reflections and pinpoint areas for additional research. Finally, we will synthesize our findings in a conclusion.

III. What is the Metaverse and How Can It Be Used for Healthcare?

Before we can explore the ethical challenges of a healthcare metaverse, we need to clarify what the metaverse is and how it can be utilized for healthcare purposes.

Following Matthew Ball, the "metaverse" can be understood as "[a] *massively scaled* and *interoperable network* of *real-time rendered 3D virtual worlds* that can be experienced *synchronously* and *persistently* by an *effectively unlimited number of users* with an *individual sense of presence*, and with *continuity of data*, such as identity, history, entitlements, objects, communications, and payments." [28] To unpack this dense definition, the term "metaverse" typically refers to a virtual universe filled with various worlds that individuals can enter as avatars or virtual representations of themselves, engaging and interacting in real-time with their virtual environment, other users, or artificial characters [29]. Virtual worlds in the metaverse can be created and hosted by users themselves, private-sector companies, or non-profit organizations, and range from replicas of real-world settings to fantastical worlds. Unlike regular video games or movies, which are viewed on a monitor, the optical "immersion" in the metaverse usually takes place via head-mounted displays. This increases the immersivity of virtual worlds and allows users to experience their digital environment and interactions with other characters as very lifelike [30]. The avatar is controlled either via handheld controllers, via sensors attached directly to the body that determine the position of certain body parts and transmit them to the avatar ingame, or a combination of both. While the metaverse has primarily been used for gaming and entertainment purposes for a long time, its application for healthcare has recently garnered significant attention [4].

One of the most significant opportunities of the metaverse for healthcare is the establishment of so-called "virtual hospitals" [31], i.e., virtual environments resembling real clinics or medical practices that individuals can "enter" for diagnosis, medical care, or health education. According to Patel and Shokouhi [32], virtual hospitals can serve as substitutes for traditional medical practices and clinics, allowing individuals to receive medical care and advice in a virtual environment. This is especially beneficial for those who face challenges in visiting a physical doctor or clinic, such as those living in remote locations or with limited mobility. Virtual clinics employ both human and AI doctors, with the latter handling routine diagnoses, thereby reducing wait times for patients and allowing "real" doctors to focus on more complex cases. This enables a smaller number of human doctors to care for a larger number of virtual patients, alleviating the burden on real-life hospitals and emergency rooms – as people who would otherwise have visited for a diagnosis can now be diagnosed in the metaverse and are only referred to a "real" clinic if a virtual diagnosis is inconclusive or if a serious illness is suspected.

It is also possible to perform certain treatments in virtual environments. Particularly significant potential is emerging in the treatment of mental illnesses such as body dysmorphism symptoms, anxiety disorders, or social deficits [11, 12]. For

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example, it is possible to expose patients to virtual stress situations and, under professional supervision, train them to cope with them. Additionally, there is further potential for rehabilitation measures [33], such as professionally instructing people to perform specific physical rehabilitation exercises and tracking and evaluating their progress – has the patient's mobility or physical endurance improved or deteriorated? – in real time using sensors [4]. Treatments like these can be administered and supervised equally by medical experts or by specialized AI.

Moreover, the metaverse offers new avenues for health communication [16, 17] and medical education [14, 15, 34]. For instance, aspiring doctors can utilize immersive simulations to gain a deeper understanding of human anatomy and various organs [35]. They can also practice making diagnoses and performing treatments using both real and simulated patients. Furthermore, patients can be educated about various health conditions and preventive measures through virtual representations, empowering them to make more informed decisions about their wellbeing [16]. Altogether, this can lead to a better educated and empowered patient population, and a more skilled and efficient healthcare workforce.

Last but not least, the potential to provide easier access to medical services significantly broadens its scope, a development that could profoundly influence the entire healthcare system, including public health concerns [36]. This opens exciting possibilities for preventive health initiatives such as stress reduction, burnout prevention, and rehabilitation outside of traditional healthcare settings, like physiotherapy. This potential for widespread health care accessibility signifies a promising leap toward comprehensive and inclusive health care.

IV. What is the Advantage of a Healthcare Metaverse Compared to Other Forms of Telemedicine?

The benefits of a healthcare metaverse seem to be numerous, but one might ask why we need it. Telemedicine can be conducted over the phone or through videochat, and collaboration among specialists, consultation with AI, creation of stress scenarios for training purposes, and instruction and assessment of rehabilitation exercises can also be achieved through more traditional communication channels. Neither medical education nor health communication necessarily require immersion in virtual environments. So, if all these things can be accomplished without the metaverse, what are its unique advantages and its "amazing possibilities" [4]?

Admittedly, diagnoses do not work any better in the metaverse than via telephone or video calls. After all, you do not need an immersive environment to describe symptoms to doctors. If patients want to ask their doctors about physical abnormalities they are concerned about, this might even work better via webcam than with an avatar in the metaverse, as questionable abnormalities can be shown via webcam, but not on the avatar. And for diagnoses that require physical examinations, all these media are equally useless.

However, when it comes to virtual treatments, medical education or health communication, the metaverse can unfold great potentials thanks to its immersive nature as well as the extremely vivid experiences and more direct interactions of the persons with their virtual environment and characters that it allows [37]. Simulated stress or anxiety situations in the metaverse can appear much more real and engaging than "experiencing" them on a screen or imagining them in one's mind. As a result, treatment sessions can be more "lifelike", and patients may have a greater chance of success in learning to deal with such challenging situations [4]. Virtual rehabilitation measures can also benefit from the metaverse's immersivity. A more engaging environment and intensive interaction with a counterpart or training partner can increase motivation and spur patients to perform physical exercises more effectively, as some may have experienced in real-life gym situations. Something similar is true for medical training and health communication, which can also benefit from the immersive nature of the metaverse and its enhanced visualization techniques [38]. In medical education, the improved visualization techniques of the metaverse can expose future physicians to lifelike situations similar to their later everyday work [39], providing them with "practical experience" and bridging the theory-practice gap that exists between theoretical training in medical school and its application in practice. The immersive nature of the metaverse can also aid in health communication. In addition to contributing to better understanding, providing vivid demonstrations of the consequences of compliance or non-compliance with preventive measures, patients may be more likely to implement these measures consistently [16].

In summary, while the metaverse may not open up entirely new possibilities, it has the potential to significantly improve the effectiveness of various telecare, medical education, and healthcare communications. Key to this is the metaverse's strong immersive capabilities, that are enabled by combining advanced communications, data processing, AI, and visualization technologies [8].

V. What are the Ethical Challenges of a Healthcare Metaverse?

For the healthcare metaverse to operate effectively, it requires a large software and hardware ecosystem, including virtual worlds and servers for hosting, end-user devices for controlling avatars, and significant computing power and fast internet connectivity [8]. Only when these components are available and integrated can the healthcare metaverse unfold its full potential [8]. However, in addition to the technical and associated financial, social, and coordination challenges, as well as the legal challenges [40], the healthcare metaverse also presents ethical challenges. As highlighted in a scoping review by Petrigna and Musumeci [41], little has been written about these.

As mentioned in the previous section, the healthcare metaverse closely aligns with various advances in digital medicine, including telemedicine and the application of medical data and AI tools. A new aspect added to the metaverse is that of immersivity. As the healthcare metaverse can be seen as an extension of digital medicine [24], it seems plausible that its ethical challenges would also manifest as expansions of the ethical challenges inherent in digital medicine. Thus, to identify the ethical challenges of the healthcare metaverse, we will examine the key ethical

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challenges of digital medicine and explore how these challenges manifest themselves within the context of an immersive healthcare setting.[1]

In order to identify the key ethical challenges of digital medicine, we engaged with systematic reviews that were specifically concerned with these central ethical issues [25-27]. By critically assessing which of the issues highlighted in the reviews are of particular significance in the context of the healthcare metaverse, we pinpointed the key ethical concerns. Though there are undoubtedly more ethical challenges associated with digital medicine, we recognized the following six as being fundamental to our analysis: 1) *accessibility*, 2) *fairness*, 3) *discrimination and bias*, 4) *responsibility*, and 5) *privacy, data safety and security, and data ownership*, as well as 6) *environmental issues*.

A. Accessibility

The healthcare metaverse promises to make medical care more accessible, especially for people who cannot physically visit hospitals or doctor's offices due to illness or old age. However, comprehensive use of the healthcare metaverse and receiving high-quality virtual medical care require expensive software and hardware, such as head-up displays and controllers, a powerful computer, a fast Internet connection, and ideally, additional sensors [38]. These requirements are currently quite costly [4]. Additionally, there is still a digital divide, and many older people struggle to use the necessary technologies and navigate virtual worlds. These factors are problematic, as the healthcare metaverse is intended to provide high-quality healthcare to older individuals and those with lower socioeconomic status. While these accessibility issues may not directly relate to immersivity itself, they are related to the prerequisites necessary for immersivity.

B. Fairness

Although the healthcare metaverse allows doctors to diagnose and treat more patients efficiently, it does not guarantee that every patient will be seen immediately. Even in virtual hospitals, patients may have to wait for a human doctor's appointment, sometimes for several hours [32]. Alternatively, patients may choose to schedule an appointment with an AI-doctor, which raises the question of how access to doctors is fairly coordinated in the healthcare metaverse. Specifically, there is a concern that some patients may pay for premium access to skip the digital queues, while others have to wait for extended periods or settle for AI doctors [8]. Although these issues also exist in the "real-world", they become more acute in the metaverse. In real hospitals, patients can detect preferential treatment and lodge complaints when others who came after them are "served" first, or when they only interact with AI doctors. However, in the metaverse, it is challenging to track who waits for how long or who receives priority. It is also difficult to differentiate between "real" and AI-doctors.

C. Discrimination and bias

Discrimination and bias are a risk wherever data are analyzed, particularly when done with the help of AI [42]. There is a danger that certain groups of people are over- or under-represented in the training data, which can lead to biased or one-sided results [24, 43]. For example, if self-learning algorithms are primarily fed with data from white males, this can produce biased or worse results for women, people of color, and especially women of color [44]. In face-to-face situations, physicians have the possibility to recognize and address such biases and discrimination. If a Black person, for example, is in front of them and they know that Black persons may be underrepresented in the AI's training data, they can critically examine the results and recommendations to uncover any biases and false results. However, in the healthcare metaverse, physical cues do not exist. A person with female genetics can give themselves a male avatar, and someone with darker skin can assume a white avatar [45]. This lack of cues can prevent doctors from being particularly sensitive to potential biases and can lead to discrimination going undetected.

D. Responsibility

Extensive discussions on AI ethics have highlighted that whenever AI is used, there is a risk of "responsibility gaps" [46] or "responsibility diffusion" [47]. This means that it is almost impossible to clearly identify who can be held morally responsible and legally accountable for the outcomes of a decision made with the help of AI. This proves particularly problematic in the medical context, and even more challenging when AI is used in the healthcare metaverse. For instance, if an AI-assisted diagnosis made in the healthcare metaverse is found to be incorrect, it can be more difficult than in real life to determine who is responsible for the error and whether it is due to a technical deficiency or lack of safeguards in the virtual environment, or human error. Human errors, such as incorrect diagnoses by physicians or retrospective unwise decisions by patients, are an inherent part of healthcare. However, distinguishing the source of these errors can be complex. For instance, if a medical misdiagnosis is apparent, it is necessary to ascertain whether the doctors made an erroneous decision despite having accurate data or if the data they were given was faulty, ambiguous, or skewed in the first place. In the former scenario, the responsibility would lie with the physicians for misinterpreting data, even if it was generated by an AI system [48]. However, in the latter scenario, the physicians would be absolved of blame. This is because, within the metaverse, they must rely on the data they receive without any means to validate its veracity or confirm the positioning of the sensors that recorded it. In cases where a patient's decision leads to a negative outcome, it can be challenging to determine the role of the virtual environment in the wrong decision, and whether the patient would have made a different decision in a real-world setting. These complexities underscore how much the virtual environment of the healthcare metaverse can make the attribution of responsibility more difficult.

[1] Alternatively, we could adopt a reverse approach, starting with the metaverse's ethical challenges and examining their implications for healthcare. However, since new ethical questions frequently arise in healthcare, we believe it's more effective to begin with the ethical challenges of digital medicine and investigate how they are transformed when the metaverse's immersive dimension is introduced.

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E. Privacy, data safety and security, and data ownership

The generation of data, particularly medical data, invariably raises issues concerning privacy, data security, and ownership. Key questions that emerge include who owns the data, who has the authority to control and use it, and for what reasons – be it treatment, research, advertising, or monetization [23, 41, 49]. How effectively is this data shielded, and to what extent is user privacy safeguarded against invasive attempts and malicious hacking [24, 31]?

As the healthcare metaverse generates and transmits medical data extensively [22], and patients may be more predisposed to divulging sensitive details such as personal health records, medical history, treatment preferences, or even financial information due to the perceived trust and intimacy within the virtual environment, these concerns become increasingly urgent [50].

TABLE I. ETHICAL CHALLENGES OF THE HEALTHCARE METAVERSE

Challenges	**A comparison of the ethical challenges of digital medicine and the healthcare metaverse.**	
	Ethical challenges of digital medicine	***Ethical challenges of the healthcare metaverse***
Accessibility	Access to quality medical care, encompassing state of the art medical devices and digital applications, should ideally be universal [25-27]. Nevertheless, the high cost of specialized medical equipment often restricts its availability to limited locations. This scarcity poses a particular challenge for individuals who are rendered immobile due to illness or the natural aging process, hindering their ability to access specially equipped medical facilities [38].	The healthcare metaverse proposes to bolster accessibility by enabling individuals to attend virtual clinics or engage in virtual medical consultations from anywhere in the world. However, utilizing the healthcare metaverse entails having the necessary hardware and software, as well as the technical proficiency to operate them [38]. First, these requirements can prove to be prohibitively expensive [4]. Second, it's often the case that older individuals find it particularly challenging to navigate such technologies [38]. This can exacerbate accessibility issues – especially for those already grappling with them.
Fairness	The principle of equal access to high-quality medical care is a fundamental one [25-27]. Yet, in practice, disparities often exist where individuals with greater financial resources receive preferential medical treatment. This can manifest as shorter waiting times or access to better facilities and cutting-edge equipment.	The healthcare metaverse promises to enhance fairness in healthcare provision. It allows for patients to immediately book appointments with AI doctors, who, by design, treat all patients impartially. However, the availability of human doctors within the healthcare metaverse remains limited [32]. There's a looming risk that wealthier individuals might purchase premium access, thereby receiving preferential treatment [8]. This form of preferential treatment in the metaverse is less noticeable and overall, lacks transparency.
Discrimination and bias	Medical algorithms are often skewed, as they are trained predominantly on data from white males [24, 42, 43]. This bias in data collection can result in AI diagnoses and treatment suggestions that are less accurate and less effective for, e.g., women and people of color [44].	The use of virtual environments and fictional avatars in the metaverse can make it more challenging for doctors to discern their patients' gender or ethnicity [45]. While this could potentially mitigate human biases and discrimination [45], it simultaneously complicates the recognition of any biases and discrimination present in AI diagnoses or treatment recommendations. The reason being, doctors might be less sensitized to the fact that their patient belongs to a group underrepresented in the training data used for AI.
Responsibility	When AI comes into play for making medical diagnoses or suggesting treatments, the landscape of responsibility can become muddled. It grows unclear who – be it the doctor, the AI, or other involved parties – holds moral responsibility for certain decisions and who is legally liable for any resultant consequences [46, 47].	Within the realm of the healthcare metaverse, these blurred lines of responsibility intensify. Added to the puzzle of determining responsibility – whether it falls on the doctor, the AI, or other parties – is the question of whether the same decisions would have been made by doctors in a real-world setting [48]. The degree to which the virtuality of their environment influences their decisions introduces yet another layer of complexity.
Privacy, data safety and security, and data ownership	Digital medicine operates with vast quantities of data, some of which are particularly sensitive. This triggers pressing questions about who rightfully owns this data, how well it's protected, and who has the authority to utilize and dictate its use [23, 24, 31, 41, 49].	In the metaverse, issues concerning data safety and security, privacy, and ownership become even more heightened. This amplification results from two primary factors. First, the metaverse creates a higher volume of data compared to traditional digital medicine [22]. Second, the perceived level of trust and intimacy within the virtual environment might encourage patients to share more sensitive information [50].
Environmental issue	Digital medical tools, particularly those involving AI applications, demand extensive computational resources and produce enormous volumes of data [55]. This process is intrinsically linked to a high level of energy consumption, resulting in the substantial emission of greenhouse gases.	The process of creating the virtual environments for the healthcare metaverse, and coordinating them across multiple devices in real-time, demands an even greater level of computational power and generates even more data than traditional digital medicine. This leads to a corresponding increase in the emission of greenhouse gases [56]. Additionally, the VR devices raise concerns about their recyclability and the potential for electronic waste [57].

Table 1. Overview of the ethical challenges of the healthcare metaverse (right column) in direct comparison to the ethical challenges of digital medicine (left column).

Another crucial challenge to address is this context is: how to utilize the collected data for collective benefit – such as enhancing existing systems – while ensuring individuals retain control over their personal data. Navigating this delicate

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balance between communal progress and personal autonomy is a central task in the burgeoning field of virtual healthcare [51, 52].

F. Environmental issues

From an environmental standpoint, the digital transformation of medicine emerges as a double-edged sword. On the one hand, digitalization enables the execution of virtual meetings, including medical consultations or check-ups, thereby reducing travel and, in turn, cutting significant greenhouse gas emissions. Some optimistic studies even posit that the incorporation of digital and AI tools might lower the global healthcare carbon footprint by up to 80% [53]. With the advent of the healthcare metaverse, the possibilities for telemedical diagnoses, treatments, and continuous monitoring will grow further, potentially yielding additional savings in greenhouse gas emissions [54].

On the other hand, digital medical instruments themselves consume vast amounts of energy, consequently generating an immense volume of greenhouse gases. The training and deployment of medical AI systems, which manipulate extensive data and therefore necessitate multiple servers and robust computing capacities, are especially energy-hungry [55]. While no specific figures or projections are available at present, it seems plausible to assume that the healthcare sector's carbon emissions will experience a substantial surge with the advent of a healthcare metaverse. Crafting virtual environments demands high-powered processors and GPUs, producing copious data that must be transmitted globally and updated on multiple devices at millisecond intervals, both of which consume significant energy resources [56].

Beyond the extraordinary energy needs and the resultant greenhouse gas emissions, end devices, such as smart glasses and high-performance equipment, require a plethora of rare resources. Their extraction often involves intensive energy and water usage. Moreover, questions loom regarding the recyclability of VR devices. Will they, like much other electronic waste, ultimately find their way into landfills or other parts of the environment? [57] The answer remains uncertain, adding yet another layer to the complex environmental equation of the healthcare metaverse.

G. Summary

To elucidate the ethical challenges of the healthcare metaverse, we will condense the insights from this chapter into a table. Table I will serve to succinctly outline the ethical challenges unique to the healthcare metaverse, drawing clear parallels with corresponding challenges found in digital medicine. By doing so, we aim to underscore how the immersive nature of the healthcare metaverse amplifies existing ethical dilemmas within digital medicine, rendering them even more urgent and demanding of our attention.

Table I's rows list the individual ethical challenges that have been addressed in this chapter. In the columns, these issues are contextualized, showing how they manifest in digital medicine (in the left column) and in the context of the healthcare metaverse (in the right column). Content-wise, the table doesn't introduce any new insights – instead, it serves to succinctly summarize the material explored in this chapter, making it more accessible and easily digestible.

VI. Discussion

Having now provided an overview of the central ethical challenges of the healthcare metaverse, we wish to discuss these insights a little bit further. First, we will consider how one might address these challenges and propose next steps towards developing a convincing ethics of the healthcare metaverse. Then, we will identify some limitations of our investigation.

A. Next steps towards an ethics for the healthcare metaverse

In the preceding chapter, we conducted an examination of the ethical challenges pertinent to the healthcare metaverse. Our investigation was founded on two key premises: first, that the ethical challenges encountered within the healthcare metaverse parallel those found in digital medicine; and second, that the metaverse's element of immersivity intensifies the urgency of these challenges. What do these findings mean for the next steps toward an ethics for the healthcare metaverse?

If the ethical challenges of the healthcare metaverse parallel those of digital medicine, only amplified by the metaverse's immersivity, it seems logical to approach ethics for the healthcare metaverse from the perspective of digital medicine. Consequently, we should reevaluate approaches and principles from the ethics of digital medicine, such as data sovereignty [58, 59], explainability [60], or meaningful human control [61-63], in light of the immersive aspect.

The journey towards crafting a comprehensive ethics of the healthcare metaverse commences by grounding it in the ethical principles and approaches of digital medicine, and then reexamining and reshaping them against the backdrop of the metaverse's immersive nature. Thus, the next step is to cultivate a nuanced understanding of the metaverse's immersive characteristics. As emphasized by Liam Jarvis in his seminal work Immersive Embodiment [64], the concept of embodiment within immersive environments is set to play a pivotal role.

Indeed, as alluded to earlier, immersion promotes a sense of disembodiment, liberating individuals to explore places, execute actions, and interact without leaving the comfort of their home, involving themselves in strenuous movements, or engaging in direct face-to-face encounters. Nonetheless, the physical body retains a critical role in this new frontier, serving a dual purpose: first, in controlling the avatar, and second, as a driving force propelling individuals to venture into the healthcare metaverse. After all, the motivation behind seeking virtual clinics is not for the welfare of the virtual avatar, but rather for the health of the user's physical body.

Recognizing this, it becomes clear that the physical experience within these immersive technologies warrants significant attention. In the future, it will be particularly important to study this empirically. Such investigation can help us to better understand the user's embodied experience within the virtual space and to broaden our ethical considerations around these issues. This focus on the physical within the virtual could potentially redefine our approach to immersive healthcare technologies.

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Once we have fostered a robust understanding of embodiment in immersive environments and, as a result, gained insights into the nature of immersivity,[2] we can leverage this knowledge to revisit the ethics of digital medicine and its fundamental approaches and principles. Consequently, we will be well-equipped to formulate a robust and meaningful ethics of the healthcare metaverse, one that is aptly tailored to address the ethical challenges presented by immersive environments.

B. Limitations of this study

In closing, it is crucial to identify two significant limitations that form the foundation of this study.

First, the considerations that we have presented in this work are largely conceptual. However, when aligning with contemporary ethical concepts such as embedded ethics or the wide reflective equilibrium, these emphasize the importance of engaging theoretical considerations with empirical data, thereby lending additional evidence to one's conclusions. We have referred to empirical data or studies at key points in the text. Nevertheless, it would be beneficial to further emphasize empirical aspects in subsequent research, for instance, by delineating the views, attitudes, and hopes of key stakeholders concerning the healthcare metaverse, or by assessing the actual state of the metaverse's accessibility on a population level.

Second, we have articulated in our conclusions that a deeper engagement with the concept of embodiment could be a valuable starting point for the ethics of the healthcare metaverse. However, we have alluded to this rather than fully elaborating on it. There remains a need for further research in this area, both on theoretical and empirical levels. Theoretically, it needs to be more clearly outlined what role embodiment should play for ethics concerned with the healthcare metaverse and how embodiment should be conceived in virtual environments. Empirically, investigations must be conducted to understand how individuals perceive embodiment in virtual versus real environments, how these altered body-experiences change their interactions with others, and what implications this has for healthcare within the metaverse.

These limitations, while integral to the current discourse, also serve as beacons guiding future scholarly inquiry and experimentation in this multifaceted and rapidly progressing field. They underscore the complexity of the subject matter and signal uncharted territories that beckon further exploration and understanding.

VII. Conclusion

In this article, we have endeavored to identify the ethical challenges associated with the healthcare metaverse and to take a significant step toward formulating an ethics specific to the Healthcare Metaverse. We began with an introductory overview of the metaverse itself and its potential applications within healthcare, providing a snapshot of the current research landscape concerning the intersection of metaverse and healthcare. Following this, we delineated the unique advantages that the healthcare metaverse may hold over other forms of telemedicine.

Our central inquiry led us to a deep exploration of the ethical challenges particular to the healthcare metaverse. Recognizing that this metaverse can be seen as an extension of digital medicine – with its increasing reliance on data-driven and AI-centric approaches – we posited that the ethical considerations in the healthcare metaverse must inherently parallel those found in digital medicine. A defining distinction, however, lies in the immersive aspect of the healthcare metaverse. Subsequently, we identified and thoroughly examined six key ethical challenges specific to digital medicine – 1) *accessibility*, 2) *fairness*, 3) *discrimination and bias*, 4) *responsibility*, and 5) *privacy, data safety and security, and data ownership*, as well as 6) *environmental issues* – and analyzed how these are manifested within the virtual confines of the healthcare metaverse. It became apparent that the metaverse's immersive nature further intensifies these ethical challenges.

In our discussion, we briefly outlined the limitations of our study, showing possibilities for future research, and contemplated the future trajectory for developing an ethics framework tailored for the healthcare metaverse. We concluded that the next logical steps must involve careful consideration of the concept of embodiment within immersive environments. By leveraging these insights, there is an opportunity to advance existing ethical principles in digital medicine, including but not limited to sovereignty [58, 59], explainability [60], or meaningful human control [61-63].

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Authors` contributions

All authors have participated in drafting the manuscript. All authors read and approved the final version of the

[2] To cultivate this understanding of immersive embodiment, we can draw on valuable insights from a diverse range of disciplines including dance studies [65], theatre and performance studies [66], or video game studies [67, 68], neuro- and cognitive sciences [69, 70], philosophy [71-73] or phenomenology [74], sociology [75], critical race studies [45, 76], queer studies [77, 78], or theology [75, 79].

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manuscript. All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Architecting the Future: A Model for Enterprise Integration in the Metaverse

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Abstract— Although it has a history that goes back about three decades, Metaverse has grown to be one of the most talked-about subjects today. Metaverse gradually increased its influence in the realm of business discourse after initially being restricted to discussions about entertainment. Before getting deep into the Metaverse, it should be noted that failure and deviating from the business path are highly likely for an enterprise that relies heavily on information technology (IT) because of improper use and thinking about IT. The idea of enterprise architecture (EA) emerged as a management strategy to address this issue. As the first school of thought of EA, it sought to transform IT from an unnecessary burden in an enterprise to a guiding and supporting force. Then an extended EA model is suggested as a result of the attempt made in this paper to use the idea of EA to steer virtual enterprises on Metaverse-based platforms. Finally, to evaluate the conceptual model and demonstrate that the Metaverse can support businesses, three case studies—Decentraland, Battle Infinity, and Rooom—were utilized.

Keywords: Metaverse, Industrial Metaverse, Enterprise Architecture, Virtual Enterprise, Virtual World

I. INTRODUCTION

The major definition of an enterprise is to provide services and values for stakeholders, such as customers. Since the expansion of data and information in the enterprise caused complexities and problems in the 1960s, computer systems became a hero to help handle processes and tasks. One particular challenge presented itself in the 1990s: siloed IT systems meant that integration and interoperability appeared as major issues [1]. Once the Clinger-Cohen Law was approved in 1996, enterprises began considering Enterprise Architecture (EA) as a widely recognized approach to seriously aiding the alignment of IT and business objectives [2]. By joining information systems and improving coordination between them, EA helps businesses become less complicated. EA enables an enterprise to experience a variety of advantages, including the foresight to recognize opportunities, the agility to respond to change, and a roadmap to ease the transition to a desired future step [1].

In the contemporary landscape, cutting-edge technologies like cloud computing, big data analytics, Artificial Intelligence (AI), and the Internet of Things (IoT) are fundamentally altering the traditional operational procedures within enterprises and emphasizing the imperative of implementing EA. In essence, these trends serve as catalysts for digital transformation within enterprises. They not only enhance fundamental value and capabilities but also open up a realm of exponentially growing prospects for both services and products [3]. Digitization, as a vital part of EA, enables human beings and autonomous objects to collaborate beyond their working space using digital technologies. The revolution of Industry 4.0 delivered these new technologies, and the collaboration of humans and systems is explained in Industry 5.0, which is a concept of the future of enterprises and industries around a human-centric, sustainable, and resilient system [4, 5].

Metaverse, an innovative technological trend that combines elements from both Industry 4.0 and 5.0, can serve as the cornerstone for a comprehensive digitally-driven business concept. Following Facebook's rebranding to Meta, the Metaverse has become one of the most highly sought-after areas for research and investment[5]. Metaverse is a concept for which there is no common definition. It is a garden in which 100 flowers are blooming and 100 schools of thought contend [6]. However, one of the expressions that introduces the features of the Metaverse well defines it as follows: "*The Metaverse is a massively scaled and interoperable network of real-time rendered 3D Virtual Worlds (VWs) and environments that can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence and with continuity of data, such as identity, history, entitlements, objects, communications, and payments*" [7]. All the things we have in the actual world could be presented in this VW but in an unreal setting. Users, also known as humans in the Metaverse, can create their arbitrary avatars and carry out regular activities in any Metaverse just as they would in the real world. Fig. 1 depicts the rise of Metaverse acceptance in academic fields in recent years, according to the Google Scholar and DBLP repositories.

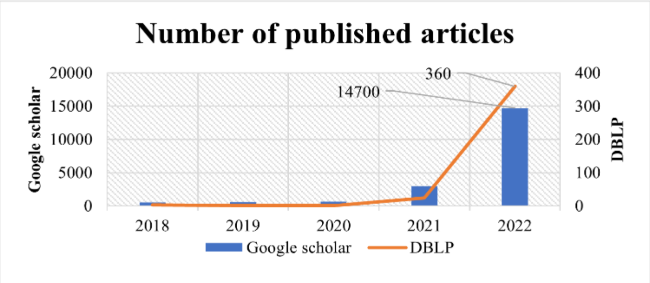

Fig. 1. The number of published articles with the keyword "Metaverse" based on Google Scholar and DBLP (2018-2022)

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Changing the needs of enterprises due to the customer's dynamic requests is an inevitable matter that affects the agility and complexity of the enterprises simultaneously. The hardship of overseeing operations, the cost of maintenance, and the difficulties of hiring internationally to be responsive to those demands are instances of influencing factors that encourage the concept of "Virtual Enterprises" (VEs). VE refers to an organization or enterprise that is completely executed based on computer systems. Metaverse can be introduced as a platform for a huge number of VEs with a wide range of goals and purposes thanks to its immersive and three-dimensional capabilities. The translation of this concept into practical applications has only taken place recently; however, the realization of intended enterprises has not been universally successful. This can be attributed to the misalignment between their strategic objectives and the core principles of virtualization. It's worth noting that the establishment or migration of enterprises into the VW, especially concerning staff-related functions, has become a distinct consideration. It appears that the digital transformation journey and the evolution from the fourth to the fifth industrial revolution will make the convergence toward the Metaverse an essential pursuit for all enterprises. This necessity requires a comprehensive reengineering of enterprises and all their objectives. Table. 2 on the next page, which is the result of a study conducted on 39 implemented Metaverse instances, indicates the extent of the enterprise's inclination toward it. As evident from the results of this table, more than half of the Metaverse-implemented platforms encompass the context of business or a combination of entertainment and business. Regardless of platforms, with inaccessible user information, Table 1 illustrates the total number of monthly active users (per 1000) across these platforms categorized by their respective contexts. While the number of registered users in certain VWs in business and multiple contexts is high, it is just one-twentieth of those in the entertainment category. What fuels this pronounced contrast between these segments?

Table 1. Distribution of Metaverse platform users by their contexts

Context	*Total Approximate users (per 1000)*
Business	6,000
Entertainment	2,000,000
Multiple	4,500

Given that enterprises weren't initially conceptualized as virtual entities, the evident explanation for this discrepancy is the relative immaturity of enterprises within VWs, despite the long-standing virtual nature of games dating back to the advent of computers. Another rationale for this variation could be attributed to the tendency of enterprises to involve their stakeholders within these virtual environments. This approach diverges from the conventional strategy employed in games, which focuses on maximizing user engagement and encouraging their active participation. EA has emerged as a means to bridge the gap between IT and enterprise operations in our tangible world, akin to the first school of thought [2], [8]. Such an approach seems to be needed in Metaverse enterprises because there are businesses operated over a Metaverse platform, which indicates the remarkable role of IT. There is a significant difference between enterprises in the Metaverse and the physical world. Enterprises in physical mode need EA to improve and stabilize their governance by aligning IT and business concepts, which IT governance will appear as an artifact, but in the Metaverse mode, enterprises try to enhance and stabilize their governance by benefiting from the available IT governance. The intended approach takes the form of a specifically designed EA tailored for Metaverse. This architecture would seamlessly manage the enterprise's business operations within the Metaverse, effectively positioning IT as the foundational pillar of the enterprise's existence. The remaining sections of the paper review the related literature after outlining the background theory of the models used. Then an EA model for the Metaverse enterprises is provided in the following, and finally, it will be reviewed to ensure that it is accurate and in accordance with the relevant enterprises.

II. THEORETICAL BACKGROUND

Converging EA and Metaverse to craft architectural solutions for Metaverse enterprises demands a comprehensive understanding of both the Metaverse itself, including its architectural structure and established EA models. This section provides an overview of Metaverse architecture and well-regarded EA models.

A. NIST Enterprise Architecture Model

The following five layers make up the model that the National Institute of Standards and Technology (NIST) has developed to describe the EA idea in Fig. 2:

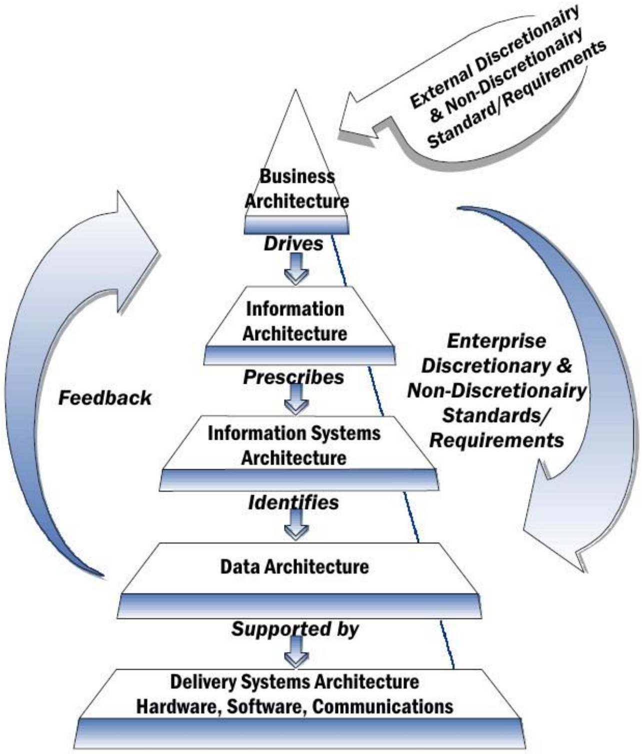

Fig. 2. NIST EA model[9]

- **Business Architecture** refers to managing, navigating, and controlling the design, development, and implementation of the business objectives that are valuable for the company and its stakeholders. This layer demands a high level of analysis and decision-making in the workflow to support and respond to the

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business mission and vision in addition to objectives [1], [10].

- **Information Architecture** explains the company from the perspective of information and knowledge, which is directly effective on the business layer and its decision-making processes. Information architecture includes identifying and analyzing the information components used by processes within the enterprise. The correlations between various flows of information are also clarified in this architecture, which indicates where, when, and how information is needed and shared to support the responsibility of the functions [10].

- **Information Systems Architecture (also known as Application Architecture)** represents the applications and their interactions in the enterprise. The applications, whether unique to the enterprise or not, are classified based on their designated functions, such as data capture, transformation, management, and storage. However, it's essential to note that this constitutes a broad overview of the applications and their interconnectedness within the enterprise context [1], [10].

- **Data Architecture** illustrates the methods of data maintenance, utilization, and accessibility. Taking a high-level perspective, it establishes and portrays the connections among data components within information systems using three distinct models: conceptual, logical, and physical [1], [10]. Usually, a conceptual model showcases various data entities and their interconnectedness, revealing how they mutually influence one another. This model can be designed either at the level of individual business functions or across entire enterprises, especially when there is a need to represent the information flow in complex supply chains. Generating the conceptual model, a logical data model provides further insights into the data's utilization and comprises three primary elements, including entities, their attributes, and relations. While not mandatory, physical data models can prove to be invaluable initial references for data architects. Leveraging these models, data architects can deduce conceptual data models and, subsequently, logical data models, which form the basis for baseline architectures.

- **Delivery Systems Architecture (also known as Infrastructure Architecture)** is the basis of the EA model, which is known as delivery systems, infrastructure, or technology architecture that supports hardware, software, IT services, and platforms, including the relationships between them [1], [10].

B. FEAF Framework

Another description of EA is the Consolidated Reference Model (CRM) of the Federal Enterprise Architecture Framework (FEAF), which is an evolved version of the NIST model. This model is specifically tailored for the Office of Management and Budget (OMB) and federal agencies to have a unified language and framework for describing and analyzing investments. In this model, two additional layers named PRM (Performance Reference Model) and SRM (Security Reference Model) have been added to the core five-layer of the NIST model. It's worth noting that the data and information layers in this model are addressed as the DRM (Data Reference Model) layer. The intended model is depicted in Fig. 3.

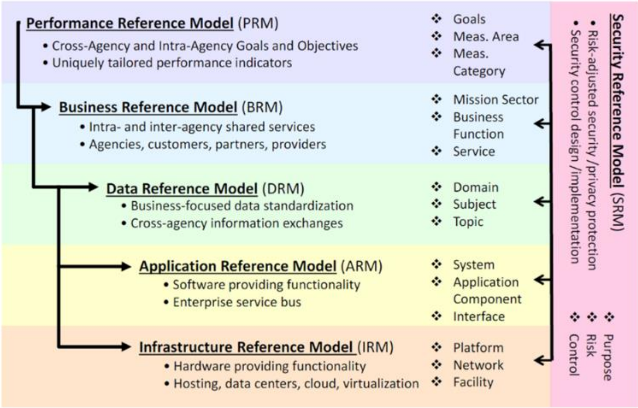

Fig. 3. *CRM from FEAF framework*[11]

- **Performance Reference Model** (PRM) serves as a linkage between enterprise strategy, internal business components, and investments. Its purpose is to provide a measurable way to assess the impact of these investments on strategic outcomes [11].

- **Security Reference Model** (SRM) provides a standardized language and methodology for discussing security and privacy in the context of enterprises' business and performance objectives [11].

In this model, PRM serves as the starting point, connecting the agency's strategic plan to BRM and subsequently to the broader EA. SRM is pervasive, influencing decisions across various sub-architectures to ensure the seamless integration of security into IT systems right from their inception.

C. Metaverse Architecture

Metaverse is a three-dimensional VW with social interactions, designed to offer a user-friendly interface for vast human interaction and create a comprehensive experience. To integrate the virtual and real worlds in the Metaverse, a combination of various cutting-edge technologies from Industry 4.0, such as networking, AI, IoT, digital twins, blockchain, and XR, is essential. Jon Radoff, the CEO of the Beamable platform, developed a seven-layer model [12] in 2021 to present the architecture of Metaverse, which is shown in Fig. 4.

Fig. 4. Architecture of Metaverse[12]

- **Experience:** This layer focuses on providing users with immersive and interactive experiences, enabling them

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to engage with VW through various sensory stimuli and interactions. The Metaverse, by removing the constraints of the real world, gives rise to a multitude of personalized services that can offer unique experiences for users. Virtual concerts, where each individual is provided with the best seat, serve as an example of this phenomenon.

- **Discovery:** The discovery layer involves the use of AI and machine learning to assist users in finding relevant content, communities, and activities within the Metaverse.
- **Creator Economy:** This layer empowers users to generate and contribute their content, fostering a creative ecosystem where individuals can share and monetize their creations.
- **Decentralization:** The layer advocates for a decentralized and interoperable structure for the Metaverse, emphasizing experimentation, growth, and sovereignty for creators over their data and creations. Decentralized technologies, such as blockchain, play a crucial role in ensuring transparency, security, and trust within the Metaverse, enabling user ownership and control of their assets.
- **Human-Computer Interaction:** This layer focuses on enhancing the user interface and experience, enabling intuitive and natural interactions between users and the Metaverse. Advancements in technology are evidenced by interfaces ranging from laptops, smartphones, and wireless VR devices to even biological sensors and brain-computer interfaces, underscoring the evolution in this domain.
- **Infrastructure:** The infrastructure layer encompasses the foundational elements that support the entire Metaverse, including networking, data storage, computing resources, and other essential components.

Table 2. The comparison matrix of 39 famous global Metaverses

Platform	*Establishment*	*Blockchain*	*Currency*	*AVG # Monthly Active Users (per 1000)*	*Context*	*Country*
Second Life	2003	-	Linden dollar	5,000	E	USA
IMVU	2004	-	VCOIN	5,000	B	USA
Roblox	2006	-	ROBUX	1,785,000	E	USA
Minecraft	2011	-	Synex coin	181,227	E	Sweden
Sandbox	2012	Ethereum	SAND	300	E	Hong Kong, Taiwan and mainland China
GTA Online	2013	-	In-game Dollar	15,024	E	USA
Altspace VR	2013	-	-	-	-	SHUT DOWN by March 2023
Stageverse	2017	Ethereum	ERC721	-	E	USA
Sansar	2017	-	Sansar dollar	6	M	USA
Cryptovoxels	2018	Ethereum	-	3	B	New Zealand
Axie Infinity	2018	Ethereum	AXS	7,782	E	Vietnam, India
Sensorium Galaxy	2018	Wakatta	SENSO	-	E	Multi Nation, mainly in the USA
WEMIX	2018	WEMIX 3.0	WEMIX	500	E	UAE
Sorare	2019	Ethereum	Own NFT	650	E	France
GALA	2019	Ethereum	GALA	13,000	E	Spain
Rooom	2019	-	-	310	B	Germany
uHive	2019	Ethereum	HVE2	400	B	-
Somnium Space	2020	Ethereum	CUBE	21	E	UK, Canada, and Mainly in India
Illuvium	2020	Ethereum	ILV	7	E	Australia
Upland	2020	EOS	UPX	150	E	Ukraine, USA
Gather	2020	-	GTH	3,000	M	USA
Decentraland	2020	Ethereum	MANA	240	B	Argentina
Spatial	2020	Polygon	GSTA	-	M	USA
Microsoft Mesh	2021	-	-	-	B	USA
Horizon Workrooms	2021	-	-	20	B	USA
Metahero	2021	BSC	HERO	-	B	UAE
NFT worlds	2021	Ethereum	WRLD	50	E	-
Horizon Worlds	2021	-	-	300	E	USA
Star Atlas	2021	Solana	ATLAS	18	E	Canada
NAKAverse	2021	Polygon	NAKA	200	E	Thailand
High Street	2021	Ethereum	HIGH	-	E	-
Bloktopia	2021	Polygon	Bloktopian	57	M	Isle of Man, Ireland
Everdome	2021	BNB	DOME	-	M	UAE
Battle infinity	2022	BSC	IBAT	1500	M	UK, Canada and Mainly in India
Hyper Nation	2022	BSC	HNT	-	M	-
Viverse	2022	Ethereum	-	-	M	Taiwan
Efinity	2022	Polkadot	EFI	-	M	Singapore

E: Entertainment context, B: Business context, M: Multiple contexts

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III. RELATED WORKS

The background of this research can be examined from both academic and industrial perspectives, which are discussed in separate sub-sections.

A. Academic works

The movement of enterprises toward the Metaverse started with the concept of the industrial Metaverse, which converged with the VE. The industrial Metaverse for smart manufacturing systems is introduced in [13]. This term aims to accelerate various manufacturing processes, such as repairs, starting new manufacturing lines, remote monitoring, and user/manager training through simulation. It utilizes immersive technologies to enhance the configuration layer of cyber-physical systems and acts as a digital twin of the workspace. [14] investigates the expansion of the industrial Metaverse and provides insights into the essential technologies and procedures linked to this groundbreaking development. Furthermore, it explores the ramifications of the industrial Metaverse on various scales, including the firm level, national level, and global level.

[15] has provided an overview of the Metaverse as a potential business platform and its impact on IT industries. It acknowledges that the concept of Metaverse is still unfamiliar to many technical professionals and business managers. The paper proposes a framework for enterprise digitization in the context of the Metaverse. The framework focuses on several critical concepts, such as blockchainization, gamification, tokenization, and virtualization. These concepts are discussed about the 4Ps of the marketing mix: People, Place, Product, and Process.

Several studies within this domain have directed their attention toward the potential impact of the Metaverse on enterprise management processes. [16] proposes a structure for the information space of a VE and develops its core virtual office using augmented reality (AR). It emphasizes the enterprise knowledge base as the main resource for managing the virtual office. Through a simulation experiment on an online store, it was demonstrated that using AR can significantly reduce order processing time, resulting in a threefold increase in efficiency. The authors plan to further develop an integrated virtual environment for virtual enterprises using AR.

The authors in [17] introduce VR-EA+TCK (EA enhanced with Tools, Content, and Knowledge), a solution concept to address the challenges of managing a complex and dynamic IT landscape in EA. Existing digital repositories like Knowledge Management Systems (KMS), Enterprise Content Management Systems (ECMS), and EA Tools (EAT) often remain disconnected, limiting insights and analysis. VR-EA+TCK combines EAT, KMS, and ECMS capabilities in Virtual Reality (VR) to enable stakeholders to visualize and interact with EA diagrams, knowledge chains, and digital entities, promoting grassroots enterprise modeling and collaboration in the Metaverse. The paper presents an implementation and case study to demonstrate the concept's feasibility and potential in various enterprise analysis scenarios. [18] discusses how EA management can support the implementation of VEs for Small and Mid-sized Enterprises (SMEs). It emphasizes the importance of VEs as a way for SMEs to adapt to new market conditions. The article highlights the significance of managing Information and Communication Technology (ICT) effectively to avoid it becoming a bottleneck in new cooperative efforts. The main focus is on exploring how EA principles and methodologies can enhance the coordination, integration, and alignment of ICT within VEs. The article likely discusses how EA can optimize business processes, information flows, and technology infrastructure to facilitate seamless collaboration and improve overall performance in VEs.

B. Industrial works

The industrial exploration of incorporating Metaverse into enterprise contexts has been dedicated to nurturing an immersive user experience arising from users' active participation within the Metaverse environment—a realm closely mirroring the real world. Industrial enterprises venturing into the use of Metaverse in their operations are pioneers, each with distinct objectives for its utilization. The diverse approaches to employing the Metaverse within the industry can be categorized into the following groups:

- **Production:** The first aspect of production in the Metaverse involves seamless real-virtual coexistence within the research and development phase. Researchers and developers, regardless of their physical locations, can enter the virtual realm together for purposes such as planning, three-dimensional product design, troubleshooting, extensive trial phases, and addressing unstable production processes. The second aspect of real-virtual coexistence in Metaverse production involves managing production through real-time and pervasive simulation of data via IoT and digital twin systems. For instance, companies like Amazon and Pepsi currently utilize similar technologies, such as 5G radio networks and digital twins, to optimize the design of their distribution centers and simulate alternative layout designs [19].
- **Marketing:** While most commercial industries have considered global expansion in their vision, a survey conducted in [20], using data collected from 1015 marketing managers, indicates that even sectors such as energy, resources, industries, life sciences, and healthcare have been inclined toward the Metaverse and are utilizing it for marketing purposes. The companies that use the internet for advertising will also move toward using Metaverse for advertising. For example, while walking in the Metaverse, avatars might encounter advertising billboards. By judiciously integrating Metaverse into the business model, even non-digitally native enterprises can attract younger consumers and update their offerings for the pervasive internet [21].
- **Service Enhancement:** Despite media attention often focusing on revenue potential, some of the most significant applications of the Metaverse within enterprises may lie in achieving equitable access to company processes and developmental opportunities. For instance, various governments like the city of

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Santa Monica, South Korea, and Saudi Arabia are exploring how the Metaverse can enhance public services [22], [23]. At an enterprise scale, NVIDIA has developed an Omniverse platform where manufacturers like BMW can simulate entire factories. The automaker anticipates about 30% increases in efficiency to optimize floor movements [21].

- **New business models:** Just as some companies in the early 2000s pioneered online-only business models, other companies might also have innovative revenue models built around Metaverse, although they may assume higher risks. Such companies are currently in the process of developing technologies, platforms, products, services, content, and other enabling components of the Metaverse. A notable example is Niantic, the creator of the mobile game Pokémon Go, which provided AR experiences to tens of millions of users, boosting its valuation from $150 million to $9 billion [21]. Snoop Dogg, the renowned rapper, invested $450,000 to acquire a piece of land within the Sandbox Metaverse. He intends to utilize this virtual space for hosting a range of events, including music festivals and concerts, catering to participants seeking immersive experiences in the digital realm [24].
- **Enhanced Workforce Experience:** Several companies are pursuing pervasive technologies like AR and VR to offer personalized experiences for learning and collaboration that are visually engaging, user-friendly, and scalable. These solutions can provide better insights into participation levels, the time apprentices dedicate to lessons, and the stages where they face challenges, thereby enhancing the effectiveness of education. Efforts undertaken by the defense ministry and military forces to create educational environments using digital twins and mixed reality (MR) are important examples of this approach. Soldiers wear glasses that project simulated battle scenarios onto their physical surroundings, preparing them for real engagement situations [25]. The Metaverse also presents a favorable approach for educating high-risk professionals. A notable example is Exelon, the largest electric utility company in the United States, which has gained substantial benefits from incorporating VR training. Given that electrical utility positions can pose dangers to unfamiliar individuals, the virtual environment enables Exelon's employees to engage in learning experiences while wearing protective equipment and solving electrical problems, all without compromising their safety [21].

IV. INTEGRATING METAVERSE AND EA CONCEPTS

The task of aligning EA concept with Metaverse can be approached from two perspectives, including Metaverse as an enterprise and Metaverse as an infrastructure or virtual platform for implementing an enterprise. Subsequently, we will provide a detailed explanation of each of these proposed approaches.

A. Metaverse as an Enterprise

Here we have encountered a large-scale enterprise that is still grappling with considerable uncertainties. Aligning EA models with Metaverse, particularly its architecture, presents significant challenges.

- EA is the process through which enterprises align their IT infrastructures with their business objectives. While the business of Metaverse as an enterprise is not yet fully defined, it is still in its infancy. Metaverse, in its role as an enterprise, is far from reaching maturity and currently confronts significant uncertainties.
- The architecture designed for the Metaverse is a combination of various technologies to suit its distinct characteristics. This architecture entails that lower layers are constructed using Metaverse-building technologies. From the standpoint of users, the upper layers of the architecture have been delineated, while considering enterprise dynamics, a synthesis of user, technological, and intermediary layers has been outlined. This is why EA primarily revolves around the enterprise's viewpoint and the integration of IT within its structure. As a result, these two architectures appear to be disparate and not readily comparable.

The CRM model is an enhanced view of the NIST model, which describes an enterprise alignment with the IT concepts in the first school of thought. To more clearly visualize the architecture of the Metaverse-based enterprise, the NIST model was used as the basis and foundation for the concept of EA and CRM as an advanced model of it. As a result, the mapping of various layers of the EA models and the Metaverse architecture model won't be one-to-one. This mapping could take the form of one-to-many, many-to-one, or even occur without a direct counterpart of a layer in the opposing architecture. Fig. 5 illustrates this mapping. As illustrated in this figure, the layer sequence is consistent in both the Metaverse and NIST architectures. The architecture of CRM has been adapted from the NIST model, implying an implicit alignment within it as well. The infrastructure layers refer to all the hardware and network equipment required for the implementation and execution of Metaverse, as well as facilitating user connection, presence, and interaction within it. These devices are equivalent to all the IT infrastructure needed within enterprises. In the Metaverse, the decentralization layer is focused on blockchain infrastructure and maintaining data on a distributed platform. In EA models, this layer can encompass any database schema and data management techniques.

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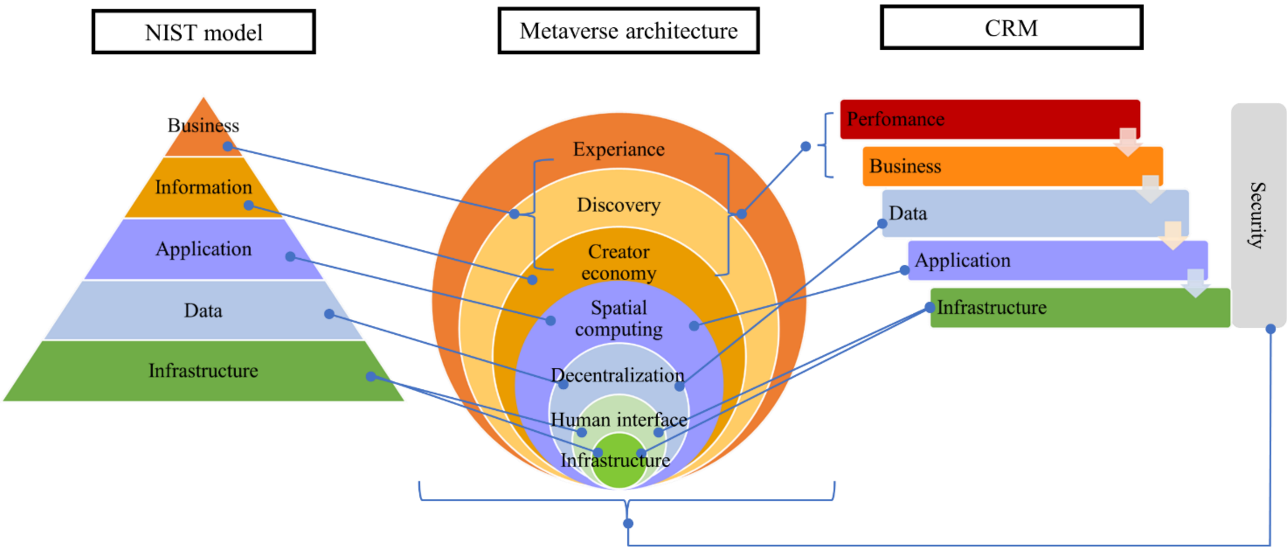

Fig. 5. Incorporating the Metaverse architecture through the EA models

The application layer in the EA models corresponds to the spatial computing layer in the Metaverse model. This alignment is primarily due to one of the focal points of spatial computing, which involves employing digital twin technology for the representation of the real world and mirroring various enterprise use cases within it. However, from another perspective, we can also regard the spatial computing layer as a foundational platform for diverse enterprise applications. In this scenario, platform or user-generated content in Metaverse can shape the desired enterprise applications. Analyzing stored data results in the extraction of information. This process involves processing data stored in the blockchain, thereby establishing the Metaverse economy. The Metaverse economy encompasses the complete financial and digital assets of individuals within this environment.

Integrating the economy, discovery, and experience layers within the Metaverse yields an environment where businesses materialize, processes unfold, and ultimately lead to the acquisition of digital assets or income/tokens. So, the integration of these three layers can seamlessly correspond with the EA business layer. Following this trajectory, the assets that individuals accumulate within the Metaverse, along with their degree of satisfaction within this domain and other measurable factors, can be assessed using the lens of the experience layer. As a result, these three layers seamlessly align with the business and performance layers in the CRM model. Although an enterprise established in the Metaverse might adopt architectures similar to traditional models like NIST or CRM, the complete virtual infrastructure within such entities has necessitated the customization of EA to suit their unique needs. Fig. 6 visually depicts the tailored EA for digitalized or Metaverse-based enterprises.

- **Business Architecture**: As with the origin model, business objectives, processes, and strategy planning are the base concepts of this layer, but in a virtual environment, which seems to be easier, more agile, and less complex. Chief Architecture must mind the demands that are given by the information layer because each decision-making will be effective as soon as possible due to the absence of physical obstacles, which has made it less time-consuming and more flexible. Furthermore, the business services, processes, and tasks within the enterprise are completely transparent and traceable. For instance, in process management, by utilizing the BPMN modeling language [26], there is no longer a need for assembling a human workforce or investing time and expenses into process mining. Incorporating an intelligent system to perform such activities provides process modeling in the shortest time possible and with the highest accuracy.

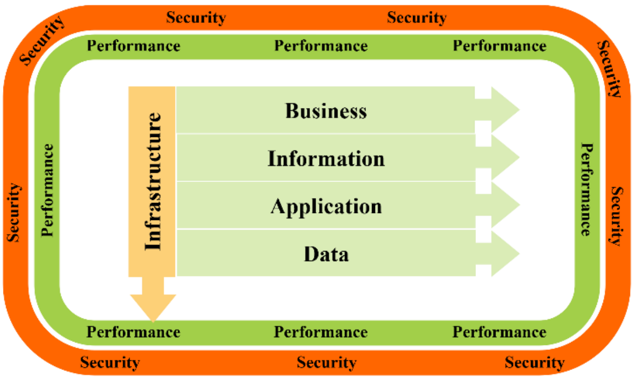

Fig. 6. The proposed model to bring the EA concept through Metaverse-based enterprises

- **Information Architecture**: The essence of the information layer is the same as in the discussed models. Due to full digitalization, a huge mass of information flows can cause the creation of large information silos. Adequate attention is required to sort and classify these information flows to deliver accurate and trusted information to the business layer.

- **Application Architecture**: It is obvious that the application architecture defines and clarifies the relationships between various types of applications. However, a flexible approach to development allows for describing applications as services or microservices within a bank. These can be accessed simply by invoking the designated ones. The important

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point is that there may be no need to develop and design an application specific to an enterprise.

- **Data Architecture**: In the traditional EA models, data architecture can be described in conceptual, logical, and physical models; these structures are also available here. However, a huge mass of data will be assumed in this layer due to the digitization of all documents and activities, as well as the emergence of a new type of data categorized as personal, behavioral, and communication patterns of enterprise users that must be noted.

- **Infrastructure Architecture**: Infrastructure is now seen as a vertical layer. The reason refers back to the use of technology elements, and the survival of the enterprise depends on the availability of this architecture; without it, the entire enterprise is inaccessible. It's noteworthy that the infrastructure layer still retains its physical nature, as connecting with the Metaverse world might necessitate the use of equipment such as computers, VR headsets, and AR glasses in the most minimal scenario. In physical enterprises, the temporary loss of IT infrastructure results in the cessation of many services and activities (particularly those directly reliant on IT), while some non-IT-dependent activities persist. For example, consider the temporary loss of infrastructure in an in-person educational institution, leading to a slowdown in systemic activities such as grade recording and email communications while teaching and learning continue in a non-systemic manner. However, this scenario doesn't hold for a highly digital enterprise, as the loss of infrastructure in such a case would lead to the enterprise's nonexistence.

- **Performance Architecture**: This layer tries to measure the performance of the inner layers, which is started by determining the Key Performance Indicators (KPIs), measuring the performance, and finding the bottlenecks and Critical Success Factors (CFSs) to handle and design the best architecture development.

- **Security Architecture**: The biggest and most important layer that addresses the security issues in all the main layers; for instance, business security is doing the right processes or infrastructure security as ensuring the CIA triads (Confidentiality, Integrity, and Availability). Another important issue is ensuring data transmission between the real world and the VW is secure, which emphasizes the role of authentication for the users who are attending the specified Metaverse. This is an important gap that was found during the research.

It's important to highlight that the presented model is designed to support Metaverse businesses. By considering Metaverse as an enterprise or a unit of an enterprise, while some businesses can function entirely in a virtual manner, such as educational institutions, others might operate in a semi-virtual mode, like manufacturing companies. So, it doesn't imply that EA should exclusively apply to either fully virtual (EA tailored to VO) or entirely physical enterprises. Taking a broader view, a Metaverse-based company is one place where AI can be widely embraced as an enticing yet somewhat terrifying technology. In every layer of the enterprise architecture, an architect is tasked with designing and structuring the specific layer in alignment with the enterprise's activities and goals. With the full digitization of all data and information, each layer's architecture can be entrusted to one or multiple AI entities known as enterprise architects. Beyond the enterprise architecture, the role of top-level managers can also be entrusted to an AI that plans and defines the enterprise's goals, problem-solving approaches, and pathways to achieve them. If the widespread use of AI occurs significantly, the only human actors within the enterprise might be its customers and owners. This kind of thought expresses an example of a strategy for determining the desired Metaverse's application and future: What is the Metaverse's primary use as a business place, who uses it, and for what purposes?

B. *Metaverse as an Infrastructure*

As mentioned in Section 2.1, the infrastructure layer is the foundation of virtual enterprises. Metaverse can be a platform for running a virtual or semi-virtual edition of some enterprises. In this context, IT infrastructures not only align with enterprise strategies but also become essential for the existence of these enterprises. In other words, the Metaverse, as a result of various informational and communicational technologies, is positioned as an infrastructure for all enterprise processes and layers. In this view, Metaverse can be implemented by the enterprise itself or provided as a service by a cloud service provider. Investigating Metaverse as an infrastructure layer in EA models is not included in the scope of this article.

V. PROOF OF MODEL

As explored in Section 4, if Metaverse is approached as an enterprise, both EA models explored in this paper align well with it. Table 1 presents an examination of around 39 Metaverses, accompanied by their type of data storage. The data underscores a prevalent trend: a significant portion of these Metaverses are structured around distributed databases using blockchain technology. This choice reflects a strategic emphasis on data security within the enterprise layers by harnessing the inherent strengths of blockchain technology. Moreover, capitalizing on the capabilities afforded by this technology, these Metaverses offer a promising vision for both internal and external interactions, enabling users to seamlessly exchange assets across different Metaverse platforms. To assess the applicability of the introduced model to enterprises operating within the Metaverse, an examination of Metaverse-based enterprises becomes imperative. Given the wide array of businesses operating within the Metaverse, this study encompasses three distinct Metaverses representing varying contexts. Table 3 shows the results of applying the Metaverse-based EA model.

- **Decentraland**[1]: Decentraland is a browser-based 3D VW platform that allows users to purchase virtual plots

[1] https://decentraland.org/

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of land as non-fungible tokens (NFTs) using the cryptocurrency MANA, which is based on the Ethereum blockchain. In this VW, users can interact, explore, and create various experiences on their land. Designers have the opportunity to create and sell virtual clothes and accessories that can be used to customize avatars within the VW. The platform leverages blockchain technology and NFTs to provide a decentralized and unique virtual experience for its users, where ownership of virtual assets is secured and verified through the Ethereum blockchain.

Table 3. Proof of the proposed model with example in the aforementioned Metaverses

EA \ Metaverse	Decentraland	Battle infinity	Rooom
Business Architecture	-Trade anything built by users -Token economy	-New social media -Play P2E -Discover new creations	-Perform workshops, showrooms, etc. shopping in the Metaverse -Monetize virtual or hybrid events -Educations
Information Architecture	-Monthly active users from specific IP address	-Amount of sold NFTs in a limited timing range	-Amount of held workshops by a specific user
Application	-Designing tools for personalized assets	-Internal designing tools for NFT designers	-Integrated services to hold conferences
Data Architecture	-Caught data from the blockchain infrastructure e.g usernames	-Caught data from infrastructure e.g. IP addresses	-Caught data from the blockchain infrastructure e.g. dates
Infrastructure	-5G networking and its equipment -AR/VR equipment	-5G networking and its equipment -AR/VR equipment	-5G networking and its equipment -AR/VR equipment
Performance	-Satisfaction of users -Security and privacy	-Customer relationship -Efficiency of infrastructure	-Governance of service -Process effectiveness
Security	-Availability -Accurate data -Out-of-service applications - Authentication issues	-Amount of attacks -Best routing -Trusted information - Maintaining the financial value of the related token	-Amount of attacks -Defective devices -Out-of-service apps -Wrong business strategies

- **Battle infinity**[2]: Battle Infinity is a gaming platform that offers a diverse ecosystem of Player-to-Environment (P2E) battle games, all integrated within the VW known as 'The Battle Arena,' which is part of the Metaverse. This platform allows gamers not only to participate in battles and gameplay but also to immerse themselves in the VW of the Metaverse. Within the Battle Arena, users can engage in various activities such as interacting with others, performing actions, watching events, exploring virtual environments, and more. The platform aims to provide a comprehensive and immersive gaming experience within the Metaverse.

- **Rooom**[3]: Rooom is a particular type of enterprise to transform an exhibition, store, or showroom into a virtual space and share with users experiments in digital marketing, sales, education, or events.

Examples of each layer are provided in the above Table to demonstrate that this paradigm is not incompatible with VEs of any type. In contrast to this comparison, EA encompasses a wide variety of documentation, business strategies, artifacts of each layer, EA administration, and other things.

VI. CONCLUSION AND FUTURE WORK

IT is essential to enterprises, perhaps much more so in virtual ones because the entire VE runs on computer systems. Both virtual and physical enterprises can utilize EA to synchronize business management, decision-making, and enterprise vision with IT. This paper broadened the EA idea to handle new issues that virtualization has brought forth because of the endless and pervasive aspects of VWs. The business, information, data, application, and infrastructure layers are the five primary components of this model, and two performance and security layers that surround the main layers complete the entire model, which follows the NIST and CRM models. Although the suggested model's compatibility with the Virtual EA was acknowledged, further evidence is still required to support this claim. As an overview, the first school of thought in EA, which is enterprise IT architecture, has been explained over Metaverse, and the other two thoughts as enterprise integrating and enterprise ecological adaptation, still need more research and analysis [8]. Additional study and analysis are required on documentation, enterprise resource planning, corporate culture, authenticating users as a security feature, and other related topics that can provide useful ideas for future works in the Metaverse context.

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AUTHORS` CONTRIBUTIONS

All authors have participated in drafting the manuscript. All authors read and approved the final version of the manuscript. All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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