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Identification and Prioritization of Metaverse Infrastructure with a Fuzzy Approach

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ABSTRACT

The aim of the research was to identify and prioritize metaverse infrastructures with a fuzzy approach. This analysis has been done in a quantitative and applied manner. The identified criteria were screened using the fuzzy Delphi analysis method, and the internal and external relationship of the screened components was investigated using the fuzzy Dimetal technique. The surveyed community were experts in the field of information technology and artificial intelligence. 14 people were selected using purposive sampling. Using MATLAB software, Fuzzy DeMetal analysis and EXCEL software for fuzzy Delphi analysis were performed. The identified criteria were determined based on the library method in the previous section. 8 criteria were identified. In this research, 8 main criteria were identified based on the fuzzy multi-criteria decision-making method of Delphi and DEMATEL. These 8 criteria are: virtual reality and augmented reality technology, complex networks and communications, powerful processing, servers and cloud infrastructure, metaverse development platforms and software, security and information protection, interactive technologies and artificial intelligence technologies. Based on the Delphi technique, all items were confirmed. In the Fuzzy Dimetal technique, it was found that interactive technologies have the highest priority. Artificial intelligence technologies ranked second. Interactive technologies based on existing technologies have a special place in Metaverse. Augmented reality provides an opportunity to merge the real world with virtual elements. **©authors**

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Introduction

The metaverse will change everything we know today, from how we work, how we communicate, how we earn and learn, how we play, and other aspects of life (Rosenberg, 2021). The metaverse is a developing phenomenon that drew more attention to meta when Facebook changed its name in October 2021. Currently, metaverse worlds have emerged such as metaverse fashion (Ghamya et al., 2023)

However, it may be necessary to add the clarification that the metaverse is not an object, but a state, an ecosystem in which things happen and connect. As a comprehensive definition, Metaverse offers three-dimensional and immersive experiences based on virtual reality and augmented reality technology. It appears to be a fictional 3D space in the media, but Fuller et al. (2020) stated that the metaverse creates mirror images based on the real world, like digital twin technology. In addition, the metaverse combines economic, social and identity aspects and allows each user to produce content and change the world both virtual and physical (Caragliu and Chiara, 2019).

Identifying and prioritizing metaverse infrastructure is very vital and important in today's world. With the increasing growth of emerging technologies, the virtual world and digital space are evolving rapidly, and the concept of metaverse has been developed and defined as a virtual world that constitutes more than a real world (Miao et al., 2022). In this concept, people interact with each other in parallel and virtual worlds, play games, social experiences, and purchases and do their work in these spaces. The metaverse has grown in popularity due to its potential to create direct monetary value for its creators through blockchain-based technology, such as NFTs, smart contracts, and consensus algorithms. The power over one's information can be defined as the "leap" of today's systems, which has the ability to include active participation. A future where all members of society have the opportunity to benefit from the real value of their activities (Gustafsson, 2022).

The importance of identifying the metaverse infrastructure is evident from different aspects. First, with the growth of these virtual spaces, people interacting with them provide a lot of information about themselves and others, which requires careful management and security. Ensuring data security and protecting people's privacy are prominent priorities in this field (Qorbani et al., 2021). Secondly, the creation of metaverse infrastructure provides the foundations of e-commerce and digital economy. Trading in these virtual worlds has led to requirements for online payment and validation, transaction security, and blockchain infrastructure to keep track of transactions (Balis, 2022).

These virtual spaces play a very important role as a new environment for reflecting and transmitting the cultures and values of societies (Hector, 2022). In these platforms, social, educational and recreational interactions are carried out in a more civilized and extensive manner, which requires the identification and prioritization of suitable digital infrastructures. Finally, the identification and prioritization of metaverse infrastructures plays a very important role in creating a safe, dynamic and advanced world. From virtual and augmented reality technologies to complex information and communication technology networks, all are interconnected and cannot provide greater productivity individually. These fields should be prioritized and developed according to the importance, needs and social demands in order to take full advantage of the possibilities of the digital world and lead to a better and smarter world. Therefore, this research seeks answers to the following questions:

What is the metaverse infrastructure in today's world?

How important is the infrastructure of Metaverse in today's world?

Literature Review

In the field of information technology, the metaverse often refers to a large and interactive virtual world that combines virtual reality, augmented reality, social networks, and other technological elements (Park and Kim, 2022). This is the concept of a digital world where users can interact with other characters, objects, and content, like an extended virtual world. Creating a "Metaverse" world is a simple process in theory, but in reality it faces many problems (Wang et al., 2022). However, digital worlds, at least today, have incomplete databases and experience limited communication with each other and the physical world (Al-Jundi et al., 2022). Finally, with improved connectivity and hardware, independent 3D environments are connected to the overall metaverse landscape. The fourteen main areas of the Metaverse industry fall under two key aspects, ecosystem and technology. Key technologies enable the digital Big Bang that feed and support the ecosystem (Ning et al., 2021).

The four fundamental components of the metaverse structure are content and experiences, platforms, infrastructure and hardware, and enablers. Additionally, 10 technological “layers,” which include back-end technology enablers such as engines, blockchain, and hardware devices as well as digital platforms and virtual worlds, are important because they define the physical and operational foundations (Kim and Jung, 2021).

The highly functional elements in metaverse design can be advanced versions of our everyday tools and design processes. Digital cognate technologies are the most prominent elements of the metaverse world (Hennig-Thurau et al., 2023). Architects repeat physical worlds in three-dimensional models to interact and adapt to their desired result (Bailenson, 2021). Digital equivalents are smart structures combined with city and building data to enable more informed data-driven decision-making. Data represents the real world digitally, such as the movements of people, vehicles, objects, weather, and spaces. BIM/DT professionals can add, interact and manipulate such complex structures (Far et al., 2022).

Metaverse experiences in today's world based on technological advancement represent a small subset of the larger spectrum of the metaverse (Skalidis et al., 2022). Currently, the Metaverse is envisioned as a cartoonish fantasy world that facilitates socialization and uses cryptography to underpin an open creative economy with new ownership models. These structures are digital files, from simple photos (jpg) to 3D worlds and gif/video assets (digital art, fashion pieces). However, the metaverse, in combination with virtual reality (VR), augmented reality (AR) and mixed reality, can also be seen as a media technology whose main idea is to present content in an attractive and realistic way (Masadeh, 2022).

Metaverse infrastructure includes technologies, platforms, networks and systems that create and support this virtual world (Nath, 2022). By combining various components such as virtual reality, augmented reality, complex communication networks, powerful processing, servers, interactive systems and more, these infrastructures create an interactive and extensive space for users. Based on the investigations carried out, Metaverse infrastructures were identified in Table 1:

Table 1. *Metaverse infrastructure components*

Source	Definition	Component
(Ghamya et al., 2023)	Creating virtual reality and augmented reality experiences that allow users to interact in the virtual world.	Virtual reality and augmented reality technology
(Masadeh, 2022).	High-speed and stable networks that ensure continuous communication between users within the Metaverse.	Complex networks and communications
(Bailenson, 2021).	High-powered processing systems used to process and display complex information in metaverse environments.	Powerful processing
(Gustafsson, 2022).	Cloud storage and processing space that helps provide access to content and information for users.	Servers and cloud infrastructure
(Hector, 2022).	Tools and environments that developers can use to create and develop Metaverse apps, games, and experiences.	Metaverse development platforms and software
(Ning et al., 2021).	The systems and technologies required to protect users' personal information and the security of Metaverse space.	Security and information protection
(Al-Jundi et al., 2022).	Means of control and interaction with the Metaverse world, including controllers, sensors, augmented reality and virtual reality devices, etc.	Interactive technologies
(Balis, 2022).	Using artificial intelligence to create artificial characters, interactive experiences and achieve more complex levels of coordination and interaction.	Artificial intelligence technologies

Method

This analysis has been done in a quantitative and applied manner. The identified criteria were screened using the fuzzy Delphi analysis method, and the internal and external relationship of the screened components was investigated using the fuzzy Dimetal technique. The surveyed community were experts in the field of information technology and artificial intelligence. 14 people were selected using purposive sampling. Using MATLAB software, Fuzzy DeMetal analysis and EXCEL software for fuzzy Delphi analysis were performed. The identified criteria were determined based on the library method in the previous section. 8 criteria were identified.

Findings

In the first step, an effort has been made to identify effective indicators in Metaverse. A set of indicators has been determined based on research literature. FDM fuzzy Delphi technique has been used to screen the indicators and identify the final indicators. The opinion of 10 experts about each indicator is shown in Table 2:

Table 2. *Fuzzification of the opinion of the expert panel for each of the research indicators*

Expert 1	Expert 2	...	Expert 13	Expert 14	
(5, 6, 7)	(5, 6, 7)	...	(7, 8, 9)	(5, 6, 7)	Virtual reality and augmented reality technology
(9, 9, 9)	(6, 7, 8)	...	(9, 9, 9)	(5, 6, 7)	Complex networks and communications
(9, 9, 9)	(6, 7, 8)	...	(5, 6, 7)	(9, 9, 9)	Powerful processing
(9, 9, 9)	(7, 8, 9)	...	(5, 6, 7)	(9, 9, 9)	Servers and cloud infrastructure
(6, 7, 8)	(6, 7, 8)	...	(5, 6, 7)	(9, 9, 9)	Metaverse development platforms and software
(9, 9, 9)	(9, 9, 9)	...	(7, 8, 9)	(7, 8, 9)	Security and information protection
(5, 6, 7)	(5, 6, 7)	...	(9, 9, 9)	(5, 6, 7)	Interactive technologies
(7, 8, 9)	(5, 6, 7)	...	(7, 8, 9)	(9, 9, 9)	Artificial intelligence technologies

In the next step, the fuzzy average of the fuzzy averages of people's scores should be calculated. In this study, we have used the method (minimum, geometric mean, maximum):

Table 3. *Fuzzy average of the opinion of the expert panel for each of the research indicator*

mean	max	geonean	min	
(9,7.62,5)	9	7.62	5	Virtual reality and augmented reality technology
(9,7.59,5)	9	7.59	5	Complex networks and communications
(9,8.47,6)	9	8.47	6	Powerful processing
(9,7.2,5)	9	7.2	5	Servers and cloud infrastructure
(9,8.03,5)	9	8.03	5	Metaverse development platforms and software
(9,7.8,5)	9	7.8	5	Security and information protection
(9,7.01,5)	9	7.01	5	Interactive technologies
(9,7.62,5)	9	7.62	5	Artificial intelligence technologies

The fuzzy average and de-fuzzified output of the values related to the indicators are shown in Table 4. In this study, tolerance threshold of 7 is considered. Therefore, the de-fuzzified value greater than 7 is accepted, and any index with a score above 7 is accepted.

Table 4. *Fuzzy average of the opinion of the expert panel for each of the research indicators*

Result	Crisp	mean	max	geonean	min	
ACCEPTED	7.21	(9,7.62,5)	9	7.62	5	**Virtual reality and augmented reality technology**
ACCEPTED	7.2	(9,7.59,5)	9	7.59	5	**Complex networks and communications**
ACCEPTED	7.82	(9,8.47,6)	9	8.47	6	**Powerful processing**
ACCEPTED	7.07	(9,7.2,5)	9	7.2	5	**Servers and cloud infrastructure**
ACCEPTED	7.34	(9,8.03,5)	9	8.03	5	**Metaverse development platforms and software**
ACCEPTED	7.27	(9,7.8,5)	9	7.8	5	**Security and information protection**
ACCEPTED	7	(9,7.01,5)	9	7.01	5	**Interactive technologies**
ACCEPTED	7.21	(9,7.62,5)	9	7.62	5	**Artificial intelligence technologies**

Therefore, the most important indicators will be selected and will be used to determine the final priority.

Identifying internal relationships with the FDEMATEL technique

Based on the research model, the second step is to calculate the internal relationships of the main criteria. In this way, the relationship matrix of the main criteria of W22 will be obtained. In order to reflect the internal relationships between the main criteria, the fuzzy Dimetal technique has been used. So that experts are able to express their opinions regarding the effects (direction and intensity of effects) among the factors with more mastery. It should be noted that the matrix resulting from the DEMATEL technique (matrix of internal communication) shows both the cause and effect relationship between the factors and the influence of the variables. The phase spectrum used is given in the table.

Table 5. *Phase spectrum and Dimetal technique*

Linguistic variable	Fuzzy equivalent
Effectless	(0.0, 0.1, 0.3)
low impact	(0.1, 0.3, 0.5)
Medium impact	(0.3, 0.5, 0.7)
high impact	(0.5, 0.7, 0.9)
Very high impact	(0.7, 0.9, 1.0)

Calculation of direct correlation matrix ($\tilde{X}$)

First, the opinions of experts have been collected and fuzzified with the fuzzy spectrum of Table 5. If the relations of n criteria have been examined by k experts, the initial matrix of the examination of the relations of n criteria from the point of view of k experts will be as follows:

$$\begin{bmatrix} 0 & \tilde{X}_{12}^{(k)} & \cdots & \tilde{X}_{1n}^{(k)} \\ \tilde{X}_{21}^{(k)} & 0 & \cdots & \tilde{X}_{2n}^{(k)} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{X}_{n1}^{(k)} & \tilde{X}_{n2}^{(k)} & \cdots & 0 \end{bmatrix}$$

so that each row of this initial triangular fuzzy numerical matrix will be as follows:

$$\tilde{X}_{ij}^{(k)} = (\tilde{l}_{ij}^{(k)}, \tilde{m}_{ij}^{(k)}, \tilde{u}_{ij}^{(k)})$$

When the opinion of several experts is used, the simple arithmetic average of the opinions is used and we form the fuzzy direct correlation matrix or $\tilde{X}$. The fuzzy average of n triangular fuzzy numbers will be calculated as follows:

$$F_{AVE} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n}$$

Table 6. *Calculation of the fuzzy direct correlation matrix*

X	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0, 0.1, 0.3)	(0.45, 0.64, 0.81)	(0.29, 0.46, 0.64)	(0.37, 0.56, 0.73)	(0.35, 0.54, 0.72)	(0.3, 0.48, 0.66)	(0.33, 0.52, 0.71)	(0.23, 0.4, 0.6)
C2	(0.51, 0.7, 0.87)	(0, 0.1, 0.3)	(0.26, 0.44, 0.63)	(0.32, 0.5, 0.69)	(0.16, 0.32, 0.51)	(0.3, 0.46, 0.63)	(0.43, 0.62, 0.79)	(0.21, 0.36, 0.55)
C3	(0.25, 0.4, 0.58)	(0.37, 0.56, 0.73)	(0, 0.1, 0.3)	(0.27, 0.46, 0.65)	(0.47, 0.66, 0.82)	(0.36, 0.54, 0.71)	(0.32, 0.5, 0.69)	(0.35, 0.52, 0.7)
C4	(0.27, 0.44, 0.62)	(0.27, 0.44, 0.62)	(0.27, 0.44, 0.63)	(0, 0.1, 0.3)	(0.31, 0.48, 0.67)	(0.37, 0.56, 0.73)	(0.37, 0.56, 0.74)	(0.33, 0.5, 0.67)
C5	(0.29, 0.46, 0.63)	(0.37, 0.56, 0.74)	(0.2, 0.36, 0.55)	(0.26, 0.42, 0.6)	(0, 0.1, 0.3)	(0.33, 0.52, 0.7)	(0.31, 0.48, 0.66)	(0.33, 0.5, 0.68)
C6	(0.15, 0.3, 0.5)	(0.33, 0.52, 0.7)	(0.42, 0.6, 0.77)	(0.25, 0.42, 0.61)	(0.31, 0.5, 0.68)	(0, 0.1, 0.3)	(0.4, 0.6, 0.76)	(0.27, 0.44, 0.63)
C7	(0.37, 0.56, 0.74)	(0.3, 0.48, 0.66)	(0.25, 0.42, 0.61)	(0.43, 0.62, 0.78)	(0.44, 0.62, 0.77)	(0.46, 0.66, 0.84)	(0, 0.1, 0.3)	(0.4, 0.6, 0.78)
C8	(0.39, 0.58, 0.74)	(0.33, 0.52, 0.7)	(0.36, 0.54, 0.72)	(0.37, 0.56, 0.74)	(0.26, 0.44, 0.63)	(0.32, 0.52, 0.71)	(0.4, 0.58, 0.75)	(0, 0.1, 0.3)

$$\tilde{a}_i^{(k)} = \sum \tilde{X}_{ij}^{(k)} = \left(\sum_{j=1}^{n} \tilde{l}_{ij}^{(k)}, \sum_{j=1}^{n} \tilde{m}_{ij}^{(k)}, \sum_{j=1}^{n} \tilde{u}_{ij}^{(k)} \right)$$

$$\tilde{b}^{(k)} = max \left(\sum_{j=1}^{n} \mathrm{u}_{ij}^{(k)} \right); 1 \le i \le n$$

Therefore, the normalized matrix will be as follows:

$$\begin{bmatrix} \tilde{N}_{11}^{(k)} & \tilde{N}_{12}^{(k)} & \cdots & \tilde{N}_{1n}^{(k)} \\ \tilde{N}_{21}^{(k)} & \tilde{N}_{22}^{(k)} & \cdots & \tilde{N}_{2n}^{(k)} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{N}_{n1}^{(k)} & \tilde{N}_{n2}^{(k)} & \cdots & \tilde{N}_{nn}^{(k)} \end{bmatrix}$$

so that each row of the normal matrix will be as follows:

$$\tilde{N}_{ij}^{(k)} = \left(\tilde{X}_{ij}^{(j)}\right) / \tilde{b}^{(k)} = \left(\frac{\tilde{l}_{ij}^{(k)}}{\tilde{b}^{(k)}}, \frac{\tilde{m}_{ij}^{(k)}}{\tilde{b}^{(k)}}, \frac{\tilde{u}_{ij}^{(k)}}{\tilde{b}^{(k)}} \right)$$

$$\tilde{b}^{(k)} = 5.48$$

$$k = max \left(\sum_{j=1}^{n} u_{ij} \right) = 5.48$$

$$\tilde{N} = \frac{1}{k} * \tilde{X}$$

Table 7. *Calculation of fuzzy normal direct correlation matrix*

N	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0, 0.02, 0.05)	(0.08, 0.12, 0.15)	(0.05, 0.08, 0.12)	(0.07, 0.1, 0.13)	(0.06, 0.1, 0.13)	(0.05, 0.09, 0.12)	(0.06, 0.09, 0.13)	(0.04, 0.07, 0.11)
C2	(0.09, 0.13, 0.16)	(0, 0.02, 0.05)	(0.05, 0.08, 0.11)	(0.06, 0.09, 0.13)	(0.03, 0.06, 0.09)	(0.05, 0.08, 0.11)	(0.08, 0.11, 0.14)	(0.04, 0.07, 0.1)
C3	(0.05, 0.07, 0.11)	(0.07, 0.1, 0.13)	(0, 0.02, 0.05)	(0.05, 0.08, 0.12)	(0.09, 0.12, 0.15)	(0.07, 0.1, 0.13)	(0.06, 0.09, 0.13)	(0.06, 0.09, 0.13)
C4	(0.05, 0.08, 0.11)	(0.05, 0.08, 0.11)	(0.05, 0.08, 0.11)	(0, 0.02, 0.05)	(0.06, 0.09, 0.12)	(0.07, 0.1, 0.13)	(0.07, 0.1, 0.14)	(0.06, 0.09, 0.12)
C5	(0.05, 0.08, 0.11)	(0.07, 0.1, 0.14)	(0.04, 0.07, 0.1)	(0.05, 0.08, 0.11)	(0, 0.02, 0.05)	(0.06, 0.09, 0.13)	(0.06, 0.09, 0.12)	(0.06, 0.09, 0.12)
C6	(0.03, 0.05, 0.09)	(0.06, 0.09, 0.13)	(0.08, 0.11, 0.14)	(0.05, 0.08, 0.11)	(0.06, 0.09, 0.12)	(0, 0.02, 0.05)	(0.07, 0.11, 0.14)	(0.05, 0.08, 0.11)
C7	(0.07, 0.1, 0.14)	(0.05, 0.09, 0.12)	(0.05, 0.08, 0.11)	(0.08, 0.11, 0.14)	(0.08, 0.11, 0.14)	(0.08, 0.12, 0.15)	(0, 0.02, 0.05)	(0.07, 0.11, 0.14)
C8	(0.07, 0.11, 0.14)	(0.06, 0.09, 0.13)	(0.07, 0.1, 0.13)	(0.07, 0.1, 0.14)	(0.05, 0.08, 0.11)	(0.06, 0.09, 0.13)	(0.07, 0.11, 0.14)	(0, 0.02, 0.05)

Calculation of the complete correlation matrix

$$N_l = \begin{bmatrix} 0 & l_{12} & \dots & l_{1n} \\ l_{21} & 0 & \dots & l_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ l_{n1} & l_{n2} & \dots & 0 \end{bmatrix} \quad N_m = \begin{bmatrix} 0 & m_{12} & \dots & m_{1n} \\ m_{21} & 0 & \dots & m_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n1} & m_{n2} & \dots & 0 \end{bmatrix} \quad N_u = \begin{bmatrix} 0 & u_{12} & \dots & u_{1n} \\ u_{21} & 0 & \dots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \dots & 0 \end{bmatrix}$$

Finally, the following operations are performed to obtain the complete correlation matrix:

$$T_l = N_l \times (I - N_l)^{-1}$$
$$T_m = N_m \times (I - N_m)^{-1}$$
$$T_u = N_u \times (I - N_u)^{-1}$$
$$\tilde{t}_{ij} = \left(t_{ij}^{l}, t_{ij}^{m}, t_{ij}^{u}\right)$$

Table 8. *Calculation of the complete fuzzy correlation matrix*

T	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0.04, 0.19, 1.65)	(0.12, 0.29, 1.81)	(0.09, 0.24, 1.66)	(0.1, 0.27, 1.76)	(0.1, 0.27, 1.75)	(0.1, 0.26, 1.8)	(0.1, 0.28, 1.84)	(0.08, 0.23, 1.68)
C2	(0.12, 0.28, 1.69)	(0.04, 0.19, 1.67)	(0.08, 0.23, 1.61)	(0.09, 0.25, 1.7)	(0.07, 0.22, 1.66)	(0.09, 0.25, 1.74)	(0.12, 0.28, 1.8)	(0.07, 0.22, 1.62)
C3	(0.09, 0.24, 1.7)	(0.11, 0.28, 1.8)	(0.04, 0.18, 1.61)	(0.09, 0.25, 1.74)	(0.12, 0.29, 1.77)	(0.11, 0.28, 1.81)	(0.1, 0.27, 1.84)	(0.1, 0.25, 1.7)
C4	(0.08, 0.24, 1.65)	(0.09, 0.25, 1.73)	(0.08, 0.23, 1.61)	(0.04, 0.18, 1.63)	(0.09, 0.25, 1.69)	(0.1, 0.27, 1.75)	(0.11, 0.27, 1.79)	(0.09, 0.24, 1.64)
C5	(0.09, 0.24, 1.62)	(0.1, 0.26, 1.71)	(0.07, 0.21, 1.56)	(0.08, 0.23, 1.64)	(0.04, 0.18, 1.59)	(0.1, 0.26, 1.71)	(0.1, 0.26, 1.74)	(0.09, 0.24, 1.6)
C6	(0.06, 0.21, 1.62)	(0.1, 0.26, 1.73)	(0.11, 0.25, 1.63)	(0.08, 0.24, 1.67)	(0.09, 0.25, 1.68)	(0.04, 0.19, 1.67)	(0.11, 0.28, 1.78)	(0.08, 0.23, 1.62)
C7	(0.11, 0.28, 1.81)	(0.1, 0.28, 1.88)	(0.09, 0.25, 1.75)	(0.12, 0.29, 1.85)	(0.12, 0.29, 1.85)	(0.13, 0.31, 1.92)	(0.05, 0.22, 1.87)	(0.11, 0.28, 1.79)
C8	(0.11, 0.27, 1.76)	(0.1, 0.28, 1.84)	(0.1, 0.26, 1.71)	(0.11, 0.28, 1.8)	(0.09, 0.26, 1.78)	(0.1, 0.28, 1.85)	(0.12, 0.29, 1.89)	(0.04, 0.19, 1.66)

After calculating the complete correlation matrix, the values can be de-fuzzified. The obtained matrix is the same as the complete correlation matrix and it can be used to calculate the pattern of causal relationships. There are many solutions for debuzzification, in this study, the surface center method is used.

Table 9. *De-fuzzified complete correlation matrix (deterministic)*

T	C1	C2	C3	C4	C5	C6	C7	C8
C1	0.5157	0.6273	0.5574	0.5989	0.5954	0.6057	0.6242	0.5552
C2	0.5933	0.5238	0.5377	0.5737	0.5452	0.5848	0.6203	0.5322
C3	0.5662	0.6165	0.5013	0.5851	0.6159	0.6169	0.6232	0.5758
C4	0.5523	0.5783	0.5386	0.5086	0.5702	0.5999	0.6114	0.5538
C5	0.5439	0.5840	0.5142	0.5481	0.4951	0.5804	0.5864	0.5415
C6	0.5288	0.5869	0.5598	0.5572	0.5694	0.5240	0.6131	0.5423
C7	0.6189	0.6358	0.5825	0.6399	0.6397	0.6670	0.5911	0.6162
C8	0.6040	0.6227	0.5832	0.6133	0.5948	0.6262	0.6477	0.5194

Table 10. *Matrix of significant relationships of study variables*

T	C1	C2	C3	C4	C5	C6	C7	C8
C1	×	0.63	×	0.60	0.60	0.61	0.62	×
C2	0.59	×	×	×	×	0.58	0.62	×
C3	×	0.62	×	0.59	0.62	0.62	0.62	×
C4	×	×	×	×	×	0.60	0.61	×
C5	×	0.58	×	×	×	0.58	0.59	×
C6	×	0.59	×	×	×	×	0.61	×
C7	0.62	0.64	0.58	0.64	0.64	0.67	0.59	0.62
C8	0.60	0.62	0.58	0.61	0.59	0.63	0.65	×

According to the pattern of relationships, it is possible to determine the set of effects and effects:

Table 11. *De-fuzzified complete correlation matrix (deterministic)*

D-R	D+R	R	D	Main Criteria	
0.16	9.20	4.52	4.680	Virtual reality and augmented reality technology	**C1**
-0.26	9.29	4.78	4.511	Complex networks and communications	**C2**
0.33	9.08	4.37	4.701	Powerful processing	**C3**
-0.11	9.14	4.62	4.513	Servers and cloud infrastructure	**C4**

-0.23	9.02	4.63	4.394	Metaverse development platforms and software	**C5**
-0.32	9.29	4.80	4.481	Security and information protection	**C6**
0.07	9.91	4.92	4.991	Interactive technologies	**C7**
0.37	9.25	4.44	4.811	Artificial intelligence technologies	**C8**

- The sum of the elements of each row (D) indicates the influence of that factor on other factors of the system. It is clear that interactive technologies have the greatest impact on other elements of the system. Artificial intelligence technologies are also the second most influential factor.
- The sum of the elements of the column (R) for each factor indicates the influence of that factor on other factors of the system. Interactive technologies are most influenced by other factors and are the product of the interaction of other elements.
- The horizontal vector (D+R) is the degree of influence of the desired factor in the system. Interactive technologies have the most interaction with other elements in the organization.
- The vertical vector (D-R) shows the influence power of each factor. In general, if D-R is positive, the variable is considered a causal variable, and if it is negative, it is considered an effect.

Discussion

In this research, 8 main criteria were identified based on the fuzzy multi-criteria decision-making method of Delphi and DEMATEL. These 8 criteria are: virtual reality and augmented reality technology, complex networks and communications, powerful processing, servers and cloud infrastructure, metaverse development platforms and software, security and information protection, interactive technologies and artificial intelligence technologies. Based on the Delphi technique, all items were confirmed. In the Fuzzy Dimetal technique, it was found that interactive technologies have the highest priority. Artificial intelligence technologies ranked second. Interactive technologies based on existing technologies have a special place in Metaverse. Augmented reality provides an opportunity to merge the real world with virtual elements. Among the examples of this technology in Metaverse can be mentioned the use in education and interactive training, project management, and even in medicine and clearer diagnosis of diseases. Users can access information and combine it with the real environment. In virtual reality, users enter a completely virtual world that creates rich and imaginative experiences. In Metaverse, VR is used as a solution for education, interactive games, virtual meetings, and even psychological and physical therapy. Sensory augmentation technologies such as vibrators, sounds, and smells can be used to create realistic interactive experiences in the metaverse. These components allow users to achieve more realistic experiences in the virtual environment.

Metaverse strives to take human-computer interactions to a higher level. From cognitive technologies to advanced user interfaces, these technologies help users interact more intelligently with content and the virtual world in Metaverse. By combining and interacting with these interactive technologies, Metaverse allows users to achieve attractive, informative and realistic experiences that are used in a variety of industries and applications. Ning et al. (2021), showed that for the sociality of the metaverse, we focus on the metaverse as a virtual social world. Considering the extra-space-time feature, we introduce Metaverse as an open, immersive and interactive 3D virtual world that can remove time and place limitations in the real world.

Conclusion

As a complex combination of multiple technologies, including virtual reality and augmented reality, the metaverse exploits complex networks and communications to create unique experiences for users. From this combination, there is an attractive result that provides unique and diverse experiences under the support of powerful processing and cloud infrastructure. These platforms leverage Metaverse development software to provide tools and environments where developers can create and improve interactive and realistic experiences. The security and protection of information is also very important in this process so that users can safely access Metaverse experiences.

Interactive technologies achieve this combination so that users can actively and interactively interact with content and virtual environments. Also, artificial intelligence technologies play an important role in improving user experiences, including recognizing and suggesting appropriate content, improving human-computer interactions, and predicting user needs.

In general, by combining different technologies and taking advantage of the potential of networks, powerful processing, cloud infrastructure, development software, security and protection, interactive technologies and artificial intelligence, Metaverse creates an innovative environment and a unique experience that is used in all kinds of industries from education and training to Entertainment and health are usable and connect in a way that goes beyond ordinary interactive reality.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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