Track 3: Metaverse Paradigms

A Hybrid Fuzzy AHP-VIKOR Framework for Systematic Evaluation and Ranking of Metaverse Applications

Sabarna Sarkar[1], Saptarshi Roychowdhury[2,*], Binod Kumar Singh[3]
National Institute of Technology Jamshedpur, Adityapur, Jamshedpur, Jharkhand 831014, India
[1] 2023pgcscs003@nitjsr.ac.in, [2] 2020rscs001@nitjsr.ac.in,
[3] bksingh.cse@nitjsr.ac.in
* Corresponding author: Saptarshi Roychowdhury, 2020rscs001@nitjsr.ac.in

Abstract. The metaverse is an emerging technological paradigm that has revolutionizing potential across various sectors such as healthcare, education, defence, and also in entertainment. But assessing and prioritizing metaverse applications is a real challenge due to the complexity and uncertainty of multiple criteria. We propose a new framework, a hybrid Multi-Criteria Decision-Making approach that combines two fuzzy methods, to systematically rank metaverse applications. While first method handles uncertainty in calculating criteria weights, second one identifies the best alternatives by considering a compromise between the group utility and individual regret measures in the ranking. The selected set of applications were evaluated against defined set of criteria using expert evaluations collected from domain experts. Legal and Judicial Systems come out on top as the highest Application Area, it performs well as it aligns nicely with compliance and other ethical challenges. Applications like Cultural Preservation and Heritage and Banking and Financial Services rated lower due to issues with scalability and innovation. This systematic framework gives stakeholders actionable insights to make informed decisions within the evolving metaverse ecosystem.

Keywords: Metaverse, Fuzzy AHP, Fuzzy VIKOR, Multi-Criteria Decision-Making (MCDM)

1 Introduction

As a convergence of virtual and augmented realities, the metaverse has transformative potential in many spaces, including healthcare, education, defense, and entertainment. The metaverse has attracted attention from industries, policymakers, and researchers through immersive experiences and new interaction paradigms [1]. Yet, as its adoption accelerates, stakeholders face the challenge of prioritizing applications that bring the greatest societal, technological, and economic benefits. Effective prioritization of its application is fundamental to ensure the efficient allocation of resources, alignment with user needs, and mitigation of risks such as technological misuse and ethical problems [2].

Multi-Criteria Decision-Making (MCDM) methods have become powerful tools for ranking and selecting alternatives in complex decision-making environments. This tool analyzes multiple criteria such as advantages, disadvantages, features with sustainability during the evaluation of metaverse applications [3]. Hybrid MCDM approaches which combines algorithms of criteria weightage and ranking are widely recognized for their ability to integrate different criteria and generate compromise rankings of alternative [4].

In this paper a hybrid model of Fuzzy AHP-VIKOR is presented for the prioritization of criteria and ranking of metaverse applications. Uncertainty in decision-making is addressed using fuzzification. Fuzzy AHP is used to evaluate criteria based on their relative priority. The next step is to identifies optimal ranking of metaverse applications through Fuzzy VIKOR [5]. VIKOR balances group utility and individual regret. This hybrid model enables a structured comparison of applications across a range of determinative factors which includes security and privacy concerns, technical chance of success, ethical factors and user adoption [6].

The primary aim of this research includes the development of a hybrid fuzzy AHP-VIKOR framework to evaluate metaverse applications. The framework evaluate weightage across key criteria considering all the given others factors. Hence, the study provides insights into how metaverse applications align with goals of industry as well as research which offers a comprehensive approach to guide policymakers to take best possible decisions for society [7].

2 Background Studies and Related Work

2.1 Metaverse and Its Application

The metaverse is a combination of virtual and augmented realities which provides immersive and interactive ecosystems across multiple domains. The metaverse facilitates remote medical consultations, therapy and accessibility solutions for people with disabilities which accelerates the field of healthcare and telemedicine [8][9].

Virtual classrooms open new dimension of education and training which makes possible of skill-building by replicating real life experience [10][11]. Similarly, the gaming and entertainment industries have transformed by offering real-life gaming experience and innovative storytelling opportunities within the metaverse [12][13].

Corporate houses utilize the metaverse for virtual workspace, remote collaboration, team-building using metaverse [14][15]. Real estate industry provides virtual tours, property simulations, and augmented reality-based purchasing experience using metaverse [16][17]. After having these many applications investing in metaverse is still not risk free. Due to variations in requirements, risks, security concerns, implementation cost and scalability issues it is required to have a proper selective criteria and prioritization to optimize resource allocation and achieve targeted goals [18][19].

2.2 Overview of Fuzzy AHP and Fuzzy VIKOR

Fuzzy logic is mathematical framework designed to handle uncertainty in information. This helps to reduce ambiguity by representing data as degree of truth. This is so useful for data regarding modern technology like metaverse, where decision making is often relies on subjective data. Techniques like triangular fuzzification captures variability through ranges defined by lower, middle and upper bounds. It integrates seamlessly with different MCDM algorithm like AHP and VIKOR. Fuzzy logic's adaptability to dynamic systems and its ability to translate qualitative judgments into actionable insights make it a powerful tool for improving decision-making in critical environments [20][21].

Fuzzy Analytic Hierarchy Process (Fuzzy AHP) extends classical AHP by incorporating fuzzy logic to resolve uncertainties and ambiguities in expert judgments. This approach enhances the reliability of pairwise comparisons between criteria and sub-criteria, where qualitative values such as "low importance" or "high importance" are translated into fuzzy numbers. Here, pairwise comparison refers to the process of comparing two criteria at a time to evaluate their relative importance. These comparisons are organized into a matrix $A = [a_{ij}]$, where a_{ij} represents the importance of criterion i over j, and the reciprocal property $\mathrm{a_{ji}} = 1/\mathrm{a_{ji}}$ ensures logical consistency. Fuzzy AHP is particularly suitable for metaverse applications, which often involve subjective criteria like inclusivity, scalability, and innovation. It provides an algorithm to weighting decision factors by structuring the problem hierarchically [22][23].

The VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) method focusing on ranking alternatives. It needs the weightage of criteria and criteria-alternate matrix dataset. The fuzzy implementation of VIKOR allows to mitigate the uncertainty in evaluating alternative. It calculates the utility and regret, and rank the alternates best on their closeness to the ideal solution [24][25]. VIKOR method is a perfect choice for ranking alternatives based on criteria used in this research. For example, "Inclusivity and Accessibility" might conflict with "Cost of Implementation" since creating a more inclusive metaverse could require additional investments. Similarly, prioritizing "Security and Privacy Concerns" could make the platform less user-friendly which affects "User Adoption and Acceptance". VIKOR helps by finding a compromise that balances overall benefits with minimizing the worst-case outcomes.

2.3 Hybrid MCDM Approaches in Emerging Technologies

Hybrid MCDM methods are widely employed to evaluate complex systems across various domains. For example, Das et al. [26] used fuzzy based AHP-VIKOR to propose a framework for risk accessing in nuclear power plant. Fuzzy based MCDM algorithms like Fuzzy Delphi, Fuzzy COBRA is used by Tadic et al. [27] for accessing strategies to overcome barriers in using drone for logistic delivery. In addition of these Afful-Dadzie et al. [28] proposed an approach based on fuzzy VIKOR to evaluate internet health information. These studies show the importance of fuzzy hybrid MCDM for accessing risk and uncertainties related to any metaverse application.

2.4 Related Work

Metaverse is a technology which generating a lot of interest from different research areas. The area of MCDM in metaverse is evolving and we can find several recent studies related to this space. Sleem et al. [29] explored the use of MCDM algorithm such as CRITIC method to analyze the needs of customer in virtual reality products. On the other side, Mohamed et al. [30] proposed a ranking algorithm based on MCDM algorithms like TOPSIS, COPRAS, VIKOR for selecting optimal metaverse platform. Yawised et al. [31] examined advantages-disadvantages and implementation feasibility of metaverse application in corporate environments. Abrar-ul-Haq et al. [32] explored the challenges and risk associated in application of metaverse in case of real estate. Husin et al. [33] developed a privacy evaluation framework for metaverse tools using a Fuzzy MCDM approach to prioritize tools based on privacy-related criteria for industrial cyber physical system.

2.5 Research Gap

Hybrid MCDM algorithms are extensively in use to rank and prioritizing different application in the domain of science and technology. But there is a lack of comprehensive frameworks which address the unique challenges in metaverse. This study addresses this gap by proposing a framework using fuzzy AHP and VIKOR. This proposed method evaluates and ranks metaverse application by considering various criteria.

3 Methodology

In this research a hybrid MCDM framework combines fuzzy AHP and VIKOR to systematically rank applications of metaverse. Here, data is collected from domain experts. These data are basically in crisp value scales and then apply fuzzifications techniques to handle uncertainties. The complete process involves data collection, criteria weight computation and final application ranking.

3.1 Data Collection

The data collection process for this study involved gathering inputs from 20 domain experts across various fields related to metaverse applications, such as technology, user experience, and policy. These experts were carefully chosen to provide diverse perspectives, ensuring comprehensive evaluations. For Fuzzy AHP, pairwise comparisons of the 12 criteria are provided via a crisp numeric scale from 1 to 9 [34], where 1 represents equal importance between two criteria, and 9 represents the extreme importance of one criterion over the other. The pairwise comparison matrix is constructed as $A = [a_{ij}]$, where a_{ij} represents the importance of criterion i over criterion j, and satisfies the reciprocal property:

$$a_{ji} = \frac{1}{a_{ij}}, \quad \forall i, j, \quad i \neq j$$

Inputs were later fuzzified using triangular membership functions to address uncertainties in expert judgments.

Table 1. Crisp Pairwise Comparison

	C1	C2	C3
C1	1	a	b
C2	1/a	1	c
C3	1/b	1/c	1

Table 1 is an example of how the pairwise comparison matrix looks like for AHP. Similarly, for Fuzzy VIKOR, experts evaluate the performance of 10 metaverse applications against the 12 criteria on a scale of 1 to 10, with higher values indicating better performance. The evaluation matrix is represented as $\boldsymbol{X} = [\boldsymbol{x_{ij}}]$, where $\boldsymbol{x_{ij}}$, denotes the performance score of application $\boldsymbol{i}$ with respect to criterion $\boldsymbol{j}$. Similar to Fuzzy AHP, the crisp data collected was fuzzified to incorporate subjective variations in expert evaluations. The responses from all 20 experts were aggregated by averaging their ratings, ensuring a balanced and consensus-driven dataset while preserving the diversity of opinions**.** Table 2 represents linguistic values of criteria.

Table 2. Linguistic Variable of Criteria

Keyword	**Severity level**	**Risk of Damage**	**Score**
Very Low	System is not endangered	Very Low	(0,1,2)
Low	Slight system disturbance	Low	(1,2,4)
Medium	Potential disturbance presents	Medium	(3,4,6)
High	High system disturbance presents	High	(5,6,8)
Very High	Extreme disturbance	Very High	(7,8,10)

3.2 Fuzzy AHP for Criteria Weight Calculation

The criteria weights are calculated using Fuzzy AHP, which accounts for uncertainty in expert judgments. The pairwise comparison matrix is first transformed into a fuzzy triangular matrix $\tilde{A} = [\widetilde{a_{ij}}]$ where each entry $\widetilde{a_{ij}}$ is represented as:

$$\widetilde{a_{ij}} = (l_{ij}, m_{ij}, u_{ij})$$

Here, l_{ij}, m_{ij}, and u_{ij} are the lower, middle, and upper bounds, respectively. For example, a crisp value a_{ij} is fuzzified as:

$$l_{ij} = 0.9 \cdot a_{ij,} \quad m_{ij} = a_{ij}, \quad u_{ij} = 1.1 \cdot a_{ij}$$

Next, the fuzzy synthetic extent S_i for each criterion is calculated as:

$$S_i = \frac{\sum_{j=1}^{n} \widetilde{a_{ij}} \otimes \widetilde{w_j}}{\sum_{k=1}^{n} \sum_{j=1}^{n} \widetilde{a_{kj}}}$$

S_i is a fuzzy number, and the resulting S_i will have the form:

$$S_i = (l_i, m_i, u_i)$$

The fuzzy weights $\widetilde{w_i}$ are then defuzzified using the centroid method to obtain crisp weights w_i:

$$w_i = \frac{l_i + m_i + u_i}{3}$$

Finally, the weights are normalized to ensure they sum to 1:

$$W = \frac{w_i}{\sum_{i=1}^{n} w_i}, \quad i = 1,2, \dots, n \text{ ; n represents number of criteria}$$

3.3 Fuzzy VIKOR for Ranking Applications

The ranking of metaverse applications is conducted using Fuzzy VIKOR. The crisp evaluation matrix $X = [x_{ij}]$ is transformed into a fuzzy triangular matrix $\tilde{X} = [\widetilde{x_{ij}}]$, where:

$$\widetilde{x_{ij}} = (0.9 \cdot x_{ij}, x_{ij}, 1.1 \cdot x_{ij})$$

The fuzzy ideal ($\widetilde{A^+}$) and fuzzy negative-ideal ($\widetilde{A^-}$) solutions for each criterion are identified as:

$$\widetilde{A^+} = \max(\widetilde{x_{ij}}), \quad \widetilde{A^-} = \min(\widetilde{x_{ij}})$$

For each application, the utility measure S_i and regret measure R_i are computed. The utility measure aggregates the weighted performance of an application across all criteria:

$$S_i = \sum_{j=1}^{n} w_j \cdot \frac{\widetilde{A^+} - \widetilde{x_{ij}}}{\widetilde{A^+} - \widetilde{A^-}}$$

n represents number of criteria, w_j represents weight of j[th] criteria

The regret measure captures the largest deviation from the ideal solution on any single criterion:

$$R_i = \max_j \left(w_j \cdot \frac{\widetilde{A^+} - \widetilde{x_{ij}}}{\widetilde{A^+} - \widetilde{A^-}} \right)$$

The VIKOR index Q_i combines the utility and regret measures:

$$Q_i = v \cdot \frac{S_i - S^*}{S^- - S^*} + (1 - v) \cdot \frac{R_i - R^*}{R^- - R^*}$$

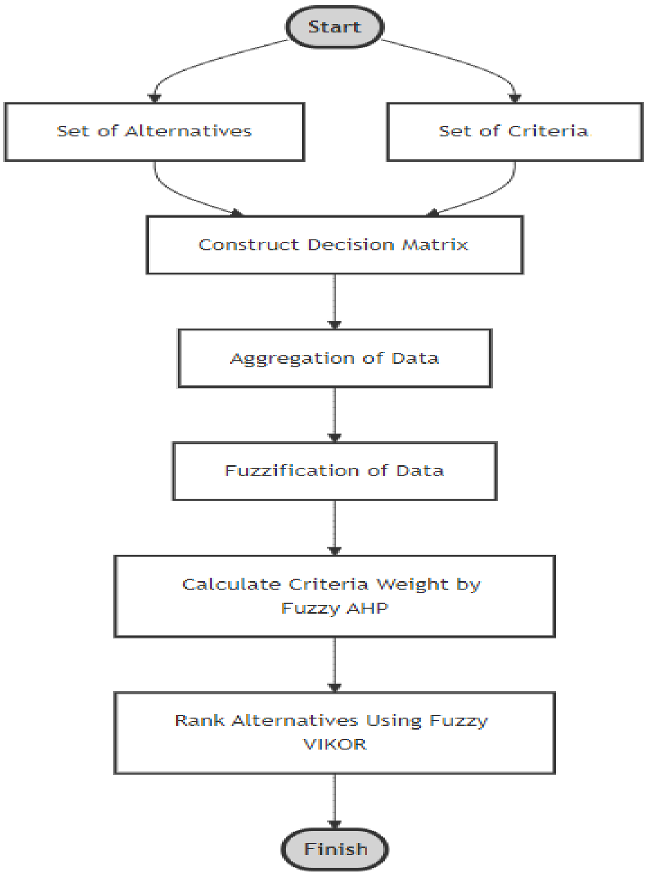

Fig. 1. Step Diagram of Hybrid MCDM Process

Finally, the fuzzy results for Q_i are defuzzified to obtain crisp values, which are used to rank the applications.

Here the alternate with smallest Q_i value is considered the best. The step diagram of the methodology is shown in Fig.1.

4 Results and Discussion

In this section, the ranking outcomes of the Hybrid MCDM framework integrating Fuzzy AHP and Fuzzy VIKOR is presented. The results include fuzzy criteria weightage, crisp value of criteria weights and the final ranked list of alternates. Each step regarding this output calculation is described earlier.

4.1 Criteria Weight Calculation using Fuzzy AHP

The criteria weights were calculated using the Fuzzy AHP methodology, which incorporated the pairwise comparison matrix collected from experts. The aggregated pairwise comparison of experts is shown in Table 3. The crisp comparison values were transformed into a fuzzy triangular matrix to. Then the fuzzy synthetic extent for each criterion is calculated.

Table 3. Aggregated Pairwise Comparison

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	1	5.8	5.55	4.7	5.2	4.4	6.65	4.5	4.9	5.95	4.9	5.5
C2	0.2	1	5.1	5.35	4.7	4.95	4.4	4.65	4.8	4.95	6	4.7
C3	0.2	0.3	1	4.8	5.45	5.25	3.95	5	5.2	3.8	4.9	5.5
C4	0.3	0.2	0.32	1	5.45	4.55	5.3	5.8	4.4	5.35	4.05	6.15
C5	0.3	0.3	0.27	0.28	1	5.8	5.05	5.8	5.4	5.3	4.75	3.95
C6	0.3	0.3	0.25	0.35	0.24	1	4.9	4.8	4.0	5.15	4.4	4.7
C7	0.1	0.3	0.48	0.29	0.32	0.29	1	5.75	5.8	5.25	4.8	5.9
C8	0.3	0.3	0.30	0.21	0.26	0.34	0.26	1	4.6	6.15	4.1	4.55
C9	0.3	0.3	0.22	0.31	0.30	0.42	0.23	0.29	1	5.45	4.1	4.7
C10	0.2	0.3	0.44	0.27	0.32	0.27	0.36	0.29	0.2	1	4.45	6.4
C11	0.3	0.2	0.31	0.39	0.34	0.35	0.33	0.40	0.3	0.34	1	5.5
C12	0.2	0.2	0.29	0.19	0.41	0.34	0.26	0.34	0.2	0.18	0.24	1

Table 4. Fuzzy Weights Derived Using Fuzzy AHP

Criteria	l_i	m_i	U_i
Criticality of Impact	0.131848	0.161147	0.196957
Security and Privacy Concerns	0.113449	0.13866	0.169473
Technological Feasibility	0.1015	0.124056	0.151624
Ethical and Legal Challenges	0.095981	0.11731	0.143379
Inclusivity and Accessibility	0.085422	0.104405	0.127606

Cost of Implementation	0.068132	0.083273	0.101778
Scalability	0.067914	0.083006	0.101451
User Adoption and Acceptance	0.050142	0.061285	0.074904
Potential for Innovation	0.039728	0.048557	0.059347
Risk of Misuse	0.032754	0.040033	0.048929
Regulatory and Compliance Complexity	0.022115	0.02703	0.033036
Sustainability	0.009196	0.011239	0.013737

The resulting fuzzy weights for all 12 criteria are shown in Table 4. The l_i (lower bound) shows the minimum or worst-case scenario, while the m_i (middle value) represents the most likely or average situation. The u_i (upper bound) reflects the best possible outcome. Together, these values give a clear picture of the range and variability of each criterion, making it easier to evaluate alternatives realistically.

Table 5. Normalized Crisp Weights Derived Using Fuzzy AHP

Criteria	W_i
Criticality of Impact	0.161147
Security and Privacy Concerns	0.13866
Technological Feasibility	0.124056
Ethical and Legal Challenges	0.11731
Inclusivity and Accessibility	0.104405
Cost of Implementation	0.083273
Scalability	0.083006
User Adoption and Acceptance	0.061285
Potential for Innovation	0.048557
Risk of Misuse	0.040033
Regulatory and Compliance Complexity	0.02703
Sustainability	0.011239

These weights are in fuzzy format. Then the fuzzy weights were defuzzified using the centroid method, calculating the crisp weights and subsequently normalized to ensure their sum equals 1. Table 5 presents the normalized crisp weights derived from Fuzzy AHP.

4.2 Application Ranking Using Fuzzy VIKOR

The performance of 10 metaverse applications was evaluated against the 12 criteria using the Fuzzy VIKOR methodology. The crisp evaluation matrix collected from experts was first transformed into a fuzzy triangular matrix to account for uncertainties in expert evaluations. The transformation resulted uncertainty in evaluations. Then fuzzy ideal ($\widetilde{A^{+}}$) and fuzzy negative ideal ($\widetilde{A^{-}}$) solutions for each criterion is calculated. This represents the best and worst possible performance levels.

The utility score S_i and regret measure R_i is calculated using these solutions. The utility score aggregates the weighted performance of an alternate across all criteria. Then the regret measure captures the largest deviation from the ideal solution on any single criterion. At the end the VIKOR index Q_i is calculated by combining the utility and regret measures. Table 6 presents the computed $S_{i,}$ R_i and Q_i values and rankings for the 10 applications.

Table 6. Final VIKOR Index and Rankings

Alternate	S_i	R_i	Q_i	Rank
Healthcare and Telemedicine	0.427	0.135	0.181	1
Government and Public Services	0.434	0.138	0.236	2
Entertainment and Media	0.516	0.121	0.280	3
Corporate Workspaces	0.523	0.121	0.303	4
Legal and Judicial Systems	0.568	0.130	0.561	5
Humanitarian and Disaster Response	0.562	0.132	0.563	6
Defense and Military	0.558	0.133	0.564	7
Banking and Financial Services	0.578	0.133	0.633	8
Cultural Preservation and Heritage	0.585	0.137	0.707	9
Education and Training	0.561	0.161	0.923	10

These results rank Healthcare and Telemedicine as the highest-ranked alternative because of its strong performance in critical criteria such as Inclusivity and Accessibility and Impact on System and Patient Safety. Government and Public Services is ranked second due to its high potential for metaverse adoption and its scalability. Education and Training received the lowest rank because of challenges in Scalability and Technological Feasibility. These rankings provide stakeholders with actionable insights to strategically prioritize metaverse applications in terms of investment and resource allocation. Fig 2 contains graphical representations of Q_i of the alternates.

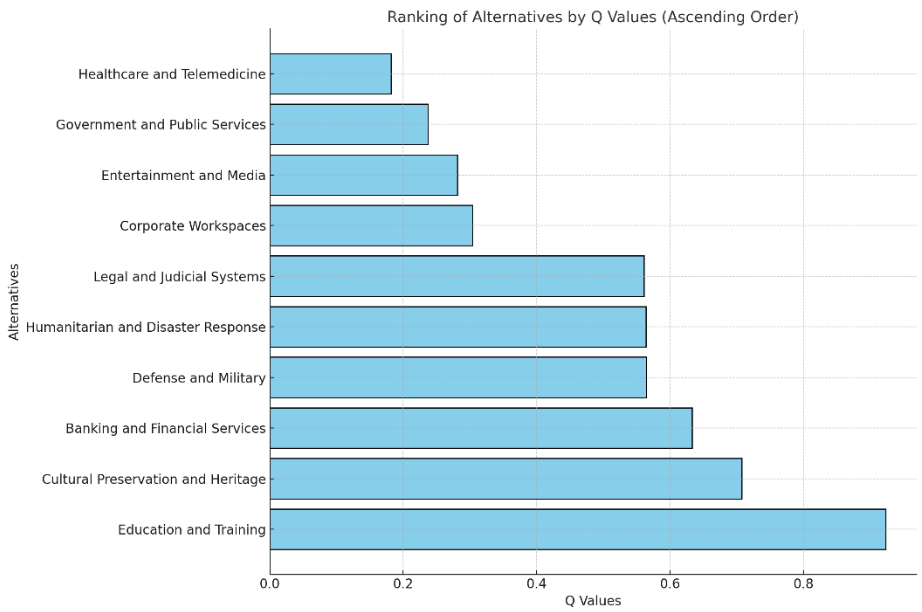

Fig. 2. Bar Chart Displaying the Alternatives Ranked by heir Q_i

4.3 Discussion

The framework ranks metaverse applications effectively, with Healthcare and Telemedicine standing out as the top-ranked application due to its strong focus on Inclusivity, Accessibility, and Critical Impact. Government and Public Services is ranked second, excelling in Scalability and Adoption Potential. On the other hand, areas like Cultural Preservation and Heritage and Banking and Financial Services face challenges in Scalability and Innovation, requiring further development. These findings highlight the need for secure infrastructure and thoughtful planning to fully realize the metaverse's potential and enable informed, impactful decisions.

5 Conclusion

This study presents a comprehensive framework that combines Fuzzy AHP and Fuzzy VIKOR to rank metaverse applications. The framework addresses uncertainty in the collected dataset and provides a structured approach to the algorithm. This approach considers critical features like technological, societal, and regulatory impacts to derive the rankings. The results highlight the importance of high-performing applications like Healthcare and Telemedicine and Government and Public Services, which excel in addressing critical challenges such as Inclusivity, Accessibility, and Scalability in the metaverse. On the other hand, lower rankings of Banking and Financial Services and

Cultural Preservation and Heritage emphasize the areas where Scalability and Technological Feasibility remain significant challenges. This tool will assist stakeholders and policymakers in making strategic decisions regarding resource allocation and aligning the use of the metaverse with societal and industrial priorities.

References

[1] Xiong, J., Hsiang, E.-L., He, Z., Zhan, T., & Wu, S.-T. Augmented reality and virtual reality displays: emerging technologies and future perspectives. Light: Science & Applications,10(1), 1–30, (2021).

[2] Benjamins, R., Rubio Viñuela, Y., & Alonso, C. Social and ethical challenges of the metaverse: Opening the debate. AI and Ethics, 3(3), 689–697, (2023).

[3] Jeong, S.-H., & Kim, H.-K. Effect of trust in metaverse on usage intention through technology readiness and technology acceptance model. Tehnički Vjesnik, 30(3), 837–845, (2023).

[4] Tinmaz, H., & Dhillon, P. K. S. User-Centric Avatar Design: A Cogni- tive Walkthrough Approach for Metaverse in Virtual Education. Data Science and Management (2024).

[5] Awasthi, A., Govindan, K., & Gold, S. Multi-tier sustainable global sup- plier selection using a fuzzy AHP-VIKOR based approach. International Journal of Production Economics, 195, 106–117, (2018).

[6] Kim, M., Oh, J., Son, S., Park, Y., Kim, J., & Park, Y. Secure and privacy-preserving authentication scheme using decentralized identifier in metaverse environment. Electronics, 12(19), 4073, (2023).

[7] De Giovanni, P. (2023). Sustainability of the Metaverse: A transition to Industry 5.0. Sustainability, 15(7), 6079, (2023).

[8] Wang, Y., Zhu, M., Chen, X., Liu, R., Ge, J., Song, Y., & Yu, G. The application of metaverse in healthcare. Frontiers in Public Health, 12, 1420367, (2024).

[9] Dagli, N. Advancement in telemedicine and teledentistry with virtual reality and metaverse. Journal of International Oral Health, Vol. 14, pp. 529–530. Medknow (2022).

[10] Prakash, A., Haque, A., Islam, F., & Sonal, D. Exploring the potential of metaverse for higher education: Opportunities, challenges, and implications. Meta- verse Basic and Applied Research, 2, 40–40, (2023).

[11] Hawkins, M. Virtual employee training and skill development, work- place technologies, and deep learning computer vision algorithms in the immersive metaverse environment. Psychosociological Issues in Human Resource Management, 10(1), 106–120, (2022).

[12] Mohammed, S. Y., Aljanabi, M., & Gadekallu, T. R. Navigating the nexus: a systematic review of the symbiotic relationship between the metaverse and gaming. International Journal of Cognitive Computing in Engineering (2024).

[13] Yang, S. Storytelling and user experience in the cultural metaverse. He- liyon, 9(4), (2023).

[14] Chen, Z. Metaverse office: Exploring future teleworking model. Kyber- netes, 53(6), 2029–2045, (2024)..

[15] Umoren, R., Stadler, D. J., Gasior, S. L., Al-Sheikhly, D., Truman, B., & Lowe, C. Global collaboration and team-building through 3D virtual environments. Innovations in Global Medical and Health Education, 2014(1), 1, (2014).
[16] Nesaif, B. M. R. B., & Shagufta, S. The Impact of Metaverse Business on the Real Estate Industry. International Journal for Innovative Research in Science & Technoology (IJIRST), 8(7), (2023).
[17] Grupac, M., Husakova, K., & Balica, R.-Ş. Virtual navigation and aug- mented reality shopping tools, immersive and cognitive technologies, and image pro- cessing computational and object tracking algorithms in the metaverse commerce. Analysis and Metaphysics, 21, 210–226, (2022).
[18] Rathore, B. Metaverse marketing: novel challenges, opportunities, and strategic approaches. Eduzone: International Peer Reviewed/Refereed Multidisci- plinary Journal, 7(2), 72–82, (2018).
[19] Shin, S., & Park, J.-Y. A Study on Metaverse Risks and Risk Perceptions, (2024).
[20] Zadeh, L. A. Fuzzy logic. In *Granular, Fuzzy, and Soft Computing* (pp. 19–49). Springer, (2023).
[21] Kreinovich, V., Kosheleva, O., & Shahbazova, S. N. Why triangular and trapezoid membership functions: A simple explanation. *Recent Developments in Fuzzy Logic and Fuzzy Sets: Dedicated to Lotfi A. Zadeh*, 25–31, (2020).
[22] Sipahi, S., & Timor, M. The analytic hierarchy process and analytic net- work process: an overview of applications. Management Decision, 48(5), 775–808, (2010).
[23] Goyal, S., Devi, S., & Rani, P. Pythagorean fuzzy information-based MCGDM method for assessing the metaverse incorporated sharing economy ap- plications in the transportation sector. Granular Computing, 9(1), 9, (2024).
[24] Isabels, R., Vinodhini, A. F., & Viswanathan, A. Evaluating and ranking metaverse platforms using intuitionistic trapezoidal fuzzy vikor MCDM: Incorporat- ing score and accuracy functions for comprehensive assessment. Decision Making: Applications in Management and Engineering, 7(1), 54–78, (2024).
[25] Liu, P., Yüksel, S., Dinçer, H., & Olaru, etG. O. Artificial Intelligence-Based Expert Prioritizing and Hybrid Quantum Picture Fuzzy Rough Sets for Investment Decisions of Virtual Energy Market in the Metaverse. International Journal of Fuzzy Systems, 1–23, (2024).
[26] Das, A., Kumar, V., & Dutta, S. A fuzzy-based AHP-VIKOR framework for risk analysis of safety-critical systems: A case study of nuclear power plant. Annals of Nuclear Energy, 209, 110841, (2024).
[27] Tadić, S., Krstić, M., & Radovanović, L. Assessing strategies to overcome barriers for drone usage in last-mile logistics: a novel hybrid fuzzy MCDM model. Mathematics, 12(3), 367, (2024).
[28] Afful-Dadzie, E., Nabareseh, S., & Oplatková, Z. K. Fuzzy VIKOR ap- proach: Evaluating quality of internet health information. 2014 Federated Confer- ence on Computer Science and Information Systems, 183–190. IEEE (2014).
[29] Sleem, A., Mostafa, N., & Elhenawy, I. Neutrosophic CRITIC MCDM methodology for ranking factors and needs of customers in product's target demo- graphic in virtual reality metaverse. Neutrosophic Systems with Applications, 2, 55–65, (2023).

[30] Mohamed, S. S., & Ali, A. M. Multi-criteria decision-making methodology for ranking and selecting optimal metaverse platform. Soft Computing Fusion with Applications, 1(1), 10–18, (2024).
[31] Yawised, K., Apasrawirote, D., & Boonparn, C. From traditional business shifted towards transformation: The emerging business opportunities and challenges in 'Metaverse'era. Incbaa, 162, 175, (2022).
[32] Abrar-ul-Haq, M., & Arkam, F. Real Estate in the Metaverse. In A. Jreisat & M. Mili (Eds.), Blockchain in Real Estate: Theoretical Advances and New Em- pirical Applications (pp. 123–151), (2024).
[33] Husin, N. A., Abdulsaeed, A. A., Muhsen, Y. R., Zaidan, A. S., Alnoor, A., & Al-mawla, Z. R. Evaluation of Metaverse Tools Based on Privacy Model Using Fuzzy MCDM Approach. International Multi-Disciplinary Conference-Integrated Sciences and Technologies, 1–20. Springer (2023).
[34] Thaker, S., & Nagori, V. Analysis of fuzzification process in fuzzy expert system. Procedia Computer Science, 132, 1308–1316, (2018).
[35] Liberatore, M. J. Book review of the analytic hierarchy process: planning, priority setting, resource allocation by Thomas L. Saaty. Taylor & Francis (1982).