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Is Metaverse Intended for Purchasing? An Empirical Investigation

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Abstract— **The metaverse, a digitally accessed immersive virtual environment, has the capacity to transform online retail by providing consumers with distinctive product experiences. This study examines how consumers behave when using metaverse platforms for purchasing. It specifically looks at how trust and perceived enjoyment play a part in influencing their desire to make a purchase. A quantitative methodology was utilized, with a total of 483 undergraduate students taking part in an experiment that entailed engaging with a metaverse retail platform called Decentraland, as well as completing a questionnaire that they administered to themselves. The results of the structural equation modelling analysis showed that the consumer's attitude towards the metaverse platform had a substantial positive effect on trust (β = 0.53) and perceived enjoyment (β = 0.39). These factors, in turn, had a favorable impact on purchase intention (β = 0.42 and β = 0.62, respectively). Furthermore, it was discovered that trust (with an indirect effect of 0.223) and perceived enjoyment (with an indirect effect of 0.241) play a major role in mediating the connection between customer attitude and purchase intention. The results enhance our comprehension of consumer behavior within the metaverse framework, highlighting the significance of cultivating trust and enjoyment to stimulate positive purchase intentions. The paper examines the consequences of the study for both theoretical and managerial perspectives. It emphasizes the importance for creators of metaverse platforms and brands to prioritize methods that build trust and boost the perceived satisfaction of users through immersive, interactive, and engaging virtual experiences. Proposed future study directions aim to overcome restrictions and broaden the scope of investigation as the metaverse continues to develop.**

Keywords— Metaverse, consumer attitude, trust, purchase intention, perceived enjoyment

I. INTRODUCTION

"Metaverse" a term used to describe a shared, immersive virtual world that is accessed by users through digital devices, such as virtual reality headsets or computer screens. In metaverse, users can interact with each other and with computer-generated environments and objects as if they were in a physical space, often using customizable avatars. A novel "snow crash" described metaverse [50] for the first time as "where humans, as programmable avatars, interact with each other and software agents, in a three-dimensional virtual space that uses the metaphor of the real world."

Facebook a leading social media platform changed its name to "Meta" to demonstrate the necessity of metaverse in future path of the planet's interaction through internet. According to a report [2], metaverse will be a part of people's life for at least one hour a day for digital footprints such as shopping, interaction and entertainment. Virtual Reality(VR) technologies, Mixed reality (MR) and Augment Reality(AR) technologies, are responsible for creating a sense of immersion in the user. In recent years, these technologies have seen significant advancements and have gained increasing popularity in both consumer and enterprise markets. According to estimates, the combined market for VR, MR, and AR technologies is expected to reach a size of around USD 250 billion by 2028 [61]. It is uncertain how the metaverse will evolve in the future, but it is probable that media technologies will progress towards delivering more layers of sensory information to users, resulting in increased immersion. Scholars have referred to this as immersion, and it is expected that it will be a key feature of metaverse as it continues to develop [12].

Metaverse has the potential to revolutionise and change how communication is delivered and how consumers respond to it, challenging our current knowledge of these processes. This is suggested by the developments being made in immersive technologies and infrastructures [21]. Customers will probably be able to live and share their experiences in metaverse in a fashion that more or less mirrors their real-life experiences [9]. Users of AR, VR, and other visual-enabling technologies may already move around, interact with things and people virtually, and real-time sense stimulation [67]. Metaverse offers an exciting opportunity for retailers to provide customers with virtual product experiences that can help them evaluate products prior to making a purchase. Research has shown that direct product experiences are crucial in enabling customers to learn about product benefits and determine whether a product is a good fit for their needs [19, 59]. However, offering such experiences can be difficult in online retail, and this is where Metaverse could prove particularly useful.

With the advent of metaverse platforms, shoppers now have the ability to virtually experience products even when physical products are not available, which can help to set realistic expectations and increase their confidence in making

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a purchase [45]. In India, Flipkart launched a metaverse shopping platform called “flipverse” which provides a virtual 3D shopping experience to interact with selected brands [54]. In order to effectively incorporate immersive technology into virtual commerce applications, it is necessary to conduct numerous behavioural studies and use them as a model for application design research and development [9]. The consumer behaviour research on metaverse platforms assesses the impact of specific design artefacts on behavioural responses such as acceptance levels and purchase intention [7].

As a consumer, there is an uncertainty about the potential of metaverse technology to enhance the shopping experience in the online retail. While there is keen interest in this technology, limited research exists that demonstrates its tangible impact in real-world contexts. However, it is understood that in order for businesses to invest in this new technology, it is essential to comprehend its potential to increase revenues. If metaverse can help consumers to visualize products in their consumption contexts and reduce product fit uncertainty, they might be more inclined to make purchases through metaverse platforms. As such, consumers are open to exploring this new technology and interested to see how it can improve their shopping experience in the metaverse.

From the previous literature, very few studies have been focused on the consumer behaviour towards the adaptation of virtual reality (VR), Augment reality (AR) and extended reality (XR) platforms [1, 44, 9, 57, 48]. In the context of adaptation of metaverse platforms for shopping in online retail world there is a clear lack in literature. From the behavioural research perspective there is a lack of quantitative empirical research done on adaptation on metaverse platforms and consumer behaviour variables [51, 48].

The questions raised by the present study are:

1. Are the Indian consumers ready to adapt metaverse platforms for shopping?
2. Does the attitude of Indian consumers towards metaverse platforms influence behavioural variable?
3. Is there any mediating relationship between consumer attitude towards metaverse and behavioural variables?

The aim of this paper is to conduct empirical research on consumer behaviour towards metaverse applications, with a specific focus on purchase intention as the desired behaviour outcome. The reason for choosing purchase intention is because it is a widely studied consumer response in existing research [7]. The second objective of the study is to find the influence of trust and perceived enjoyment mediating between consumer attitude towards metaverse and purchase intentions.

II. Theoretical Model

The study has adopted consumer purchase model to get a solid understanding of consumer behaviour. The classical model consists of five stages, commonly used to describe consumer purchase decisions, despite undergoing refinement over period of time, it remains a strong theoretical foundation [43]. Furthermore, this approach has been extensively embraced in the field of information systems to examine consumer behaviors in the realm of electronic commerce [8, 25]. The purchase decision stage is considered as the most crucial stage among the five stages of consumer decision-making process [23]. This stage signifies the consumer's readiness to make a purchase, and hence, it holds great significance in the actual purchase process. To measure the purchase decision, purchase intention is commonly used [16, 23]. Purchase intention refers to the level of willingness of a consumer to buy a specific product or service, from a particular brand [3]. It is important to recognize that the decision on purchase can be affected by the actions and variables at every stage of the customer decision-making process [29]. Consumers may not necessarily follow the sequential order of the stages during a purchase, various factors and activities might also impact their final decision [43].

Stimulus organism response model (SOR) is adopted in the study due to its wide implication in consumer behaviour research [42]. In a commerce research platform SOR model is considered as the response [8]. Researchers have investigated the impact of genuine experience on consumer’s evaluation on virtual tourism promotion to analyse cognitive and affective responses [35]. In online purchase consumers get over exposed to available information and cause unusual purchase behaviour [23]. Impulsive purchase can also be adopted due to the factors contributing to SOR model [14, 47]. A comprehensive knowledge of individual consumer purchases in virtual commerce is made possible by the merging of the SOR model and the classical model of consumer decision-making. The characteristics of virtual commerce, categorized as immersive technology or consumer behaviors, can be understood as the stimulus or organism, while the decisions made regarding purchases can be understood as the reaction [7].

III. Review Of Literature

A. Consumer attitude towards metaverse

The consumer response to commerce in virtual world is believed to have multiple factors such as attitudes, trust and enjoyment [27]. The perceived telepresence and social presence through VR and AR platforms have a two-way relationship with consumer attitude and trust. Specifically, the level of trust a consumer has in a shopping experience can be influenced by their attitudes towards shopping, as well as their perception on the level of social and technological presence in the shopping environment [41]. Consumer attitude towards the richness of the platform is highly influenced by the involvement of consumer towards their shopping experience [24]. Consumer attitudes in virtual shopping were influenced by consumer's cognitive elaboration and the platform interactivity and their goal to search for a specific product [26]. When interacting with 3D visual products, customers can feel a psychological and emotional state of flow that is comparable to their views toward virtual experiences [67]. The way that consumers feel about immersive technologies is comparable to how they feel about the quality of 3D information in their product attitude model [7]. The implementation of AR technologies in laboratories to study the attitudes of student towards the lab resulted in improved skill among the students [11]. Consumer perception of an organization to be more transparent in their communication leads to have positive attitude towards it [6], so if a platform with more transparency can generate the same attitude towards it. Consumer attitude towards the technology are shaped by their knowledge of the technology, previous experiences and perception of expected benefits [51].

B. Purchase intention in Metaverse

The purchase decision may not always result in an actual purchase, but it is the most accurate indicator of a consumer's behavioural intention [23, 16, 29]. The effects of pleasure and arousal factors on user satisfaction, buy intention, and choice confidence were examined in a study done on a virtual furniture retailing store. The study revealed that the impacts of hedonic value and user engagement were comparable [44]. Stereo VR technology has the potential to significantly enhance the consumer's purchase intention by providing them with more interactive and immersive product experience in a stereoscopic environment [28]. VR shopping technology can be utilized to create an environment where customers can engage with the product in a better tangible way, allowing them to visualize and explore its features and benefits in a more realistic and three-dimensional manner [58]. By allowing customers to virtually try on clothing items and accessories, virtual fitting rooms provide a more interactive and personalized shopping experience that can enhance customer engagement and lead to purchase intention [8]. Researchers conducted a comparative study with conventional online e-commerce sites and found AR has been touted as a promising technology for enhancing the shopping experience by allowing consumers to visualize products in a more interactive and immersive way that improved the effectiveness of AR on consumer's purchase intention [25, 51, 55, 64]. In virtual commerce, branding plays a crucial role in nurturing consumer purchase intention because a strong sense of presence and brand recall are important factors that contribute to purchase intention in VR shopping [15].

C. Role of trust and perceived enjoyment in Metaverse

The immersive and interactive nature of VR can lead to more positive attitude towards a brand or product, as consumers have more engaging and personalized shopping experience that enhances their enjoyment [58, 17]. Additionally, VR provide a greater level of transparency and credibility, which can enhance trust in the buying process [52]. By allowing consumers to explore and interact with products in a virtual environment before making a purchase, VR provide a unique opportunity for businesses to improve customer experience and increase consumer responses to their products or services. When consumers perceive the virtual environment as realistic and immersive, they are more likely to trust the shopping process and engage with the environment to achieve their goals [52, 41]. Additionally, when the virtual environment allows for social interaction, consumers feel more connected to the shopping experience, which can further enhance trust. To establish trust in online transactions, sellers should provide customer service experience in a virtual environment that closely mimics the physical one through interactive tools, detailed product descriptions, high-quality images, and customer reviews [43]. As consumers become more aware of the potential risks associated with sharing their personal data, they are less likely to trust sellers who fail to demonstrate a strong commitment to protecting their privacy in the online commerce [59]. When consumers develop a positive attitude towards a company because they trust it, they are more likely to view the company's communication as transparent, as trust is built on a foundation of transparency and honesty, which can ultimately lead to increased sales and profitability [6]. Establishing clear guidelines, protocols, and information on identity verification, secure data storage, and transparent communication is crucial to build consumer trust and confidence in remote collaborative Augmented Reality, leading to increased adoption and engagement over time [62, 47, 46, 40, 22].From the above literature it is seen that trust plays significant role when consumer interacts with immersive technologies like VR and AR, but when it comes to Metaverse shopping where human interact with machine made environment for shopping there is clear lack in literature. To test influence of consumer attitude towards the metaverse platform on trust and purchase intention, the study proposes the following hypotheses.

H1: Consumer attitude influence the consumer trust towards Metaverse platform

H2: Trust towards metaverse platform influences consumer purchase intention.

H3: Trust significantly mediates between consumer attitude and purchase intention in metaverse platform.

As a consumer in an interactive store setting, their attitude towards the store and its features can greatly influence their enjoyment of the shopping experience [56]. Factors such as ease of use, perceived quality assurance, and store layout can all contribute to a positive or negative attitude, ultimately affecting their level of engagement and satisfaction as a shopper [29]. In a virtual platform, consumers' attitude towards a product or service can be significantly influenced by factors such as telepresence and perceived social presence, where telepresence affects their engagement and investment in product interactions and immersion, and perceived social presence impacts their enjoyment and purchase intention [52, 53, 37, 31]. Consumers' attitudes towards AR can significantly impact their enjoyment experience of the technology, particularly in regards to its immersion effect, where a positive attitude combined with a strong immersion effect can lead to a highly engaging and enjoyable experience [21, 65]. Consumer perceive immersive platforms to be enjoyable and willing to adopt those that enhances the mental state of engagement [67, 64]. The quality and richness of an interactive platform has an influence over the enjoyment and behavioural intention [24]. While making purchase decision, consumers are often faced with a level of uncertainty about the product or service they are considering [16]. This uncertainty can make it difficult for them to make confident decision. However, positive affect, which includes feelings of enjoyment and favourable evaluations of the product, this can help to reduce uncertainty [34]. The literature suggests that perceived enjoyment plays a significant role in shaping consumer interactions with immersive technologies like VR and AR. However, currently there is lack of research on how enjoyment is influenced by consumer attitudes towards the Metaverse, a machine-made environment for shopping. To address this gap, the study proposes following hypotheses to test the relationship between consumer attitudes towards the Metaverse platform, perceived enjoyment, and purchase intention.

H4: Consumer attitude influences perceived enjoyment of using metaverse platform

H5: Perceived enjoyment of using metaverse platform influences purchase intention of consumers.

H6: Perceived enjoyment significantly mediates between consumer attitude and purchase intention in metaverse platform.

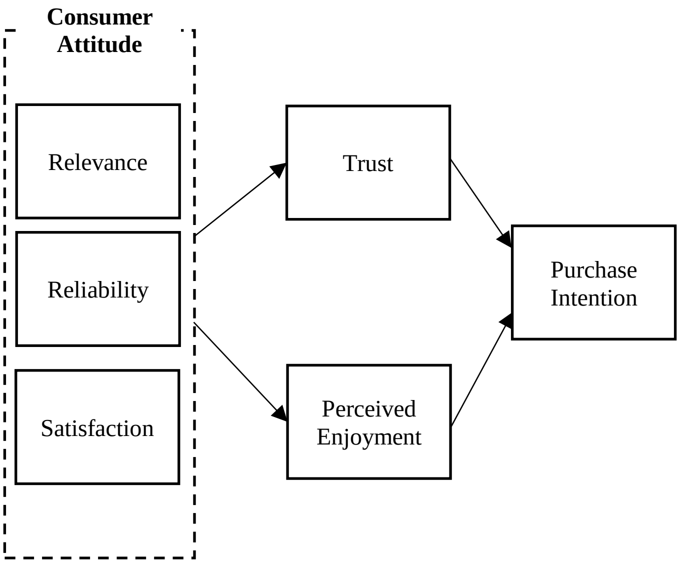

FIG. 1. CONCEPTUAL MODEL OF THE PROPOSED STUDY

IV. METHODOLOGY

A. Data collection and sampling procedure

The current study aims to investigate the parallel mediation of trust and perceived enjoyment between consumer attitude towards metaverse platforms and purchase intention. The study involved in a quantitative methodology. Authors circulated a self-administered, online questionnaire to the participants. This questionnaire was completed by the participants after interacting with metaverse platform which enables the participants to create avatar, explore the virtual environment and buy products. The participants were allowed to interact with the platform for 30 minutes to understand the actual functioning of metaverse shopping.

The participants were informed that they would be participating in a study to evaluate their opinions regarding the Metaverse platform for purchasing. The questionnaire included five sections: the first comprised questions on participant attitudes towards the platform; the second included questions relating to trust; the third focussed on perceived enjoyment; the fourth focussed on purchase intention from platform and fifth and final section comprised of sociodemographic questions.

In total, 502 undergraduate students participated in our study. Considering their uniformity, students are deemed suitable for doing research [5]. The participants were selected from eight courses using a convenience sampling method, and all of them participated voluntarily. In our efforts to manage the influence of the metaverse platform, respondents who had not exposed to the platform and did not hear about the platform were retained. Duration of data collection went up to a month because of the lab capacity and student availability. A total of 20 respondents were excluded either due to their failure to meet both criteria or because they supplied contradictory responses. The final sample consisted of 562 participants, with 46.7 percent being women and 53.3 percent being men. Additionally, 89.3 percent of the participants were between the ages of 18 and 24, 7.2 percent were between the ages of 25 and 34, and 3.5 percent were 35 years of age or older.

B. Experimental Procedure

Experiment was conducted in a laboratory set up where participants were gathered in a computer lab for interacting with the platform. The participants were introduced with metaverse platform Decentraland [4, 36] which allows them to create avatar, communicate with each other, explore virtual landscape and buy virtual space through cryptocurrency. The time span allocated for participants to interact with platform was for 30 minutes. In the first 10 minutes participants were trained to use the platform and instructions to use the platforms were provided during this period. The next 5 minutes were allocated for the participants to explore the platform and to clear the doubts that arises while playing. After this stage, Investigator explained the reason for gathering to the participants and clear explanation were provided to define the objectives behind the experiment. The final 15 minutes were given to the participants to explore the platform without any interruptions. Before going to the final step investigators ensured that participants had no doubts regarding the platform. After completion of 15 minutes, participants were shared with a structured questionnaire to measure the study variables.

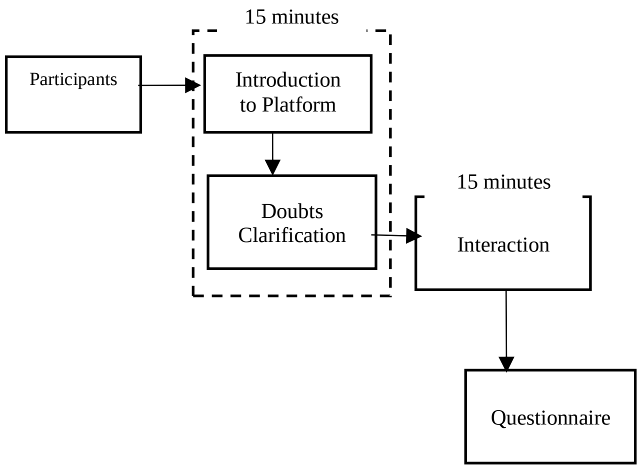

FIG. 2. OUTLINE OF THE EXPERIMENT PROCEDURE CONDUCTED

C. Measures and data analysis

The study adopted four standardized questionnaires for measuring the constructs. Consumer attitude towards metaverse application was measure using 23 item Augmented

Reality Application Attitude Scale (ARAAS) [11]. The scale has three sections (Relevance: 9 items; Satisfaction: 9 items; Reliability: 5 items). This scale was originally developed for educational purposes. Author modified the scale for shopping purpose and in relevant to metaverse application. Trust is measured using the 12-item scale [41]. The scale was developed for measuring Trust between people and automation. This scale was also altered based on this study's context by the author. Perceived enjoyment was measured using 3 item scale adopted in the study [27]. Purchase intention of consumers was measured using a 3-item scale adopted in the study [6].

The scales were initially devised for distinct objectives and subsequently adapted according to the specific research objectives. The measure items underwent exploratory factor analysis to assess the validity of the constructs. Items that exhibited inconsistent loadings were excluded from further analysis based on the results of EFA. The ARAAS scale saw removal of two items, specifically in the Relevance dimension and the Satisfaction dimension. The first ARAAS scale consisted of 23 items, but after undergoing exploratory factor analysis (EFA), it now comprises a total of 19 items. The reliability and validity of the scales were evaluated by confirmatory factor analysis (CFA) and the structural model was tested using AMOS V18. The model suggested good fit indices with current items suggested by EFA.

V. RESULTS

A. Reliability and validity

The results presented in Table I indicate that the Cronbach's α values range from 0.81 to 0.91, all of which exceed the required threshold level of 0.70 as suggested by pervious study [32]. The composite reliability indices range from 0.81 to 0.91, which above the minimum threshold of 0.70 required for measurement dependability [10]. In terms of convergent validity, all items in the model exhibit factor loadings that are statistically significant and exceed the threshold of 0.70, as established by study [10]. The average variances extracted (AVEs) range from 0.53 to 0.57, and all values are over 0.50, indicating satisfactory convergence [10].

TABLE 1. EXPLORATORY AND CONFIRMATORY FACTOR ANALYSIS RESULTS

Constructs	**λ EFA/CFA**	**AVE**	**α**
Consumer Attitude towards Metaverse		0.54	0.82
Relevance		0.51	0.81
Metaverse platform (AR, VR, XR) enhances my perception of the product when I'm purchasing (practical perspective)	0.87/0.77		
"I would like to use Metaverse platform (AR, VR, XR) applications for shopping."	0.86/0.72		
The utilization of 3D objects in the Metaverse platform (AR, VR, XR) apps elicits a sense of realness.	0.83/0.71		
I feel excited when I use Metaverse platform (AR, VR, XR) applications	0.82/0.73		
Buying the products is easier due to Metaverse platform (AR, VR, XR) applications	0.81/0.79		
Metaverse platform (AR, VR, XR) applications make my shopping process comfortable because they provide clarity	0.80/0.76		
The use of Metaverse platform (AR, VR, XR) applications in the shopping is a time efficient process.	0.79/0.72		
Satisfaction		0.59	0.83
I experience enhanced concentration on the product when utilizing applications on the Metaverse platform, which includes AR, VR, XR.	0.88/0.81		
I do shopping with enthusiasm when Metaverse platform (AR, VR, XR) applications are used	0.81/0.79		
Using Metaverse platform (AR, VR, XR) motivates me to shop more than normal.	0.77/0.79		
I enjoy shopping with Metaverse platform (AR, VR, XR) applications	0.75/0.77		
Metaverse platform (AR, VR, XR) applications catches my attention	0.75/0.82		
Overall, I believe that the utilization of Metaverse platforms (AR, VR, XR) suggests that the consumer has a keen interest in shopping.	0.73/0.78		
Reliability		0.512	0.82
I think that the generalisation of this type of Metaverse platform (AR, VR, XR) initiatives would significantly improve the quality of shopping platforms.	0.71/0.72		
Utilizing the Metaverse platform (AR, VR, XR) for shopping enables me to communicate my ideas, opinions, and perspectives with my friends and coworkers.	0.70/0.71		
Shopping with Metaverse platform (AR, VR, XR) makes me to think critically and analyse about the product.	0.68/0.71		
Metaverse platform (AR, VR, XR) has changed my attitude as a shopper, not only in this environment, but generally in all shopping environments.	0.65/0.77		
Utilizing the Metaverse platform (AR, VR, XR) enhances my proficiency in many practical skills such as tool usage and information retrieval, hence influencing my purchase habits.	0.63/0.74		
Trust		0.55	0.91
Metaverse platform (AR, VR, XR) for shopping is deceptive.	0.83/0.79		
The Metaverse platform behaves in a underhanded manner.	0.82/0.76		
I'm suspicious of the platform's intent, action or output.	0.78/0.80		
I'm wary of the metaverse platform.	0.78/0.77		
The platform's action will have a harmful or injurious outcome.	0.77/0.76		
I'm confident in the Metaverse platform	0.75/0.82		
The Metaverse platform provides security	0.73/0.78		
The metaverse platform has integrity	0.71/0.74		
The metaverse platform is dependable	0.70/0.77		
The metaverse applications are reliable	0.67/0.72		
I can trust the metaverse applications.	0.66/0.71		
I'm familiar with the metaverse (AR, VR, XR) platforms.	0.64/0.70		
Perceived Enjoyment		0.57	0.80
I can access the Metaverse platform (AR, VR, XR) for shopping easily	0.74/0.80		
The Metaverse platform (AR, VR, XR) for shopping is user-friendly and easy to use	0.82/0.72		
Metaverse platform (AR, VR, XR) for shopping provides relevant information and useful functions for the course	0.85/0.74		
Purchase Intention		0.53	0.81
I would buy this product/brand from Metaverse platform (AR, VR, XR) rather than any other brands available in traditional ecommerce platform.	0.84/0.75		
I am willing to recommend that others buy this product/ brand from the Metaverse platforms	0.81/0.73		
I intend to purchase this product/brand from the metaverse platform in the future	0.75/0.70		

λ – Factor loadings, AVE – Average Variance Extracted, α – Cronbach's alpha

TABLE 2. DISCRIMINANT VALIDITY

	1	2	3	4
Consumer Attitude (1)	0.54			
Trust (2)	0.51	0.55		
Perceived enjoyment (3)	0.49	0.46	0.57	
Purchase intention (4)	0.42	0.45	0.41	0.53

Average variance extracted on-diagonal and squared correlations among constructs off-diagonal

The confirmation of discriminant validity is based on the absence of any squared correlation (off-diagonal value) that exceeds the average variance extracted (AVE) values (on-diagonal) as outlined by previous study [10] (see to Table II for details).

B. Measurement model

We conducted a confirmatory factor analysis (CFA) using AMOS V18 to assess the suitability of the measurement models. The results demonstrate a strong correspondence between the model and the observed data. The measurement model's overall fit indices are as follows: The chi-square value is 481.28 with 216 degrees of freedom, resulting in a p-value of 0.00. The ratio of chi-square to degrees of freedom is 2.28. The NFI is 0.96 and the CFI is 0.97. The RMSEA is 0.08, with a 90% confidence interval of 0.07-0.09. Based on the criteria set by researchers [30] for CFI and NFI (with a threshold of 0.95), the suggested model demonstrates a good fit to the data, in addition to the $\chi 2$ tests. Nevertheless, the RMSEA value of 0.08 above the acceptable threshold of 0.07 [33]. In addition, the $\chi 2$ /df ratios are below 3, indicating a highly satisfactory [30].

C. Results of structural equation modelling analysis

Based on the provided conceptual framework the adequacy of the model was tested. The structural model's overall fit indices are deemed outstanding due to the fact that their values align precisely with those of the measurement model. The model accounts for 49.1% of the variance in consumer purchase intention on a metaverse platform.

TABLE 3. SUMMARY OF THE RESULTS OF STRUCTURAL EQUATION MODELLING ANALYSIS.

Hypothesis	**Path**	**Estimation**			
		Direct Effect	**Indirect Effect**	**SE**	**P-value**
H1	**CA→T**	0.53			0.001
H2	**T→PI**	0.42			0.001
H3	**CA→T→PI**	0.092	0.223	0.081	0.001
H4	**CA→PE**	0.39			0.001
H5	**PE→PI**	0.62			0.001
H6	**CA→PE→PI**	0.092	0.241	0.057	0.001

CA: Consumer attitude; T: Trust; PI: Purchase Intention; PE: Perceived Enjoyment

The structural equation modelling analysis provides valuable insights into the relationships between consumer attitude, trust, perceived enjoyment, and purchase intention in metaverse platform. Consumer attitude towards metaverse platform (CA) has a significant direct positive effect on trust (T), as evidenced by the path coefficients of 0.53 with p value less than 0.05. This supports hypothesis H1. Trust (T) has a positive direct effect on purchase intention (PI), as indicated by the path coefficient of 0.42 which supports out second hypothesis H2. Consumer attitude (CA) has a significant indirect effect on purchase intention (PI) through the mediating variable of trust (T), with an indirect effect of 0.223 and a p-value of 0.001, which is statistically significant. Hence hypothesis H3 is also accepted.

Consumer attitude (CA) has a positive direct effect on perceived enjoyment (PE), as shown by the path coefficient of 0.39 make our fourth hypothesis H4 also to be accepted. Perceived enjoyment (PE) has a positive direct effect on purchase intention (PI), with a path coefficient of 0.62, proves our fifth hypothesis H5. The consumer attitude (CA) has a significant indirect impact on purchase intention (PI) by means of the mediating variable of perceived enjoyment (PE), with an indirect effect size of 0.241 and a p-value of 0.001. This statistical significance supports hypothesis H6.

VI. DISCUSSIONS

The Study findings suggest that consumer attitude towards metaverse platform influences trust of consumer towards the platform. The favourable attitude of consumers towards the metaverse platform strengthens their commitment and boosts their positive experience, ultimately fostering trust in the platform [13]. When it comes to luxury brand attachment, there is consistently a favourable relationship between the alignment of a person's self-image and their experiences on immersive platforms [34]. This suggests that a consumer's positive attitude plays a role in establishing trust in the immersive environment. AR driven application experiences of luxury brands showed affective responses that enhance the trust and satisfaction of consumers towards the platform [18].

In online multiplayer virtual reality role-playing games, consumers enhance their sense of belonging to their community by purchasing virtual objects, driven by their developed trust and attachment [28]. Antecedents and consequences of AR marketing activities reveal their positive consumer experiences with innovative AR applications enhanced purchase intentions [60]. This suggests trust in utility of these metaverse-adjacent technologies drive purchase behaviour. This study contributes to the current body of literature on metaverses by asserting that confidence in these immersive platforms enhances consumers' likelihood of making purchases within the platform.

By finding the significant mediating role of trust between consumer attitude towards platform and purchase intention, this study stands in line with previous findings in metaverse literature. The metaverse features, such as interaction and vividness, had a beneficial impact on users' experience of telepresence, leading to a favourable attitude [52]. This, in turn, enhanced their perceived product knowledge and their intents to make purchases in metaverse stores [52]. Although not directly mentioned, trust in the metaverse experience is probably a mediating factor that connects positive sentiments towards the metaverse to intentions of making a purchase. E-service quality in VR stores emerged as the most dominant factor, suggesting that trust in the service quality of immersive VR stores mediates the relationship between positive consumer attitudes towards such environments and purchase intentions [49]. The utilization of virtual reality (VR) devices for the purpose of viewing soccer matches from the comfort of one's own home. The findings demonstrated that perceived usefulness, and positive attitudes strongly influenced individuals' intentions to purchase and utilize the product [17]. Trust in the utility and enjoyment of the virtual reality (VR) experience appeared to play a mediating role in these interactions [17].

The present study asserts that the consumer's attitude towards the metaverse platform has an impact on their perceived enjoyment. The different attributes of metaverse platforms, such as telepresence, social interaction, and economic flow, had a notable impact on users' flow experience, which can be seen as a type of perceived enjoyment [66]. This implies that having a positive attitude towards the elements of the metaverse platform helps to increase the level of enjoyment obtained from the experience. The study investigated the impact of avatar appearance similarity on virtual goods purchase intention in the metaverse [37] . The results revealed that the similarity between an individual's look and their avatar increased their intention to purchase virtual products. This influence was mediated by factors such as self-congruence and flow [26, 37]. In this sense, "flow" refers to a feeling of enjoyment. It suggests that having positive attitudes about avatar representation in the metaverse contributes to the perception of enjoyment.

The emotional reactions, including feelings of pleasure, which may be seen as a type of perceived enjoyment, positively influenced behavioural reactions, such as the desire to make a purchase, in the context of augmented reality (AR) experiences for luxury brands in the metaverse [18]. In the context of an AR shopping app, purchase intention was significantly impacted by perceived enjoyment, one of the characteristics modified by augmented reality (AR) qualities [46, 62]. The increased sense of enjoyment experienced due to the increased immersion offered by augmented reality in e-commerce has a beneficial impact on the intention to make a purchase [40]. This finding further supports the hypothesis in the context of metaverse-related technologies.

The present study offers empirical evidence that perceived enjoyment, stemming from different elements of the metaverse platform, such as augmented reality experiences, immersive environments, and advertising, acts as a mediator between consumer attitudes towards these elements and purchase intention within the metaverse context. The flow experience, facilitated by augmented reality (AR), acts as a type of perceived enjoyment that mediates the connection between consumer attitudes towards AR and their level of involvement with AR apps. This engagement, in turn, might impact their intention to make purchases inside the metaverse setting [63, 65]. Affective responses, such as feelings of enjoyment and inspiration, have a direct impact on purchase intentions and word-of-mouth recommendations [64]. They also have an indirect influence through shaping attitudes towards the product or brand in the setting of an augmented reality (AR) product presentation [64]. This finding is particularly relevant in the context of the metaverse environment. The study examined the impact of escapism in AR mobile app advertising. The study discovered that experiences of escapism, which are linked to perceived enjoyment, have a beneficial impact on sharing content on social media, intentions to make purchases based on brand attitudes, and interaction with new brands through augmented reality mobile app advertising [21, 38]. This suggests that perceived enjoyment may play a mediating role in these effects.

Multiple studies highlight the importance of enjoyment and hedonic factors in driving metaverse adoption and engagement, aligning with the "Perceived Enjoyment" construct in the model of the current study [27, 40]. One study found that perceived enjoyment positively influences hedonic benefits, which in turn impacts continuance intention [66]. The role of trust is also supported, with a study finding that establishing initial trust among supply chain partners can drive behavioural intention regarding metaverse adoption [57]. Several studies emphasize the importance of perceived usefulness and utility, which aligns with the "Relevance" aspect of consumer attitude in the model [11, 46]. The "Satisfaction" component is supported by findings that flow experience (which often leads to satisfaction) positively influences attitudes and intentions [64].

While the model focuses on consumer attitudes, good number of studies highlight the importance of technological and platform characteristics in driving adoption and engagement [53, 44]. This suggests potentially expanding the model to include platform/technology factors. Some studies found direct effects of factors like perceived usefulness on behavioural intentions, rather than being fully mediated [20]. This indicates potential direct paths could be added to the model. Few studies emphasize the role of social factors, such as social presence and interaction [36, 65]. The model could potentially be expanded to include social dimensions. Risks and challenges associated with metaverse adoption are highlighted in some abstracts [32], suggesting perceived risk could be an additional factor to consider in the model.

VII. Implications

A. Theoretical Implications

The study is consistent with the Stimulus-Organism-Response (S-O-R) paradigm, which proposes that environmental stimuli, such as the qualities of the metaverse platform, have an impact on consumers' internal states, such as trust and perceived enjoyment [52]. These internal emotions, in turn, influence consumers' behavioural reactions, such as their intention to make a purchase [59]. This study enhances the theoretical comprehension of consumer behaviour in the metaverse context by utilizing the S-O-R model. It establishes a connection between environmental stimuli and customer behaviours by considering the mediating effects of trust and perceived. This study's findings enhance the current body of research by examining the functions of trust and perceived satisfaction within the metaverse platform. The established hypotheses (H1, H2, H3) emphasize the significance of trust as a mediator between customer attitude and purchase intention in the metaverse setting. This expands the comprehension of trust beyond conventional e-commerce environments and underscores its importance in the growing metaverse ecosystem [57].

The confirmed hypotheses emphasize the interaction between emotional variables (perceived enjoyment) and cognitive factors (trust) in influencing consumer behavior in the metaverse environment. This study enhances the existing literature by offering an in-depth understanding of the components that influence the adoption of the metaverse. Previous research [64, 63] has often examined either the emotional or cognitive aspects separately, whereas this study takes a more holistic approach. Through an analysis of the connections between customer attitude, perceived enjoyment, trust, and purchase intention within the metaverse, this study helps close the gap between online and offline consumer behaviour. Based on tested theories [15, 20], consumers' real-world purchase intents may be influenced by the metaverse environment, expanding our knowledge of consumer behaviour outside of traditional retail environments.

B. Managerial Implications

The study suggests that metaverse platform developers and brands operating in the metaverse should prioritize strategies to build and maintain consumer trust. This can be achieved by ensuring transparency, data privacy, and security measures, as well as delivering consistent and reliable experiences within the metaverse environment [39, 57]. The study also implies that metaverse platform developers and brands should focus on creating immersive, interactive, and engaging experiences that foster enjoyment among users. This can be achieved through gamification elements, social interactions, personalized content, and leveraging emerging technologies like augmented reality (AR) and virtual reality (VR) [64, 63]. Metaverse platform developers and brands should adopt a holistic approach by incorporating strategies that simultaneously cultivate trust and enhance perceived enjoyment through collaborative efforts between technology experts, user experience designers, and marketing professionals. Brands should leverage the metaverse to offer virtual product trials, immersive brand experiences, and personalized interactions with consumers. This can not only drive purchase intentions but also foster brand loyalty and advocacy. As the metaverse is an emerging and rapidly evolving ecosystem, it is essential for platform developers and brands to continuously monitor consumer behaviour, preferences, and trends within the metaverse environment. This will enable them to adapt their strategies promptly, address emerging challenges, and capitalize on new opportunities to enhance consumer trust, perceived enjoyment, and ultimately drive purchase intentions.

VIII. LIMITATIONS AND FUTURE SCOPE

It is important to recognize the study's various shortcomings. First off, the findings' generalizability may be limited by the sample size of 483 college students, which may not be indicative of the larger consumer population. Furthermore, because the study was carried out in a particular area, cultural variables might have an impact on how customers feel and act regarding metaverse platforms. Additionally, since the study only examined one metaverse platform—Decentraland—customer views and behaviours may change among platforms that offer distinct features and user experiences. Since the metaverse is a new and quickly developing technology, as it develops and becomes more widely used, customer attitudes and behaviours may also change. Finally, the study concentrated on particular constructs like trust, perceived enjoyment, and purchase intention; therefore, it's possible that additional pertinent variables or constructs that affect customer behaviour in the metaverse setting were overlooked.

To improve the generalizability of the results, future study might examine customer attitudes and behaviours toward metaverse platforms across age groups, socioeconomic backgrounds, and cultural contexts. Similar research across a variety of metaverse platforms may yield insightful information about how user experiences and platform-specific features affect purchasing decisions. As the technology for the metaverse develops, longitudinal studies may be used to monitor shifts in the attitudes and behaviours of consumers. A more thorough understanding might be obtained by looking into other elements or structures, such as privacy concerns, social impact, or brand perceptions, that may affect customer behaviour in the metaverse setting. Incorporating qualitative methods like focus groups and interviews could provide more in-depth understanding of the underlying motives, attitudes, and experiences of users in the metaverse environment. Research conducted across cultural boundaries may provide insight into how cultural norms, values, and customs influence consumer views and actions regarding metaverse platforms. The findings of this study suffer from the low-quality visuals on the blockchain-based metaverse, Decentraland platform. Using platforms with more realistic images and virtual reality glasses' compatibility might greatly change the results in next experiments. Lastly, a way to close the gap between virtual and real-world consumer experiences could be to investigate the possible effects of consumer behaviour in the metaverse on real-world purchase decisions and consumption habits.

IX. CONCLUSION

The current study offers insightful information on how customers behave when they shop on metaverse platforms in an online retail setting. The results demonstrate how customer attitudes regarding metaverse platforms have a substantial impact on perceived enjoyment and trust, which in turn affects consumers' intentions to make purchases in these immersive virtual worlds. Notably, the study bridges the gap between consumer attitudes and purchase intentions in the setting of the metaverse by establishing trust and perceived enjoyment as critical mediating elements. The research adds to the growing body of knowledge on consumer behaviour in developing digital ecosystems by experimentally examining these links.

The study's conclusions have applications for companies and platform developers looking to make the most of this technology as the metaverse picks up steam and changes the online retail scene. Creating virtual worlds that are immersive, dynamic, and engaging can increase perceived satisfaction while also fostering consumer trust through transparency, data protection, and dependable experiences. These factors can encourage consumers to make positive purchase intents. Although the present study offers a basis for comprehending customer behaviour in metaverse shopping, additional investigation is critical to tackle the constraints and broaden the range of investigation. Sustained research endeavours will be imperative in maintaining pace with the swift progressions of metaverse technologies and their influence on consumer conduct, ultimately steering enterprises and platform developers through this revolutionary digital frontier.

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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.

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

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Artificial Intelligence and Consumer's Perception: A Research on Environmentally Conscious Consumer

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Abstract—**The purpose of this study is to explore the limited exploration of the simultaneous influence of beneficial artificial intelligence, destructive artificial intelligence, and risky artificial intelligence on green purchase intention and green purchase behaviour using the Technology Acceptance Model (TAM) and Innovation Resistance Theory (IRT). Further, it also checks the impact of green purchase intention on green purchase behaviour. Data was collected using a well-structured questionnaire from 124 consumers through online mode and analyzed using Confirmatory Factor Analysis (CFA) for reliability and validity concerns and Structural Equation Modelling (SEM) for interaction among the variables. The study's results exhibit the positive impact of beneficial artificial intelligence on green purchase intention and green purchase behaviour. Also, it reveals that destructive artificial intelligence has a positive impact on green purchase intention but a negative impact on green purchase behaviour. In addition, green purchase intention is found to be the predictor of green purchase behaviour. The extant literature is found on the impact of artificial intelligence on purchase behaviour. However, no research has been done on consumer perception of artificial intelligence and its impact on green purchase intention and green purchase behaviour as per the author's knowledge. This study contributes to the literature of artificial intelligence as well as green consumer behaviour.**

Keywords—Artificial intelligence, Green purchase intention, Green purchase behaviour, Technology acceptance model (TAM), Structure equation modelling (SEM), Innovation resistance theory (IRT)

I. INTRODUCTION

Artificial Intelligence (AI) is not merely a technological advancement; however, a potent transformative influence that positively impacts societies through cost and risk reduction, enhances credibility, and innovative outcomes to deal with intricate challenges [87]. The widespread integration of artificial intelligence structure spans in numerous society areas [17], provides a range of circumstances for the competitive market [38], along with influencing consumers' experiences [70], dealings [53], and commitment [50]. The escalating analytical capabilities, existing data, contextual awareness, and emotion recognition potential of artificial intelligence empower the tailoring of personalized contribution. This, in turn, makes it easier to create and maintain genuine consumer engagements and connections that have long-lasting appeal [31, 38, 57, 70].

An environmentally sustainable product makes a smaller contribution to environmental issues compared to a regular product. This differentiation stems from the sustainable traits that characterize its components, production methods, transmission techniques, disposal/recycling procedures, or product features, for example, decreased power usage [67]. Several researches highlight the positive impact of a consumer's perception of a product's environmental sustainability on their intention to make a purchase [19, 46, 66]. Practitioners, researchers, and consumers in general have recently become interested in the digitization of social behaviours, operations, and goods. Researchers have developed novel digital innovations, such as artificial intelligence, to improve the sustainable development of items. Therefore, artificial intelligence refers to the cognition demonstrated by advanced technology, as opposed to the cognitive abilities displayed by humans and other creatures [68]. The skills it has includes, self-sufficient interpretation of the environment, learning through experience, conclusion-making, solution execution, and stronger interaction with human beings and other artificial intelligence interfaces [73].

The current research landscape is limited to the impact of beneficial artificial intelligence, destructive artificial intelligence, and risky artificial intelligence on green purchase behaviour. While there is existing literature on the influence of environmental sustainability on consumer behaviour and the positive effects of beneficial artificial intelligence, there is a research gap in comprehensively understanding the interplay between these factors. The importance of bridging this gap lies in the evolving landscape of artificial intelligence technologies and their potential consequences on sustainable consumer choices [94].

Existing studies have explored the positive impact of the sustainability of the environment and surroundings on consumer purchase intention [19, 46, 66]. However, there is a lack of in-depth analysis regarding how the introduction of beneficial artificial intelligence, designed to enhance environmental sustainability, may affect green purchase behaviour. Furthermore, the potential negative impact of destructive artificial intelligence on such behaviour is an understudied area [94]. The effect of risky artificial intelligence in this context adds another layer of complexity, as consumers may weigh the potential risks associated with artificial intelligence technologies in their decision-making process. Understanding how risky artificial intelligence, beneficial artificial intelligence and destructive artificial intelligence influence green purchase intention and green

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purchase behaviour is crucial for developing a comprehensive understanding of the dynamics at play.

However, the current study aims to explore the limited exploration of the simultaneous influence of beneficial artificial intelligence, destructive artificial intelligence, and risky artificial intelligence on green purchase intention and behaviour. It is important to stay ahead of the curve in understanding how emerging technologies impact sustainable consumer choices and can inform both policymakers and businesses in shaping a more environmentally conscious marketplace.

II. Literature Review

A. *Artificial intelligence*

Marketers have been using artificial intelligence for a long time to gather consumer data [51]. With the continuous innovation in artificial intelligence, consumers have become more conscious of the power of artificial intelligence. The unethical use of artificial intelligence as happened in the case of Facebook and Cambridge Analytica [18] has led to a major shift in the acceptance of artificial intelligence by the consumer. Artificial intelligence has become a perfect solution for convenience for both companies as well as consumers [94, 86, 51]. The development in AI-enabled technologies like chatbots, voice-based artificially intelligent tools (Siri, Alexa etc.,), text editors, generative AI software (Gemini, ChatGPT etc.,) wearable AI, facial recognition AI (Snapchat) and navigation AI have elevated the customer experience [96].

Artificial intelligence is a machine which imitates the functions of the human mind when given data and interprets it in the desirable form with the help of pre-programmed instructions [51, 73, 86, 96, 98]. The benefits of artificial intelligence cannot be overlooked in terms of the amount of data (can deal in Big Data), speed, accuracy and source to name a few [98, 8]. Right from chatbots for solving queries, personalized advertising, and determining long-term customers there are several reasons why artificial intelligence has taken the front seat while dealing with consumers [47, 61]. Generative AI has sped consumers' acceptance of artificial intelligence as it can create new content within seconds [25, 40].

Even though artificial intelligence is going through a lot of advancement every day, human decision-making capability and the fact that artificial intelligence is the result of the human brain cannot be ignored [51]. In terms of the relationship of artificial intelligence with consumers, it is still contradictory. Some researchers believe the consumer has a positive relationship with artificial intelligence as it depends upon their trust in the brand using artificial intelligence [5, 51, 52]. Features like ease of use, no time barriers, cost savvy, convenience and ability to create new content have given a positive outlook to the consumer for using artificial intelligence [69]. This dimension of artificial intelligence adoption is called beneficial AI [94].

However, few researchers suggest that there is a negative relationship between artificial intelligence and consumer acceptance. Risky artificial intelligence and destructive artificial intelligence, both denote the negative side of artificial intelligence. Risky AI is a broader term and includes issues that can harm the consumer, intentionally or unintentionally [94]. The fact that consumers fear the misuse of their data and find themselves in an ambiguous situation while trusting new technologies using artificial intelligence [10, 51] is considered as risky AI. Risky AI encompasses issues such as privacy concerns, algorithmic biases, loss of control, misuse of data (hacking), job displacements and less transparency about data usage by the organization [56].

Destructive artificial intelligence is the extreme extent to which artificial intelligence can be used and encompasses potential issues that pose a threat to humanity. Consumers feel the loss of control over their data when artificial intelligence is concerned as they perceive it as an intrusive or invasive development in innovation [82]. AI-enabled technologies are largely algorithm-driven which poses a danger of causing accidents (AI-driven healthcare technologies; driverless cars, robot-run restaurants etc.,), political instability, and technological manipulations to name a few are included in destructive AI. Moreover, destructive AI comprises weaponized AI, deepfake videos, AI-driven accidents, AI surpassing human intelligence, and manipulation of public opinion [82, 94]. The perception of consumers regarding the adoption of artificial intelligence is moving on a continuum of positive (Beneficial artificial intelligence) to negative (Destructive and Risky artificial intelligence).

Diverse fields such as information technology, business, healthcare, education and arts have collaborated with artificial intelligence to generate new ideas or solve problems [14, 20, 29, 34, 103]. Various challenges associated with the adoption of artificial intelligence include regulatory challenges in terms of AI authorship for generative AI content [76]; inappropriate use of AI [88]; fear of AI replacing jobs in the market [104]; lack of empathy in AI-based voice assistants while responding to distress conditions. Perception towards artificial intelligence impacts consumer intention and consumer behaviour [3, 92, 96]. Moreover, previous studies indicate the mediating relationship between the attitude of the consumer and green purchase behaviour [3, 59, 90]. Frank [27] suggested that artificial intelligence if integrated into the product has a multiplying impact on consumer purchase intention and even provides a competitive advantage to the brand. The utility of artificial intelligence is one of the predictors of consumer behaviour [1]. Bhagat et al. [11] show the positive impact of artificial intelligence on purchase intention, thereby creating a ground for current research.

Various brands have realized the importance of artificial intelligence in making customer’s journeys more convenient [30]. Using the data of consumers, brands curate customized experiences for customers (ibid). André et al. [7] and Khan et al. [45] have found out artificial intelligence-integrated products posit positive purchase intention. Khan et al. [45] also suggest that artificial intelligence has a positive impact on consumer behaviour. Since artificial intelligence has been significantly used in numerous fields such as information technology, business, healthcare and education, research on its impact on green intention and green purchase behaviour is still in a nascent stage.

Among other factors like green awareness, environmental concerns, environmental knowledge, eco-innovativeness is also found to be an important predictor of green purchase intention and further green purchase behaviour [43, 79] but no research has been found on the relation between consumer's perception of artificial intelligence and green purchase intention. Eco-innovation has been a significant factor which deals with finding innovation in reducing the negative impact on the environment and thereby reducing carbon footprint [63]. Artificial intelligence could be regarded as a breakthrough in the field of innovation. The increasing advent of sustainability requires the exploration of beneficial artificial intelligence, destructive artificial intelligence and risky artificial intelligence and their impact on green purchase intention and green purchase behaviour to understand the consumer's perception of adopting artificial intelligence and using it for green behaviours.

Using the aspects of the Technology Acceptance Model (TAM) [22] and Innovation Resistance Theory (IRT) [71], this study aims to add to the existing body of knowledge, the consumer's motivation to use artificial intelligence using factors such as beneficial artificial intelligence, destructive artificial intelligence and risky artificial intelligence and its impact on green purchase intention and green purchase behaviour. TAM has passed the test of time and is found to be a robust model and strong explanatory power for studying new technology adoption in this case artificial intelligence in the purview of green behaviour by the consumer [60, 77, 80]. IRT would help to dig out the reasons for consumers to avoid adopting artificial intelligence [35, 81]. Beneficial AI (perceived usefulness and perceived ease of use) has been adapted and modified for research from the TAM model and destructive and risky AI (usage barrier, risk barrier, image barrier and tradition barrier) has been adapted and modified for research from IRT theory. From the above review of literature, the following hypotheses are formulated:

H_1: Beneficial AI has a significant influence on green purchase intention.

H_2: Beneficial AI significantly influences green purchase behaviour.

H_3: Destructive AI has a significant influence on green purchase intention.

H_4: Destructive AI has a significant influence on green purchase behaviour.

H_5: Destructive AI has a significant influence on risky AI.

H_6: Risky AI has a significant influence on green purchase intention.

H_7: Risky AI has a significant influence on green purchase behaviour.

B. *Green purchase intention and green purchase behaviour*

Keeping the environment in perspective, consumers are shifting towards more conscious choices [44] and they expect brands to be transparent about the green efforts made by them. Therefore, the expectations of the consumer or experience with the product influence the formation of the attitude as well as the purchase intention of the consumer [4, 48, 105]. [97] indicate that consumers have the intention to protect the environment and pay more for the same but still, there is less increase in the demand for green products [15, 44]. Green purchase intention is the intent to purchase a product by the consumer keeping the environmental concern in perspective [4, 89, 90].

Attitudes towards green products, environmental concern, perceived consumer effectiveness, eco-innovativeness and perceived environmental knowledge, and openness to experience are found to be the predictors of green purchase intentions and green purchase behaviour [13, 39, 44]. Few studies suggest the impact of COVID-19 on the shift of consumer choices to green products [23, 101, 102]. Social influence and social vision are also linked to environmentally conscious behaviour [12, 42, 62].

Green purchase behaviour refers to the actual purchase of the green product by the consumer. The green product indicates an environment-friendly product that contributes more to safeguarding nature [42]. Furthermore, there is a surge in the usage of digital methods in various areas of life [4, 41] which provides more scope for the interaction of consumers with artificial intelligence for making greener choices. The theory of planned behaviour advocates that attitude and perception impact the intention to buy and the intention to buy further influences the actual purchase behaviour for the product [2, 84]. Previous researches also indicate the impact of green purchase intention on green purchase behaviour [83, 91, 100]. This research explains the relationship between green purchase intention and green purchase behaviour in light of the perception of consumers towards artificial intelligence. From the above review of literature, the following hypothesis is formulated:

H_8: Green purchase intention positively influences green purchase behaviour.

III. Methodology

A. *Measures*

Data was collected using a well-structured questionnaire developed based on the research framework. The items of the questionnaire were adapted from previous studies and duly modified as per the current research context. This study contains five variables: beneficial artificial intelligence, destructive artificial intelligence, risky artificial intelligence, green purchase intention and green purchase behaviour. The items used for these variables and the sources are given in Table 1. Beneficial artificial intelligence was measured using four items developed by [93]. The scale ranged from 1 (strongly disagree) to 5 (strongly agree). Internal consistency was checked using Cronbach's alpha and was found to be 0.881. Destructive artificial intelligence was measured using four items developed by Tussyadiah and Miller [93]. The scale ranged from 1 (strongly disagree) to 5 (strongly agree). Internal consistency was checked using Cronbach's alpha and was found to be 0.73.

TABLE I: ITEMS AND SOURCE

Items	Source
Beneficial artificial intelligence A1. Artificial Intelligence (AI) helps in easy decision-making for purchases of products or services. A2. AI saves time, freeing up humans to pursue other activities A3 AI has better skills at solving complex problems A4. AI has a positive impact on our economy.	Tussyadiah and Miller [93]
Destructive artificial intelligence A5. AI can cause accidents involving humans A6. Humans are manipulated by intelligent machines or technologies A7. AI has harmful impacts on our environment A8. There are criminal use of AI technologies.	Tussyadiah and Miller [93]
Risky artificial intelligence A9. AI can lead to companies/government with more access to personal data/behaviour A10. AI cause job losses. A11. There is less security of personal data and privacy.	Tussyadiah and Miller [93]
Green purchase intention B12. I am willing to purchase the green product. B13. Overall, I am glad to purchase green product because it is environmentally friendly B14. I intend to rebuy green product because of environmental concern	Woo and Kim [99] Alagarsamy et al. [3]
Green purchase Behaviour C15. When there is a choice, I always choose the product that contributes to the least amount of pollution C16. If I understand the potential damage to the environment that some products can cause, I do not purchase those products. C17. I have switched products for ecological reasons	Roberts [72] Alagarsamy et al. [3]

Risky artificial intelligence was measured using three items developed by [93]. The scale ranged from 1 (strongly disagree) to 5 (strongly agree). Internal consistency was checked using Cronbach's alpha and was found to be 0.847. Green purchase intention was measured using three items developed by Woo and Alagarsamy et al. [3] and Kim [99]. The scale ranged from 1 (strongly disagree) to 5 (strongly agree). Internal consistency was checked using Cronbach's alpha and was found to be 0.923.

Green purchase behaviour was measured using three items developed by Alagarsamy et al. [3] and Roberts [72]. The scale ranged from 1 (strongly disagree) to 5 (strongly agree). Internal consistency was checked using Cronbach's alpha and was found to be 0.875. Table 2 shows all the values of Cronbach's alpha are more than 0.7, therefore it is acceptable [65]. The value for the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy came out to be 0.782 which is also significant.

TABLE II. CONSTRUCT'S CRONBACH'S ALPHA

Construct	Cronbach's Alpha
Beneficial AI	0.881
Destructive AI	0.73
Risky AI	0.847
Green Purchase Intention	0.923
Green Consumer Behaviour	0.875

The data was collected with the help of a questionnaire using the convenience sampling method. Google form was used to collect the data from the respondents. An online link was provided to them with a time frame of two months to answer the survey questions and share it with the people in their circle to gather responses. Time constraints and low response rates led the survey to be stopped after two months. Overall, 300 responses were received, but 124 samples were deemed fit for data analysis after data cleaning [6].

Demographics showed that most respondents are young, under the age group of 25 to 30 years (27 per cent) and 30 to 35 years (21 per cent). 50 per cent of the respondents are male and 47 per cent are female respondents. Most respondents (48 per cent) earn more than ₹50,000 per month. The majority (56 per cent) of the respondents are post-graduates, 23 per cent are graduates, 5 per cent are having Doctoral degrees, 10 per cent have professional or other qualifications and 6 per cent have studied up to 12th standard.

B. Data analysis

The study aimed to analyze the impact of beneficial artificial intelligence, destructive artificial intelligence and risky artificial intelligence on green purchase intention which will further lead to green purchase behaviour. Additionally, it also tries to assess if beneficial artificial intelligence, destructive artificial intelligence and risky artificial intelligence directly impact green purchase behaviour. Further, it tries to explore if destructive artificial intelligence is the predictor of risky artificial intelligence. As the questionnaire was adapted from previous studies confirmatory factor analysis was directly conducted [16]. The confirmatory factor analysis results are detailed in Table 3.

Convergent validity was assessed based on composite reliability (CR) and average variance extracted (AVE). CR should be more than 0.7 and AVE should be more than 0.5 and

CR should be more than AVE to establish convergent validity (58). For discriminant validity, AVE should be more than the maximum shared variance (MSV) (26). For convergent and discriminant validity, one statement is removed whose factor loading was less for the variable destructive artificial intelligence. Table 3 shows all conditions for convergent validity and discriminant validity are satisfied. Figure 1 shows the model for confirmatory factor analysis.

TABLE III. CONVERGENT AND DISCRIMINANT VALIDITY

	CR	AVE	MSV	MaxR(H)	Green_Purchase_INT	Behavioural	Destructive	Risky	Green_Purchase_BHV
Green_Purchase_INT	0.925	0.804	0.596	0.928	**0.897**				
Behavioural	0.886	0.662	0.248	0.897	0.483	**0.814**			
Destructive	0.753	0.505	0.282	0.766	0.327	-0.007	**0.711**		
Risky	0.851	0.658	0.282	0.876	0.250	0.063	0.531	**0.811**	
Green_Purchase_BHV	0.878	0.706	0.596	0.880	0.772	0.498	0.037	0.025	**0.840**

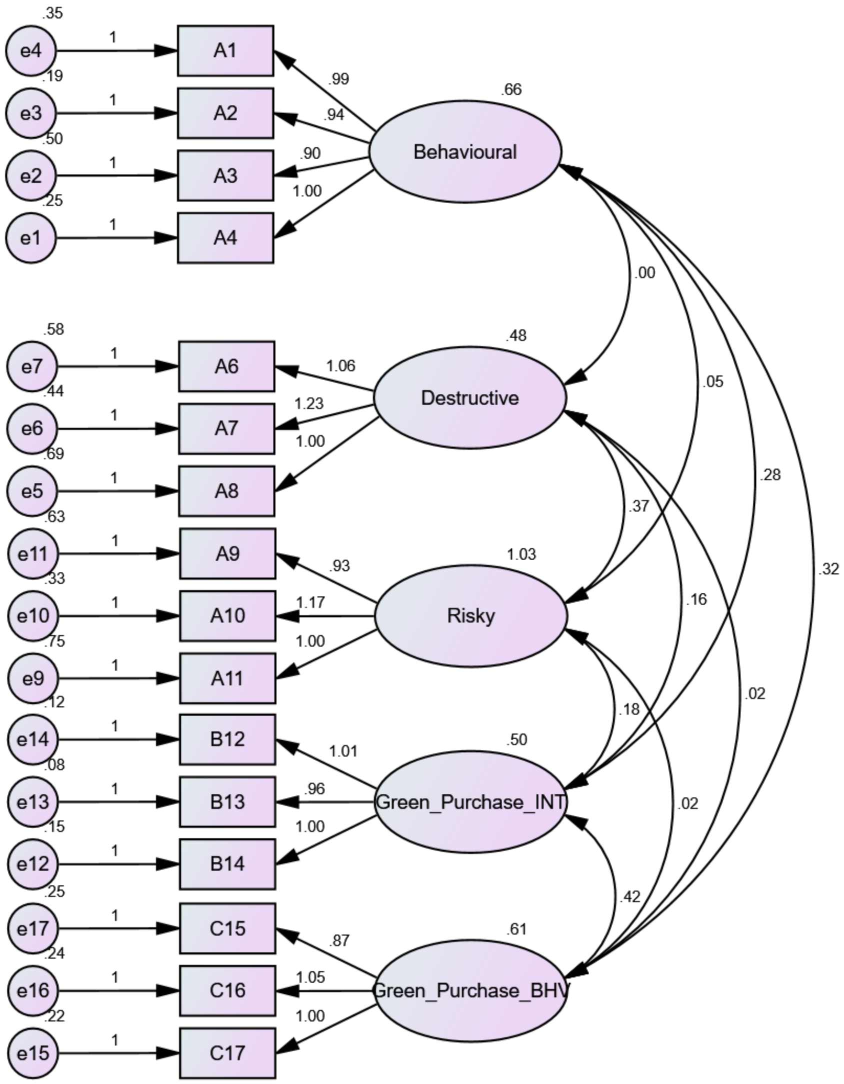

FIGURE I: CONFIRMATORY FACTOR ANALYSIS

Figure 2 shows the path model to examine the causal relationship between the variables. The fitness of the structural model was examined using five common model-fit measurements; Relative Chi-square (CMIN/df), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), Normed Fit Index (NFI), Comparative Fit Index (CFI) and Root Mean Square Approximation Error (RMSEA). In this model, the CMIN/df value is 0.171 and is in the acceptable range [33, 36, 37]. Values of other indicators such as GFI (0.999), AGFI (0.992), NFI (0.999), CFI (1.0) and RMSEA (0.0) are found to be satisfactory [33, 36, 37].

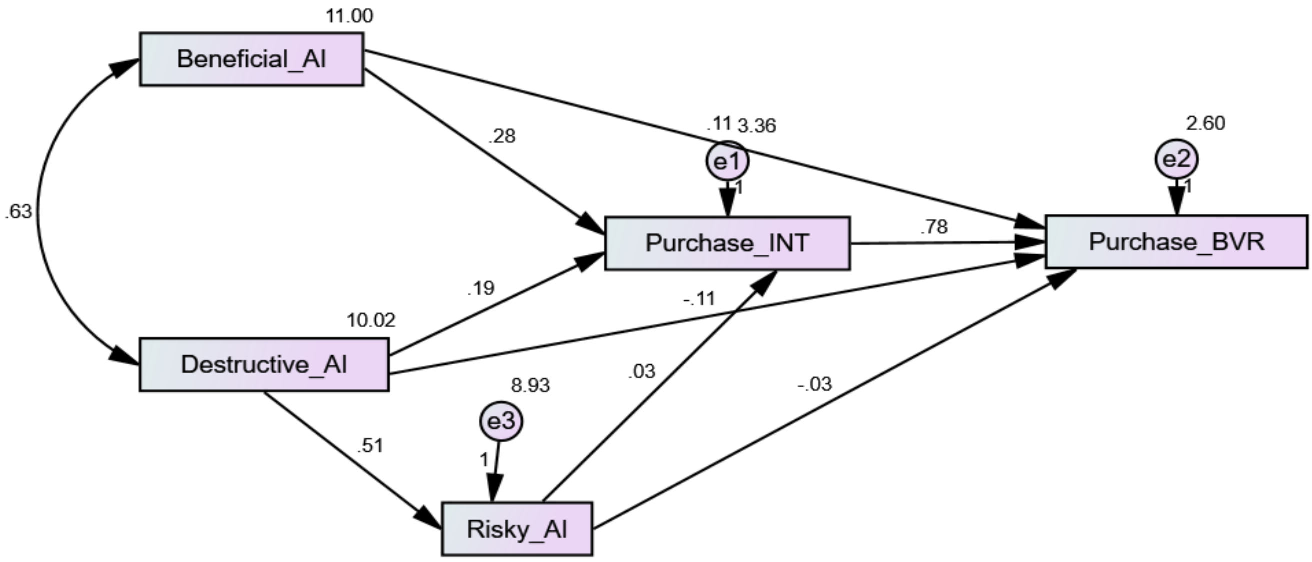

FIGURE II: PATH MODEL

Out of total eight hypotheses, six were found to be significant (Table 3). Hypotheses testing shows beneficial AI has a significant influence on green purchase intention (β = 0.281, P < 0.05). Thus, H_1 is accepted and the beta value shows positive magnitude. Also, beneficial AI is a predictor of green purchase behaviour (β = 0.049, P < 0.05), thus, accepting the H_2. Destructive AI is found to have a significant positive influence on green purchase intention (β = 0.19, P < 0.05), therefore accepting the H_3, but a negative impact on green purchase behaviour (β = -0.11, P < 0.05), therefore accepting H_4. Moreover, destructive AI is also found to positively predict risky AI (β = 0.513, P < 0.05) thus accepting H_5. Furthermore, Risky AI is neither a predictor of green purchase intention (β = 0.033, P > 0.05) nor green purchase behaviour (β = -0.034, P > 0.05), therefore failing to accept both H_6 and H_7. And lastly, green purchase intention is found to positively influence green purchase behaviour (β = 0.782, P < 0.05), thus accepting H_8. Table 4 shows the summary of the hypotheses testing results.

TABLE 4: SUMMARY OF HYPOTHESES TESTING RESULTS

H	Relationship			Estimate	S.E.	C.R.	P	Magnitude	Result
H1	Purchase_INT	<---	Beneficial_AI	0.281	0.05	5.636	***	Positive	Accepted
H2	Purchase_BVR	<---	Beneficial_AI	0.112	0.049	2.284	0.022	Positive	Accepted
H3	Purchase_INT	<---	Destructive_AI	0.19	0.059	3.186	0.001	Positive	Accepted
H4	Purchase_BVR	<---	Destructive_AI	-0.11	0.054	-2.021	0.043	Negative	Accepted
H5	Risky_AI	<---	Destructive_AI	0.513	0.085	6.027	***	Positive	Accepted
H6	Purchase_INT	<---	Risky_AI	0.033	0.055	0.603	0.546	Positive	Fail to accept
H7	Purchase_BVR	<---	Risky_AI	-0.034	0.049	-0.708	0.479	Negative	Fail to accept
H8	Purchase_BVR	<---	Purchase_INT	0.782	0.079	9.866	***	Positive	Accepted

IV. DISCUSSION

An increase in the use of artificial intelligence could help businesses incite positive changes in the behaviour of the consumer from a sustainable marketing perspective [92]. AI is a brilliant system designed to influence the intention and behaviour of consumers using chatbots, AI-based home assistants, robotic devices and other AI-optimized tools [93]. The usage of artificial intelligence in behaviour modification would work if the consumer perceives the artificial intelligence to be a trustworthy technology. This study aims to understand the perception of consumers towards the use of artificial intelligence concerning green purchase intention and green purchase behaviour.

Artificial intelligence has been used as a decision-making tool for automation processes, better decision making and enhancing productivity [21]. The current outcome supports hypotheses 1 and 2 and indicates the positive impact of beneficial artificial intelligence on green purchase intention as well as green purchase behaviour. Previous studies support that the beneficial artificial intelligence or the positive perception of artificial intelligence is due to the trust factor as well as the customization offered by the artificial intelligence tools [5, 50]. Moreover, convenience to customer, cost and benefit analysis and ease of use offered by artificial intelligence could be the factors that lead to favourable green purchase intentions and green purchase behaviour [50, 51, 68]. Artificial intelligence has made decision-making easy by providing a huge amount of information on any subject matter at the fingertips. The interaction of artificial intelligence with consumers leads to the generation of consumer data regarding purchases, likes, dislikes, attitudes about green products and many more [78]. Consumers might have concerns as to how companies might be using their data. This sensitive issue leads to the other two variables i.e. destructive artificial intelligence and risky artificial intelligence.

Data implies that destructive artificial intelligence influences green purchase intention as well as green purchase behaviour, supporting hypotheses 3 and 4. Investigating further, it shows that destructive artificial intelligence also has a positive impact on green purchase intention but a negative impact on green purchase behaviour. Earlier studies are of the view that people often find artificial intelligence difficult to understand [50, 75], as they are not aware of the use of their data by companies using artificial intelligence [48]. Moreover, the concerns of consumers regarding the ethical use [32] of their transactional data, loss of human touch, data breaches and transparency issues could be the reason for the negative relation between destructive artificial intelligence and green purchase behaviour. Results also indicate that destructive artificial intelligence also influences risky artificial intelligence, supporting hypothesis 5. This is because the consumer feels that the control is lost over the data which distresses the consumer, for they feel violated and exploited [5, 10, 68]. Interestingly, risky artificial intelligence is not found to be the predictor of green purchase intention as well as green purchase behaviour, thus, not supporting hypotheses 6 and 7. This finding contradicts previous studies that have stressed that the riskiness of using artificial intelligence could lead to negative relations between artificial intelligence with consumers [10, 68]. Perceived risk associated with using artificial intelligence has always been a factor affecting the trust of the consumer but this study refutes this.

Finally, green purchase intention positively impacts green purchase behaviour, thus supporting hypothesis 8. Past studies indicate green purchase intention is a strong predictor of green purchase value (desire to use products that meet individual's sustainability criteria) and green purchase behaviour [3, 79, 90, 96]. Willingness to buy green products is driven by the intention to contribute to the sustainability cause and practice environmentally conscious behaviour [3, 64, 92]. Based on the results, it is clear that consumers are positive about the perceived benefits of artificial intelligence but up to a certain extent only that it does not breach their data privacy and barges in to take control of their lives.

V. Managerial Implications

Artificial intelligence has shown immense advancement in recent years. The concept of artificial intelligence is quite old but the development in its usability and its reach has widened. Therefore, this study addresses the issue of acceptability and perception of consumers in the context of artificial intelligence. The results of the study can provide insights into the industries dealing with green products and sustainability. The industries that are trying to incorporate artificial intelligence tools to modify the behaviour [93] of the consumer and encourage the usage of green products could use the results of this research. This would help them understand that consumers perceive artificial intelligence to be beneficial in terms of information search, decision-making, content generation and product recommendation. Advancement in artificial intelligence has a lot of benefits for the community as the vast amounts of data could be used to identify trends and assist in scientific research for development in the fields of medicine, sustainable methods of production, less carbon emissions, green procurement and responsible disposition of products. At the same time, they also fear data breaches, algorithm biases, violation of privacy rules, AI weaponization and ethical misuse. Artificial intelligence is still a sophisticated concept for consumers and therefore, its implementation should also be accompanied by awareness and by providing answers to questions on data breaches and data privacy as well as the contribution of artificial intelligence to the green behaviour of the consumer. Firms can effectively integrate beneficial artificial intelligence while mitigating the effects of destructive and risky artificial intelligence, through stringent rules and regulations for the usage of consumer data, following the ethical code of conduct and being transparent about their work. Further, its implications also extend to academia as it is also an addition to the literature on artificial intelligence and its use in green marketing because it provides the model for understanding the perception of the consumer towards artificial intelligence and green consumer behaviour.

VI. Conclusion

Artificial intelligence has many benefits such as proactive behaviour, strategic decision-making based on algorithms, minute detailing, generating new content and control. However, consumers have ethical considerations about its usage as fear of job displacements, realignment of roles, privacy concerns, algorithmic biases, loss of control, and misuse of data are some dark sides of artificial intelligence. This study focuses on both beneficial artificial intelligence and destructive artificial intelligence, thus, taking into account both optimistic and pessimistic views about the consumer's perception of artificial intelligence concerning purchase intentions and purchase behaviour towards green products. Artificial intelligence is an unbiased source of information for consumers about green products. AI agents such as chatbots and voice assistants can provide customized suggestions to the consumer. This could help a consumer in better decision-making. Moreover, marketers can use artificial intelligence to communicate sustainability commitments by making the product journey transparent with the consumers. Consumer will make smart decisions based on calculated risks and conscious choices to reduce the hazards of impulsive decision-making, thus understanding their attitude and behaviour towards green purchases.

The negative side of artificial intelligence is data privacy, the fear of the wrong use of consumer data, the decline in human interaction, distrust or scepticism about technology acceptance, and the fear of AI taking over human intelligence. However, the era of sustainability calls for integrating artificial intelligence in marketing and using it to encourage consumers to engage in environmentally conscious behaviour. This is possible by acknowledging both the beneficial and destructive sides of artificial intelligence and finding a balance between the extent of artificial intelligence usage and human interaction to build stronger community.

VII. Limitation and Future Work

This research work aims to identify what consumers perceive regarding AI and how that perception impacts green consumer behaviour. The study is carried out under certain limitations. Firstly, the study focuses only on the impact of pro-environmental behaviour factors on the green purchase intentions and green purchase behaviour of consumers. Pro-environmental behaviour simply means green, sustainable or environmentally friendly behaviour. The impact of AI is measured under three dimensions namely, Beneficial AI, Destructive AI, and Risky AI. Perceived risk related to acceptance of new technology has always played an important role in forming intention and behaviour, however, this study found that risky AI is not the predictor of green purchase intention and green purchase behaviour. Future research could be conducted to find out the reason for the same. Further, destructive AI has a positive impact on green purchase intention but a negative impact on green purchase behaviour. Future research could address this particular limitation by using qualitative techniques like focus groups and combining them with experimental design [54] to get deeper insights into adopting artificial intelligence for green behaviour. Another limitation of this study is the small sample size. Another limitation of this study is that it does not measure the impact of trust in the company offering AI tools, brand familiarity and awareness [28, 54] which could be other factors that impact the willingness to adopt AI for green behaviour.

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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.

Conflict of interest

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

Data Availability

The data supporting the findings of this study are available upon request from the authors.

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MetaBlock: A Revolutionary System for Healthcare Industry Fusing Metaverse and Blockchain

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***Abstract*— The Metaverse is like another world functioning parallel to the actual physical world. It merges physical reality with digital virtuality by the convergence of different technologies that enable interactions with virtual objects and environment. The complete immersive experience with metaverse generates huge data which comes with its own set of challenges, a major one being the security and storage of user centric data. Considerably, blockchain offers a significant solution due to its exceptional features of decentralization, immutability, and transparency. For a detailed insight into the role of blockchain in the metaverse, the paper explores its usage in the healthcare industry. The paper then proposes a healthcare system named MetaBlock that is a fusion of both the metaverse and blockchain techniques. The paper discusses the components of the system from a detailed technical interpretation, such as data acquisition, data storage, virtual object and space simulation, data sharing and data privacy protection. Finally, an important research direction in terms of distributed consensus mechanism is discussed.**

Keywords*— *Healthcare, Blockchain, Metaverse, Immutability, Distributed Consensus

I. INTRODUCTION

Computer interaction with the physical world is essential and is rapidly changing with technological advancement. Initially, punch cards were used for input which was later replaced by keyboards, which are still an essential input device. With the invention of more sophisticated devices like interactive touchscreens, the mode of input changed to touch and gestures. The current wave of computing innovation is evolving around dimensional captivating technologies such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and Extended Reality (XR) [1]. The concept of MetaVerse (MV) then emerged which is a technology which blends all these modern tools and techniques in the global context. This led to a creation of an artificial immersive digital world better known as the "virtual world" for the intended users. Users can have a two way communication with this virtual world using their twin in the digital world known as avatars.

Virtual Reality (VR) refers to a simulated environment where users get an illusion of being in a totally different world and can even interact with the environment using specialized multi-sensor gadgets such as immersive helmets, VR headsets and omni-directional treadmills. These gadgets give the user an experience incorporating the senses of vision, sound and feel [2]. Augmented Reality (AR) immerses digital inputs into the physical environment i.e. it merges the dimensions of the physical with the virtual world [3]. Mixed Reality (MR) is a more complex concept and is often perceived as an advanced AR as the physical world interacts in real time with the digital world using dynamically generated data [4] and hence, can be said to be a combination of both AR and VR. Lately, the term Extended Reality (XR) is being endorsed as an amalgamated term for AR, VR and MR techniques. With a leap breakthrough in the cost of devices and more powerful software, XR implementation has been welcomed by different communities [5]. Priory, the use of XR persisted in specialized domains but has now extended to include a wide range of applications like gaming [6], aviation [7], disaster management [8], industrial training [9], healthcare [10], medical practice [11], education and learning [12].

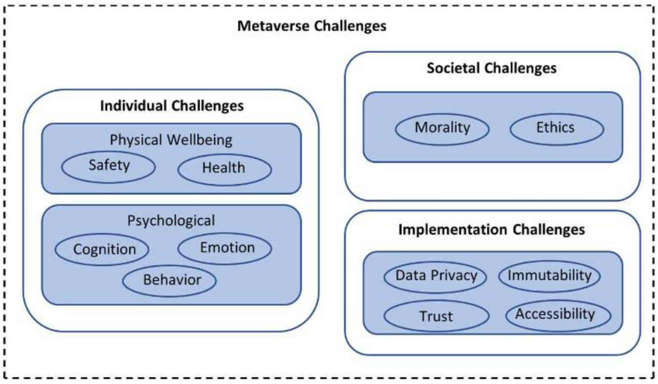

Figure 1. Challenges identified in Metaverse

As with any new technology, Metaverse also faces a number of challenges. The need for specialized equipment is definitely one of them but at the individual, societal and implementation level more challenges can be identified (Figure 1). The challenges identified in using Metaverse (MV) can be broadly classified into (i) Individual; (ii) Societal; and (iii) Implementation challenges.

- *Individual*: Prolonged and extensive use of MV may cause certain physical health concerns like motion sickness, nausea and dizziness, head and neck fatigue [1]. Further, it can lead to isolation and abstention from the real physical world and addiction. Another known drawback is its effect on users' cognition, emotions and behaviours as violent representations can trigger traumatic experiences [13].
- *Societal*: As with any open social world platform, antisocial behaviour like grieving, cyber-bullying, and harassment,

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MV is also affected by them [14]. Indulging into MV may give the users' a sense of falsity as the user may start relying on this virtual world and get disconnected from the real world [15]. Virtual violence and pornography will be readily available and might have significant social consequences [13] and hence, is a concern of morality and ethics [16].

- *Implementation*: On the implementation level of MV, data has a very pivotal role. Personal data acquisition, storage, use, sharing with third parties, achieving interoperability, immutability, and accessibility, preserving privacy and ensuring trust is of utmost importance as data is prone to be hacked or misused.

Consequently, blockchain is an encouraging solution due to its promising features that enables data protection, transparency as well as accessibility.

In line with the challenges identified, this paper explores the metaverse technique stressing on the importance of data privacy for which, blockchain is a viable solution. Data security and privacy of the users' is an essential aspect to consider in a MV based platform as specific laws pertaining to privacy protection plausible in the physical world might not be comprehensible in the virtual world [17]. In terms of privacy, security, and trust, Blockchain is considered as a revolutionary technique [18], although it was initially conceived for financial use. The most striking property of blockchain is its capability to operate without a centralized authority. Although the concept of metaverse can be dated back to 1990s [19], its implementation can be sought to [20], and MV has evolved a long way since. It is not until the current decade that metaverse and blockchain have been fused to bring up marvellous applications. As metaverse deals with vast amount of data, a notable use of blockchain is for secure data storage, sharing and interoperability. Financial dealings are synonym with blockchain and the same has been implemented in metaverse as well [21]. A layered architecture of blockchain fused with metaverse emphasized on the applications of this architecture in commercial usage [22]. The scope of MV is expanding day by day and it has a promising application in the domain of healthcare.

The remainder of the paper provides an insight into the use of metaverse and blockchain in the healthcare industry. Section 2 provides a summary of the existing use of metaverse and blockchain in healthcare management, highlighting what each has to offer. The next sections discuss the components of the proposed MetaBlock system, which is a fusion of metaverse and blockchain techniques and its application in healthcare. Section 4 and 5 highlights the scope for an important future directive in this domain followed by the conclusion.

II. Metaverse Or Blockchain For Healthcare Management

Electronic - Healthcare is evolving rapidly and the COVID-19 pandemic encouraged scientists, engineers, and health workers to devise techniques for providing services remotely. The use of metaverse could boost the healthcare sector and cause a significant improvement in future medical professionals' skills and knowledge bases [23]. Microsoft HoloLens 2 is enhancing patient treatment and enabling healthcare providers to work together more effectively and efficiently [24]. The activities of MV in medical domain is profound and varies from remote diagnosis, treatment planning, medical education, real time surgery assistance, medical marketing, to name a few. MV in healthcare can provide real like experience for remote online doctors and medical students in surgical procedures [25]. Such a simulated environment may significantly reduce surgical risks and can also offer worldwide expertise through medical practitioners online. Utilizing Health Metaverse can further provide doctors with an immersive scene, allowing doctors to enter virtual patient's body during the operation and perform high precision surgeries on subtle parts of the body's organs [26]. However, presently MV is primarily limited to health management and fitness applications in the medical field. The current need is to develop such a platform that can connect remotely different parties like doctors, patients, and administrators through a virtual environment [27]. Medical professionals and teachers can easily use MV technology to train medical students as it can provide a 360-degree holistic view of the anatomy. In addition, combined with hospital equipment information, immersive experience in a virtual world allows students to replay the experience of actual operation as if they were a surgeon themselves [28]. The Health Metaverse application can hence promote innovative medical education, surgery, medical treatment, and online health management [29]. However, the Health Metaverse also has problems and challenges such as difficulty in protecting patient privacy, data security, accessibility, interoperability, and monopoly of a centralized controller [30]. This issue prompted the authors to explore and understand the current context in which blockchain has been implemented in the medical domain. Understanding the congruity and significance of blockchain in medical services, the workplace of the World Economic Forum, made an ideation challenge for mentioning white papers on the expected usage of blockchain in medical care [31].

The main application can be summarized by a few use cases, for example, electronic clinical records, far off patient observation, drug store network and medical coverage (insurance claims). Often, the term Electronic Medical Records (EMRs) and Electronic Health Records (EHRs) are utilized reciprocally, but there is a distinction among both the terms. EMR is a computerized rendition of the prescription from the physician's office and contains the clinical and treatment or medical history of a patient in a single practice. EHRs centre around the complete well-being of the patient-going past standard clinical information gathered in the supplier's office and comprehensive of a more extensive view on a patient's consideration. From the planning study, blockchain innovation underpins the administration of EHRs. In this context, Ekblaw et. al. presented MedRec, an EHR-related execution that proposes a decentralized way to deal with oversee approval, consents and information dividing among medical services partners. MedRec utilizes Ethereum stage to empower patients to have information and data on the go and control access to who can access / view those data [32, 33]. A second application that incorporates EHR, is FHIRChain (Fast Healthcare Interoperability Records +

Blockchain). It is a blockchain-based application actualized utilizing Ethereum for sharing clinical information that centres around medical services record. FHIR-Chain gives answers for patients that meet the prerequisites from the ONC [34]. Further, Xia et. al. designed Medshare an Ethereum based application for frameworks that battle with an absence of joint effort for dividing information among cloud benefits because of the unfavourable dangers towards disclosure of confidential information. Medshare gives information provenance, evaluating, and control between large information elements for sharing clinical information in cloud archives [35]. Other blockchain-based EMR applications incorporate MedBlock and Blochie. MedBlock is a record search system that keeps up the location of blocks containing the records of a patient, assembled by a medical services supplier or division. Every patient record contains a reference to the relating record on the blockchain [36]. Blochie proposed by Jiang et. al. presents a medical services stage dependent on blockchain innovation [37]. To continue misusing existing information bases, Blochie consolidates both off-chain stockpiling, where information is put away in outside emergency clinics' information bases, and on-chain check. There is likewise another medical care blockchain-based structure, Ancile which utilizes Ethereum keen agreements to accomplish information protection, security, access control and interoperability of EMRs [38]. Roehrs et. al. present omniPHR, a circulated model that keep an interoperable single perspective on Close to home Personal Health Records (PHR) [39]. The proposed arrangement depends on a versatile, interoperable, and adaptable engineering of PHR information. Moreover, omniPHR assessment could guarantee the division of PHR into information blocks and its circulation in a steering overlay organization.

TABLE I. BLOCKCHAIN CONTRIBUTION IN HEALTHCARE APPLICATIONS

Ref No.	Highlights	
	Metaverse	**Blockchain**
[11]	Use XR devices offer new advantages to cardiology, where spatial reasoning is very important.	Not Mentioned
[17]	Uses XR devices, IoT devices, digital twins for surreal experience	Uses blockchain to provides trust in the system.
[22]	Creation of Virtual Environment	Distributed Storage, Data Transmission and consensus mechanism
[23]	Creation of virtual environment	Decentralization

It is evident from the discussion above that although blockchain alone had found vivid applications in healthcare domain [40-43], a fused approach of both MV and blockchain is very minuscule. A summary of the existing literature employing blockchain based technology has been listed in Table I. Table II then highlights what metaverse has to offer and how blockchain can contribute to make an efficient system in healthcare-based applications. The implementation details follow in the next section. The proposed concept and framework of Health Metaverse: MetaBlock, redefines the practice of traditional medical practices and promotes the transformation of providing service to users through a virtual world through an amalgamation of Metaverse and blockchain techniques to ensure utmost security and trust in the system.

TABLE II. SUMMARY OF METAVERSE AND BLOCKCHAIN CONTRIBUTION IN HEALTHCARE APPLICATIONS

Metaverse	Blockchain
Generates enormous data	Data Storage facility
Immersive real-life experience	Data security and privacy
Professional training and reduced surgical risks	Data Immutability and accessibility
Interactive environment	Data Availability and transparency

III. METABLOCK SYSTEM WORKFLOW

For blockchain applications in medical services, a significant trademark is permanence, which may strife straightforwardly with security rights along with healthcare protocols and standards that should also apply in a blockchain network. The intention of fusing metaverse is to provide real life like experiences to both the patients and the healthcare providers. Traditionally, patients leave information dispersed across different associations and the blockchain based framework may help address this issue by supporting the advancement of interoperability guidelines and prerequisites that address protection and empower the safe exchange of information across frameworks. The aim of such a framework is expected to arrange the patients' clinical datasets and characterize conventions for guaranteeing the consistency of the health care related data [44]. These are normally committed to normalizing the capacity of and managing clinical and segment information about patients. As metaverse deals with enormous amount of data, blockchain are a better mechanism to indefinitely store "ever-growing" patient medical records because apart from being immutable and secure, it also has the capacity to develop and change significantly all through its lifetime by adding new members and changing hierarchical connections, which is very likely to happen in the healthcare- based system. Keeping into consideration these factors, a metaverse and blockchain fused system architecture: MetaBlock, is designed to offer an immersive experience to the users of the system. MetaBlock intends to the give the users of the system an experience of physician consultation as if they are physically present in the hospital or clinician's office. The participating entities in the system are highlighted in Figure 2. The fusion of metaverse and blockchain is depicted in Figure 3 in terms of the metaverse and blockchain components. A detailed description follows in the subsequent sections.

A. *Data Acquisition*

Data acquisition in this setup includes data collection from users of the system (specifically patients) including their demographic details, past medical history, current ailments, etc. The data collection is metaverse enabled and backed by a blockchain network to build an immutable trustworthy system.

Metaverse Based: It is the preliminary step in any MV system as it helps create a more customized virtual experience. The data acquired for the MetaBlock virtual hospital would contain the user's personal details and medical case histories (acquired through different medical diagnostic tests). Such information is also vital in creation of digital avatars. Payment related details such as bank/credit card information are confidential but are needed to perform certain tasks. Hence, the data acquired is heterogeneous in nature [45] and can be acquired from a variety of sources like web forms, camera, images (medical reports), etc. The data generated in the metaverse is huge, dynamic and unstructured, hence data integrity becomes a challenge in metaverse as data reliability is in question [46] and inaccurate or redundant data also affects the system [47]. Acquiring valid data in MV will be made easier using blockchain technology as it allows validation of transaction records and tracing the data in the metaverse [48, 49].

Figure 2. Participants in MetaBlock

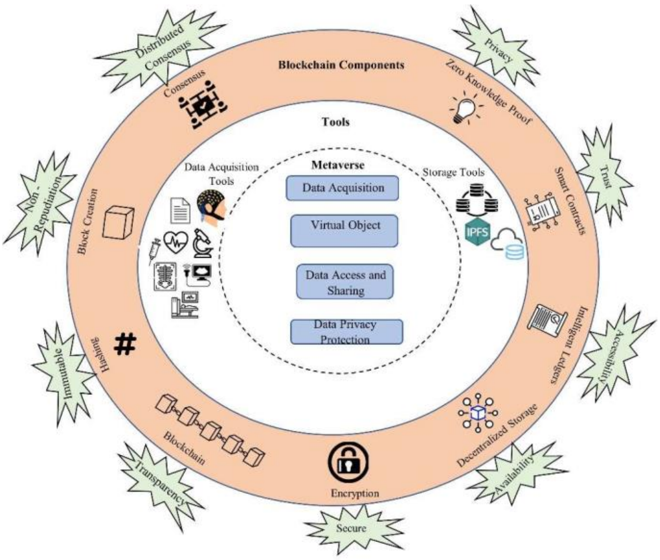

Figure 3. MetaBlock Components

Blockchain Solution: The information gathered through the metaverse is subjected to a validation process that is enabled using the consensus mechanism prevalent in a blockchain network [50, 51]. Distributed consensus can be provided through two widely used methods:

- Proof-of-work is the conventional mechanism for validating a block. Here, nodes compete to initiate the creation of the next block by using computational resources to crack a challenging mathematical problem. The first node to do so, broadcasts the solution to the other nodes on the network, which the remaining nodes verify [52].
- Proof-of-stake mechanism denounce the mathematical challenge, and few privileged nodes get the opportunity to create a block. The nodes are marked privileged based on its existing investment in the system [53].

Blockchain, thus allows a single record to be published on the network (as blocks) without requiring a central authority to approve. As the data in a blockchain is linked to the next block through means of a cryptographic hash, the chances of changing the data (immutable) and creation of duplicate block is negligible which ensures that there is no records are duplicated during data acquisition. Data collected through MV demands increasing storage space, as more data is collected over time. To address this issue in data acquisition systems, a decentralized off-chain storage mechanism is proposed in MetaBlock discussed in section 3.2.

MetaBlock implementation: The first step to implementation of such a framework begins with the patient's registration at the hospital. The data acquisition tools used here includes physical or web forms, medical prescriptions and medical reports (of different image modalities). Additionally, payment details may also be required. Blockchain creation is initiated as soon as a patient registers at the hospital.

[Patient view:] The registration process involves collection of the basic patient details and existing ailments if any. The patient may also choose to share some pre-existing medical reports or clinical imaging reports.

[Backend:] Upon successful registration each patient is assigned a unique id (PID). This PID is now used to generate a pair of keys as:

$$\text{KeyGeneration}(\text{Nonce}, \text{PID}) = (\text{KAdmin}, \text{KPatient})$$

where,

$$\text{KAdmin} = \langle ak0, ak1 \rangle \text{ and } \text{KPatient} = \langle pk0, pk1 \rangle$$

The key generation algorithm takes as input a nonce value as the initial seed point and the patient id and the output is a set of keys (KAdmin,KPatient). The key KAdmin consists of a public-private key pair <ak0, ak1> meant to be used by the admin (doctor) and a set of public-private key pair <pk0, pk1> to be used by the patient or user of the system. These key pairs generated will later aid in digitally signing the documents, encrypting/decrypting medical data records, searching through records, etc. A block is then created containing a header which includes a timestamp (the time the block has been created), nonce (a random number used only once), Merkle root (a hash of all the hashes of all the transactions). This block is termed as an Orphan block as it is not complete and is not a part of the blockchain yet, since it has not been validated. Proof- of-stake consensus mechanism has an advantage of validating a block with minimum effort. The node which creates a block will sign the message with the private key corresponding to that node's public key to validate the block [54]. Only after the consensus is achieved, is the block ready to be added to the network.

B. *Data Storage*

Due to the massive amount of data generated, an efficient storage system is required which not only provides storage space but should also support data retrieval quickly. With the increase in the issue of data privacy, using a robust storage mechanism is an utmost priority in such a system. A blockchain based storage solution is hence employed as blockchain is known to be trusted, efficient and privacy preserving system.

Metaverse Based: It is obvious that the metaverse will require a massive amount of data storage as the data continues to grow with each interaction with the virtual world. This enormous data has a significant demand for data storage capacity in the physical world. As a consequence, data storage is a crucial issue while deploying metaverse applications and the MetaBlock system as well. Centralized storage solutions also come with their own set of drawbacks as third-party control over data, data leakage, tampering, or data loss.

Blockchain Solution: In blockchain, a new block is created for every transaction and is essentially tamper proof due to chaining through cryptography hashes [55]. An off chain decentralized data storage solution is proposed in the MetaBlock system hence boosting data reliability and transparency in the metaverse. Many blocks can now contribute to the data distribution task, thereby increasing data availability which is essential in applications like vital monitoring and life support alerts in the metaverse. Furthermore, in the metaverse, the blockchain provides data reliability, transparency, and availability [56].

MetaBlock implementation: The data collected during data acquisition needs to be secured and hence there is a need to encrypt it for security purpose. These details are stored in an encrypted database at the site of generation of the data. The distributed database provides an efficient storage solution which is essentially managed by the winning node (during consensus).

[Patient view:] Patient verifies the data by digitally signing it using his / her private key pk1. Figure 4 represents the steps for digitally signing a document by the user (patient).

[Backend:] Digital signatures are used to verify the integrity of data, and it supports non-repudiation. Figure 5 represents the verification of the digitally signed document at the receiver's end.

The hospital then encrypts the patient data R using public key ak0 such that

$$E(R, ak0) \rightarrow CR$$

which finalizes the creation of the initial orphan block. The cipher-files are stored in a repository and an index is generated for the same to facilitate further search strategies. The patient then visits the doctor for consultation and new records are generated. These records also must be validated and added to the blockchain.

[Patient view:] Patient upon consultation with a doctor receives new prescription and may need further medical diagnosis by means of imaging (X-Ray, CT scans, MRI, blood tests, etc.).

[Backend:] The newly generated data has to be validated before they can be added to the blockchain. These data are validated by the admin (doctor, pathologists, radiologists) following the process depicted in figure 5 using the admin private key ak1. A hash is then generated for the same that is stored on the blockchain and broadcasted as a transaction. This ensures the trust factor in the stored records, and it will be added to the existing blockchain network of the hospital from where the trusted third parties may have access to it.

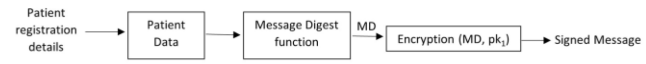

Figure 4. Digital Signature on patient registration data

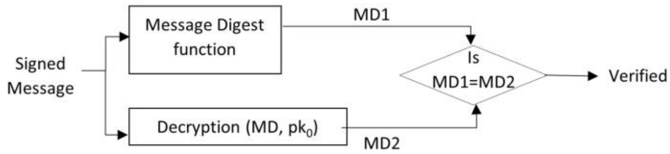

Figure 5. Digital Signature verification process

C. Metaverse Object and Virtual Space creation (Avatars/Digital Twins)

This is an essential component for a surreal experience in metaverse based system. Generation of the entire virtual space including avatar creation is dependent on the data collected and needs a lot of tools for creation.

This is an essential component for a surreal experience in metaverse based system. Generation of the entire virtual space including avatar creation is dependent on the data collected and needs a lot of tools for creation.

Metaverse Based: The avatar is a digital version of the user in the virtual world. Digital twins are advanced representations of different components of the physical world in the virtual world [57]. Representing each component thoroughly gives a better immersive experience to the users of the system. The construction of the virtual object / space creation is simulated using the data obtained from the user and other sources like sensors. The quality of data acquired readily affects the accuracy of the digital twin model used to create the system. Hence, it is essential that the data provided by the source must be authentic and of adequate quality [58].

Blockchain Solution: Blockchain encryption techniques and the data transparency achieved in blockchain validate the digital twins and enable secure data sharing. Real-world data is securely stored in distributed offchain storage locations and co-exist with their digital twins in the metaverse by means of an intelligent distributed ledger. Additionally, this also ascertains the privacy and security of the data. Every interaction of the digital twin in the metaverse will be recorded as a transaction on the blockchain, which is immutable and requires consensus to change [59]. The blockchain technology, thus ensures data trust, integrity, and safety concerns pertaining to the usage of data.

MetaBlock implementation: The use of immersive technologies like AR, VR, MR or XR is needed to mend the gap between the physical and virtual world. The MetaBlock system proposes a theoretical belief of blending the physical infrastructure to present a similar illusion in the virtual world. The need for navigation is critical on the hospital or clinic in the virtual world, where visitors can move freely in a complex environment, such an internal navigation is a significant challenge [60]. Common tools and techniques as Bluetooth beacons, Wi-Fi, cameras, sensors, etc. are needed to accurately assess the user's location and pose. The use of Artificial Intelligence (AI) is another essential technique required to help in creation of accurate digital twins in the virtual world [61]. Figure 6 showcases the mapping on the real-world entities in the virtual world.

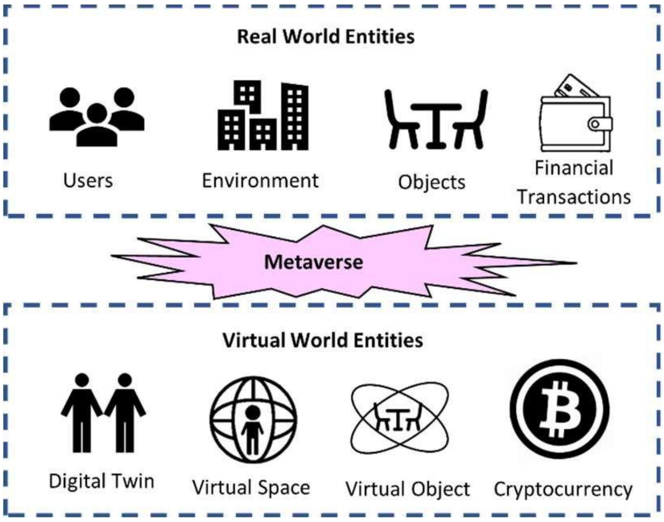

Figure 6. Physical vs. Virtual World entities

D. Data Sharing

Another essential component of the MetaBlock healthcare system is the efficient retrieval and sharing of data that too in a secure manner.

Metaverse Based: Data sharing is an implicit part of any metaverse based devices and sensors will be used to create personalized systems that are customized to the users' actions. Data analytic is also essential to understand and improve user experience. All these require massive data sharing which comes with its own risk of data compromise, theft and misuse. Sharing data via the traditional methods is highly mutable and scalability is another challenge [62].

Blockchain Solution: As discussed prior, blockchain is known to provide decentralized, immutable record of all transactions, and offers data transparency. Additionally, the data owner has complete control over their data and hence data validation is easier through blockchain. Data Availability can also be improved through Smart contracts [63].

MetaBlock implementation: Any participating entity requesting data (for a patient with PID) from MetaBlock system would place a data sharing request to the data generator which will be timestamped (Q(PID)t). Firstly, the requester's identity is verified, failing which access is denied. On successful verification the PID identifier is used to locate the record from the distributed database and the data can be decrypted using the key (ak1). Smart contracts are deployed to carry out the verification and access rights (Figure 7).

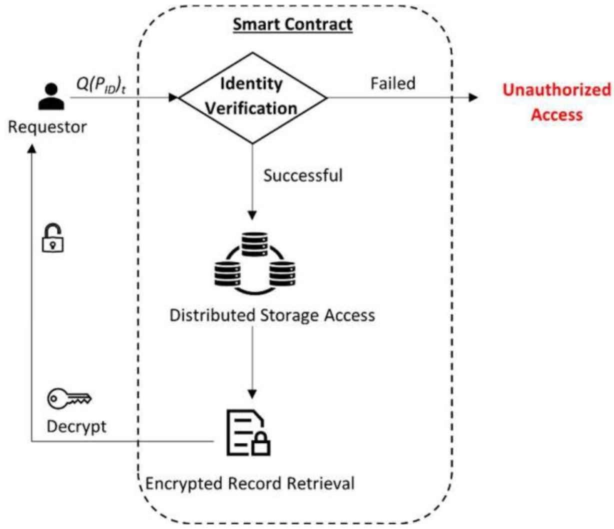

Figure 7. Smart Contract deployment in MetaBlock

E. Data Privacy Protection

Metaverse Based: The metaverse will generate massive data once functional, as more and more users will connect to the system. Sharing massive data gives rise to privacy concern to the users of the system. The metaverse ecosystem will be difficult to adapt if intruders will be able to steal sensitive and confidential data.

Blockchain Solution: Blockchain technology uses encryption technique by means of an asymmetric key pair to allow the user to control their data, effectively providing them ownership of their data. In the blockchain enabled metaverse, third-party providers do not have the permission to access the data. The concept of zero-knowledge proof on the blockchain permits a user to gain access of essential data in the metaverse while ensuring privacy protection and ownership rights. Zero-knowledge proofs in blockchain enables a user to persuade an application that information provided by them is correct and real without disclosing the actual information [64].

MetaBlock implementation: Zero-knowledge proof is a cryptographic technique, in which the data provider can convince the verifier about the correctness of the data without providing any classified data access. MetaBlock implements a zero-knowledge proof verification to ensure data privacy using a distributed ledger [65] (Figure 8).

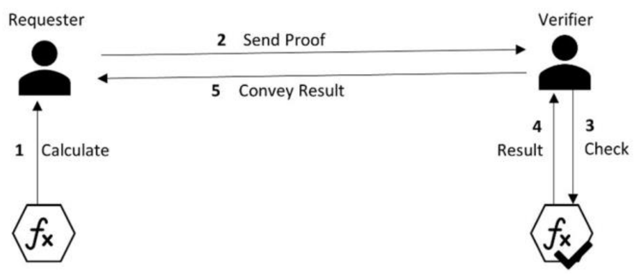

Figure 8. Zero Knowledge Proof mechanism in MetaBlock

To summarize this section, Table III lists the different components of MetaBlock along with the implementation challenges faced in metaverse and how blockchain comes to the rescue using its basic primitives.

TABLE III: METAVERSE FEATURES

Metaverse Challenges	Blockchain primitive used	Features
Data Acquisition		
Heterogeneity Unstructured	Consensus Algorithm Smart Contract	Distributed Consensus Non repudation, validation
Storage		
Massive Evergrowing	Cryptographuc promitives (Hashes) Decentralized Distributed Storage	Immutable Availability
Virtual Object / Space Creation		
Secure Data access	Intelligent Distributed Ledger	Integrity
Data Sharing		
Risk of data tampering, theft and misuse	Smart Contracts	Security and Trust

IV. FEATURES OF METABLOCK

1. Distributed Consensus: Blockchain are essentially distributed systems and are hence not managed by a central authority. A distributed consensus algorithm is well suited for the MetaBlock system as the active nodes can collectively detect transactions and seek to reach a global optimum [66]. Reaching a global consensus eliminates the issues associated with local communication between few nodes. Through iterative updates, a global decision can be made involving all the active nodes in the system. A distributed consensus algorithm will generally offer a fast convergence rate.

2. Non - repudiation: As discussed previously, MetaBlock receives data from multiple sources related to healthcare. The system relies on this data for creating digital twins and virtual environment, arriving at decisions and enabling data quality. The system possesses a validation mechanism to eliminate the chances of data duplication and false data, hereby increasing the data quality.

3. Immutable: Due to chaining of blocks using a hash function, like blockchain, MetaBlock also offers to be tamper resistant and hence, immutable. Changing a block is nearly impossible as that would require a change in all consequent blocks.

4. Transparency and Trust: Transparency ensures accessibility and trust in the system. In MetaBlock, it refers to the availability of patient centric data and clinician reports to the participants of the system. Lack of transparency can lead to safety and trust issues among the users of the system.

5. Privacy and Security: MetaBlock collects voluminous data for providing a real life immersive environment. The system with its authentication, validation, access control rights and distributed consensus mechanisms provides the user complete control of their data. Encryption techniques and hash functions also contribute to maintaining the secrecy and privacy of the data [67].

6. Sharing, Availability and Accessibility: The continuous availability of data is essential in healthcare industry as it is necessary for quick decision rendering for treatment. Uninterrupted data availability and accessibility are a primary focus of the MetaBlock network as well. Blockchain enabled decentralized and distributed storage backs the promise of data availability and access control mechanism ensure the security and privacy.

V. FUTURE SCOPE

The paper has proposed a metaverse and blockchain system for application in healthcare industry, namely MetaBlock after thorough analysis of the role and impact of metaverse and blockchain in healthcare industry. Besides making a conclusion in the next section, worth mentioning is a vital topic that can provide some future research directions as this field is still nascent. Blockchain in general has shown good potential to revolutionize the healthcare industry but incorporating it with an immersive experience to build a virtual world has its own set of challenges. Apart for hardware limitations, implementation challenges are discussed here to provide an insight for future research directions. In a metaverse + blockchain enabled system, a revolutionary breakthrough will be to arrive at an application specific consensus algorithm. Many variants of consensus techniques have been proposed and compared to achieve high throughput and low latency [68], but in the context of a metaverse enabled system, it is still a research initiative to develop and tune some intelligent consensus algorithms. Another serious global issue is high energy consumption due to a large number of participating nodes in a network. As metaverse is growing day in and out, a hybrid consensus mechanism should also consider the limit on the number of nodes participating in the process without effecting the trust in the system.

VI. CONCLUSION

The Metaverse and blockchain individually are not a new concept. However, fusing them unleashes a plethora of creativity applicable to various application domains. The paper discusses the role of metaverse and blockchain, individually in the healthcare industry. It later proposes an architecture by fusing the metaverse and blockchain technology, to come-up with MetaBlock. This system promises to have a rich, immersive experience to its users and can be used for diagnosis, training, surgery simulation, etc. as it is capable of giving its users an experience like the actual physical world. The system relies on MV tools to gather data and gives the user a real like feel and vastly relies on blockchain for reliability in the system. More importantly, the system deploys essential blockchain components of consensus, smart contracts, distributed ledgers, cryptographic primitives fused with metaverse components for successful implementation. The system also has features compatible with the implicit blockchain features of immutability, security, privacy, trust, non - repudiation to name a few. Actual implementation of the system will take some time as it extensively depends on high end hardware devices for immersive virtual reality / augmented reality experience.

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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.

CONFLICT OF INTEREST

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

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

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SmartLLMSentry: A Comprehensive LLM Based Smart Contract Vulnerability Detection Framework

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***Abstract*— Smart contracts are essential for managing digital assets in blockchain networks, highlighting the need for effective security measures. This paper introduces SmartLLMSentry, a novel framework that leverages large language models (LLMs), specifically ChatGPT with in-context training, to advance smart contract vulnerability detection. Traditional rule-based frameworks have limitations in integrating new detection rules efficiently. In contrast, SmartLLMSentry utilizes LLMs to streamline this process. We created a specialized dataset of five randomly selected vulnerabilities for model training and evaluation. Our results show an exact match accuracy of 91.1% with sufficient data, although GPT-4 demonstrated reduced performance compared to GPT-3 in rule generation. This study illustrates that SmartLLMSentry significantly enhances the speed and accuracy of vulnerability detection through LLM-driven rule integration, offering a new approach to improving Blockchain security and addressing previously underexplored vulnerabilities in smart contracts.**

Keywords*— *Smart contract, Vulnerability, Software security, Blockchain, Large Language Models

I. INTRODUCTION

In the rapidly evolving digital ecosystem, smart contracts have emerged as a transformative technology, fundamentally altering how agreements are executed and enforced. Embedded within blockchain technology, these self-executing contracts automatically carry out the terms of an agreement once predetermined conditions are met. This automation not only streamlines processes but also significantly reduces the need for intermediaries, fostering a more direct and efficient transactional environment.

The burgeoning reliance on these technologies underscores the critical need for robust security measures. Smart contracts are not impervious to vulnerabilities; their open-source nature and the immutability of the blockchain make them susceptible to various types of attacks, which could lead to significant financial and reputational damage [1]. Common vulnerabilities include reentrancy attacks [2], transaction-ordering dependence [3], timestamp dependence [3], and several others [3] that can compromise the intended functionality and security of these applications [4].

The increasing complexity and deployment of smart contracts across various industries [5] have highlighted the necessity to automate the process of finding vulnerabilities. As these contracts become more intricate, manually identifying potential security risks becomes less feasible and more error-prone [6]. This recognition has spurred interest in the research community, leading to significant efforts toward developing automated tools that can efficiently and accurately detect vulnerabilities at scale. The drive for automation is not merely a matter of convenience but a critical requirement to maintain the integrity and trustworthiness of blockchain applications. As the adoption of smart contracts continues to grow, fueled by their potential to revolutionize traditional business models, the development of advanced automated vulnerability detection frameworks becomes imperative to ensure their safe operation.

In response to the need for more effective security measures, various techniques have been employed to detect vulnerabilities in smart contracts. Traditional methods primarily involve static analysis, which analyzes the contract's code without executing it. However, those frameworks operates by comparing code against a set of predefined rules that describe known vulnerabilities. However, this approach has inherent limitations, primarily because it relies heavily on the accurate definition of these rules by human experts. As a result, this technique inherently depends on human experts to continually define new rules for newly detected vulnerabilities. The reliance on expert input not only limits the speed at which new threats can be addressed but also underscores a fundamental constraint: the system's efficacy is tied to the timely and accurate update of its rule set. Without constant refinement and expansion of these rules, the framework risks missing novel vulnerabilities, highlighting the critical need for ongoing expert involvement to maintain its effectiveness.

In recent years, the capabilities of LLMs such as GPT have garnered significant interest due to their impressive computational intelligence. These models are developed by training on vast datasets and require substantial computational resources. With billions of parameters, LLMs can discern intricate patterns and demonstrate a level of general intelligence across a range of tasks previously considered challenging for AI to achieve in the short term. A notable instance of this technology is ChatGPT, a sophisticated chatbot powered by openAI [7]. It engages users in human-like interactions, providing responses across various domains. Given these advancements, recent research has explored the potential of using ChatGPT to enhance the detection of software vulnerabilities, suggesting a new application area where LLMs could significantly impact [8, 9].

Following the same logic and to solve rule based frameworks limitations, this paper launches a study on the performance of rule generation using an in-context learning

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version of ChatGPT with different prompt designs. gpt-4o-mini-2024-07-18 is the newest version of ChatGPT when we conduct this study [10].

The contributions of this work:

- We have developed an automated system for rule creation within, which eliminates the need for continual expert intervention and accelerates the integration of new rules. This innovation enhances the responsiveness of the system to emerging vulnerabilities and streamlines the update process.
- In our research, we have identified and analyzed three new common root causes for vulnerabilities which, to the best of our knowledge, have not previously been explored in the scientific literature. We provide a detailed examination of their root causes, contributing valuable insights into the underlying issues that lead to these security flaws.
- We have built a Dataset of Five different smart contract vulnerabilities that could be used by research to test or train their models.
- We have successfully created new rules into SmartLLMSentry Analyzer component that extend its capability to detect three additional types of vulnerabilities. This expansion not only improves the comprehensiveness of SmartLLMSentry's security measures but also increases its utility in safeguarding smart contracts.
- We conducted a comprehensive study on the effectiveness of various versions of GPT models in detecting vulnerabilities within smart contracts. This investigation helps in understanding which model iterations perform best in this specific context and guides future implementations of LLM technologies in security applications.
- We explored the impact of dataset size on the performance of GPT models specifically in the context of generating rules for vulnerability detection. Our findings reveal significant insights into how the quantity and quality of training data influence the accuracy and reliability of the rules produced.
- Finally, we provide a detailed analysis of the advantages and limitations of employing ChatGPT for detecting vulnerabilities in smart contracts. This analysis offers a balanced view, highlighting where ChatGPT excels and where it may require further tuning or supplementation to meet the demands of this application.

This paper is organized as follows: Section 2 provides a review of related work in both traditional software and smart contract security, including the application of LLMs in vulnerability detection. This section also outlines the five specific vulnerabilities targeted in our study and examines their common root causes. Section 3 details the data collection and preprocessing methods employed in the research. Following this, Section 4 describes the prompt engineering process, including the various prompts utilized during experimentation. Section 5 presents and discusses the research findings, while Section 6 addresses potential threats to validity. Finally, the paper concludes with a summary of the results and suggestions for future research.

II. Related Work

A. *Static analysis techniques*

Due to both their immutability feature and the managed sensitive data, smart contract vulnerabilities should be checked and fixed before a production deployment. The rise in their complexity make manual vulnerability detection of smart contract not efficient and require to be completed by an automated scan [11] Therefore, multiple previous researches [12, 13, 14, 15, 16] have been performed to build frameworks that automatically discover those vulnerabilities in the development phase. Feist et al, [17] have built slither, a static smart contract analyzer that is capable of detecting vulnerabilities like Shadowing [3], Uninitialized variables [3], Reentrancy [18] and a variety of other known security issues, such as suicidal contracts, locked ether, or arbitrary sending of ether. Grech et al., built MadMax [19], a static analysis framework capable of detecting out-of-gaz related vulnerabilities [3]. Nguyen et al., in 2020 have built sFuzz [20] a dynamic analysis framework capable of detecting vulnerabilities like Reentrancy, Timestamp Dependency [3], Block Number Dependency [3], Integer Overflow [3], and others. Ren et al., [21] have also built a static vulnerability detection framework called Solidifier capable of detecting vulnerabilities like, Reentrancy, Timestamp Dependency, Front Running, Integer Overflow, and others.

However, a significant limitation of those frameworks lies in the manual creation of rules for vulnerability detection. This manual process can be time-consuming and prone to human error, limiting the framework’s ability to adapt to new and evolving threats. In this paper, we propose SmartLLMSentry to solve those limitations using LLMs. By leveraging LLMs, we aim to automate the rule generation process, thereby improving the efficiency and accuracy in detecting a broader range of vulnerabilities. This approach not only addresses the current limitations of static analyzers but also enhances their adaptability to emerging security threats in smart contracts.

B. *Machine learning and LLMs*

The emergence of machine learning and its proven success across various domains has prompted researchers to apply these techniques to the detection of smart contract vulnerabilities. One of those researches was a framework built by Zhipeng et al, called SMARTEMBED [22], which is a web service tool for Solidity developers. SMARTEMBED uses code embeddings and similarity checking to detect repetitive code and clone-related bugs. Applied to over 22,000 Solidity contracts, it identified a 90% code clone ratio and detected 194 clone-related bugs with 96% precision. Yu et al. developed DeeSCVHunter [23], a modular framework for detecting smart contract vulnerabilities, introducing the concept of Vulnerability Candidate Slicing (VCS) which enriches semantic and syntactic features to enhance deep learning model performance. However, DeeSCVHunter is limited to detecting re-entrency and timestamp vulnerabilities only. Wu et al. [24] introduced a smart contract representation method based on key data flow graph information to capture essential features for vulnerability detection while mitigating overfitting during training. They proposed a tool named Peculiar, which enhances detection performance by utilizing critical data flow graphs. However, the construction of these graphs is complex, and Peculiar's detection capabilities are limited to identifying reentry vulnerabilities in smart contracts. Another research performed by Nami et al, [25] resulted in building an effective framework against code rewriting attacks. Eth2vec is a machine learning-based static analysis tool, contrarely to the other models Eth2vec works with Ethereum Virtual Machine (EVM) bytecodes. Despite its strengths, Eth2vec requires manually crafted vulnerability features to maintain detection accuracy, which can be labor-intensive and limits its adaptability to new types of vulnerabilities.

Lately, AI has undergone a revolution thanks to LLMs, which have demonstrated extraordinary skill in a variety of tasks [26, 27, 28]. LLMs are founded on the principle of language modeling (LM), which involves modeling the generative likelihood of word sequences to predict future tokens. Unlike traditional LM approaches, LLMs are trained on vast datasets using powerful computational resources. Their versatility and adaptability are attributed to their billion-scale parameters [29], a level of complexity and scale unprecedented in previous models. This extensive parameterization allows LLMs to achieve remarkable performance across a wide range of language tasks. The most popular LLMs to the date of writing this paper are OpenAI’s GPT [7, 30], Gemini [31] and Claude [32]. Some of them provide an API access to finetune their model, while others do not [33]. Many recent researchs have used the LLM technology to automate the process of vulnerability detection in softwares.

LLMs have been increasingly utilized in vulnerability detection. Sihao et al. [34] provide an in-depth analysis of using LLMs, such as GPT-4, to identify vulnerabilities in smart contracts, emphasizing the challenge of balancing accurate vulnerability detection with minimizing false positives. Their empirical research demonstrates that increased randomness in responses enhances the likelihood of correct detection but also raises the incidence of false positives. To mitigate this issue, the study introduces GPTLens, an adversarial framework that divides the detection process into two phases: generation and discrimination. In this framework, the LLM functions both as an auditor and a critic. This dual-role approach, designed to expand the scope of vulnerability detection while reducing inaccuracies, significantly outperforms traditional methods, establishing GPTLens as a versatile LLM-based solution that does not require specialized expertise in smart contracts. Additionally, LLM4Vuln [35] conducts a more detailed study aimed at decoupling LLMs' vulnerability reasoning capabilities from their other functionalities, yielding promising results in the application of these models for vulnerability assessment.

However, Static algorithm-based detectors offer significant advantages in terms of deterministic and consistent results, efficiency, and transparency. Unlike LLM-based analyzers, static detectors produce consistent outputs for the same input, ensuring reliability in critical environments. They are also more efficient, requiring fewer computational resources, making them faster and more cost-effective to operate. Additionally, their decision-making process is transparent and interpretable, as they rely on predefined rules and patterns. This clarity allows developers to easily understand why a particular vulnerability was detected, simplifying the debugging process and enabling quicker remediation of identified issues. Despite all those advantages, static analyzers like any algorithm based technology suffer from a key limitation related to depending on expert knowledge to create detection rules [36]. Therefore, to avoid this dependency we use LLMs to generate the right algorithm to detect known vulnerabilities and enhance SmartLLMSentry framework detectors integration.

C. Prompt Engineering for In-Context Learning

In-Context Learning (ICL) is a method by which a pre-trained model, like a LLM, can perform new tasks without needing additional training or fine-tuning [37]. Instead, the model is given a prompt that includes examples of the task it needs to perform [37]. The model then uses these examples to infer the task and generate appropriate responses [38]. This method leverages the model's existing knowledge and patterns learned during its training to adapt to new situations quickly [38]. For instance, if the model is given a few examples of a translation task within a prompt, it can learn to translate new sentences by understanding the context provided [38].

Fine-tuning a model, on the other hand, involves adjusting the model’s parameters using a new dataset specific to a particular task [39]. This process requires additional training and computational resources [40, 41]. Fine-tuning typically allows for higher accuracy and better performance on the specific task but requires more data and time [40]. It also makes the model specialized, potentially reducing its generalization ability to other tasks [41].

We chose In-Context Learning over fine-tuning due to its flexibility and efficiency [38]. In-Context Learning allows us to leverage the model's pre-existing knowledge without the need for extensive retraining [38]. This is particularly useful when quick adaptation to new tasks is needed or when the task-specific data is limited. Additionally, ICL maintains the model’s generalization capabilities, making it more versatile across various tasks. The ability to handle multiple tasks without requiring separate fine-tuned models simplifies deployment and reduces the computational overhead [41], making it a more practical choice in dynamic environments.

Prompting-based learning has emerged as a dominant paradigm in the utilization of language models. Rather than relying on objective engineering to adapt pre-trained LMs for downstream tasks, prompting-based learning reconfigures these tasks using a textual prompt, aligning them more closely with the tasks the LM was initially trained to solve [42]. Research has demonstrated that well-structured prompts can significantly enhance the performance of LLMs across a variety of downstream tasks [43, 44]. Consequently, a diverse array of prompt design strategies has been developed to further optimize the effectiveness of this approach [42].

Concerning prompt formulation, certain studies have focused on exploring the search for optimal discrete prompts [45, 46, 47]. However, other researchs have used continuous vector as prompts [48, 49, 50]. Several studies have investigated the impact of prompts on generative models. For instance, Liu et al. [51] examine how different prompts influence the generation of visualizations by LLMs [52]. Additionally, Liu et al. [53] propose various prompt designs tailored for two distinct code generation tasks. Recent research has also begun to explore the potential of ChatGPT in the context of software vulnerability detection. Cao et al. [8] design enhanced prompt templates to leverage ChatGPT for deep learning-based program repair. White et al. [54] explore various prompt patterns aimed at improving requirements elicitation, rapid prototyping, code quality, deployment, and testing. However, to our best knowledge none of the research have analyzed the performance of combining static analysis and LLMs power to detect smart contract vulnerabilities.

D. Smart contract vulnerabilities

Effective detection of smart contract vulnerabilities relies on understanding their common root causes. This section explores the frequent origins of five vulnerabilities that will be used as a training data or testing data. By examining these underlying issues, we aim to enhance the application of LLM prompt engineering in identifying vulnerabilities. Recognizing these root causes will not only improve the accuracy of our LLM-based detection methods but also contribute to the development of more robust and secure smart contracts.

In our research, we opted for a random selection of targeted vulnerabilities to ensure that our enhanced framework is tested against a diverse and representative set of potential threats. The primary objective was to avoid any bias that might arise from deliberately selecting certain types of vulnerabilities, which could skew the results and limit the generalizability of our findings. By using a random selection process, we aimed to simulate real-world conditions where vulnerabilities can vary widely in nature and impact. This approach allows us to assess the robustness and adaptability of our framework in generating and integrating rules of a broad spectrum of security issues, ultimately leading to more comprehensive and reliable improvements. Moreover, randomness in selection helps in avoiding overfitting our framework to a specific subset of vulnerabilities, ensuring that the LLM ICL is applicable across various scenarios rather than being tailored to specific cases.

1) Array length manipulation (SWE-161)

In older versions of Solidity, it was possible to manipulate the "length" field of an array using standard arithmetic operations, leading to serious vulnerabilities. Specifically, the "length" field, which determines the size of the array, could be decremented using code such as anArray.length--;. If this operation caused the length to underflow, it would result in the array size being set to the maximum possible integer value [55].

This underflow vulnerability could have severe consequences, potentially disabling a smart contract by allowing unauthorized or unintended access to memory locations far beyond the array's intended bounds. Such an issue could be exploited to disrupt the contract's functionality or even lead to the loss of critical data, as the contract might behave unpredictably [3].

2) Message call with hardcoded gas amount (SWE-134)

Hard forks in blockchain networks can lead to significant changes in the gas costs associated with executing Ethereum Virtual Machine (EVM) instructions. These changes can disrupt existing smart contracts that were deployed with the assumption of stable gas prices. As a result, hardcoding a fixed gas amount for specific contract operations can become a critical vulnerability over time. If the gas cost of certain EVM instructions increases due to a hard fork, the previously sufficient hardcoded gas limits may no longer cover the necessary execution, leading to a DoS condition [4].

This issue is particularly problematic because smart contracts, once deployed, are immutable and cannot be easily updated to accommodate new gas costs. For instance, the implementation of EIP-1884, which increased the gas cost of the SLOAD instruction [56], inadvertently disrupted the functioning of many existing smart contracts [57]. These contracts had hardcoded gas values based on the previous cost of SLOAD, and the increase rendered them unable to execute certain operations, leading to failures and potential vulnerabilities. The potential for such disruptions underscores the risks associated with hardcoding gas values in smart contracts. As blockchain protocols evolve and undergo hard forks, the assumptions underlying gas costs may no longer hold, and contracts that depend on these assumptions can become vulnerable to DoS attacks [3].

3) Transaction order dependence (SWE-114)

In blockchain networks where the validation order of transactions is not strictly enforced, nodes often prioritize transactions with higher fees to optimize their financial returns. This practice introduces a potential security risk, particularly for smart contracts that depend on the specific sequence in which transactions are validated. When the correct functioning of a smart contract is contingent on the order of transactions, a race condition may arise, leading to what is known in the blockchain domain as a Transaction Order Dependence (TOD) vulnerability [3].

A TOD vulnerability occurs when the outcome of a smart contract can be manipulated by altering the order of transactions [58]. This type of vulnerability is particularly relevant in scenarios where multiple transactions interact with the same contract in a short time frame. An attacker can exploit this by submitting a transaction with a higher fee to ensure it is processed before others, thereby gaining an unfair advantage or causing unintended consequences within the contract’s logic [3, 58].

A common example of this vulnerability is found in the use of the approve() function in ERC-20 tokens. The approve() function allows a token holder to grant another address permission to spend a specified amount of their tokens [59]. However, if two transactions to modify the approved amount are processed out of order, it can lead to inconsistencies in the allowance, potentially enabling unauthorized spending or other malicious activities. This example illustrates how TOD vulnerabilities can compromise the security and expected behavior of smart contracts, emphasizing the importance of careful design and implementation to mitigate such risks.

4) Locked Money (SWE-138)

Smart contracts that accept tokens or funds without incorporating a mechanism for their retrieval are susceptible to vulnerabilities that can lead to the permanent locking of assets. This vulnerability is inherent in any contract that receives tokens or funds but lacks a clear procedure for their return or withdrawal. Such a design flaw can result in funds being trapped indefinitely, as the contract does not provide a way to reverse or access the deposited assets [3].

Furthermore, the use of the _mint() function to create and allocate tokens to unknown addresses introduces additional risks. If the recipient address does not support the specific type of token being minted, the tokens may become inaccessible, resulting in a loss of resources [59]. This issue arises because the receiving address may lack the necessary functionality or compatibility to handle the minted tokens effectively [59].

To address this problem, it is advisable to use a safeMint function instead. The safeMint function incorporates additional safety checks to ensure that the recipient address can handle the token being minted [59, 60].

5) Improper handling of exceptions (SWE-140)

One of the common root causes of the SWE-140 vulnerability is the use of the send or transfer functions for sending funds in smart contracts. These functions automatically impose a limit of 2300 gas for their execution [61], which acts as a safeguard against reentrancy attacks by restricting the amount of code that can be executed in the fallback function [3]. However, with the enhanced protections now available in modern smart contracts, it is increasingly considered safe to use the call function instead of send or transfer. The call function does not impose the same gas limits, allowing the receiving contract to execute more complex code within its fallback function [62, 63].

III. Method

A. Framework design

The architecture of SmartLLMSentry is characterized by 2 main parts Figure 1. The first one is the framework core which is also built of three interdependent components as shown in Figure 1. The pre-compiler, compiler, and analyzer, each contributing to a holistic and thorough smart contract analysis pipeline. The pre-compiler module, positioned as the inaugural stage, serves as the entry point for the analysis process. It accommodates diverse inputs, allowing users to specify either a GitHub URL or a smart contract address on the Ethereum Blockchain. The flexibility in input sources caters to various development and deployment scenarios.

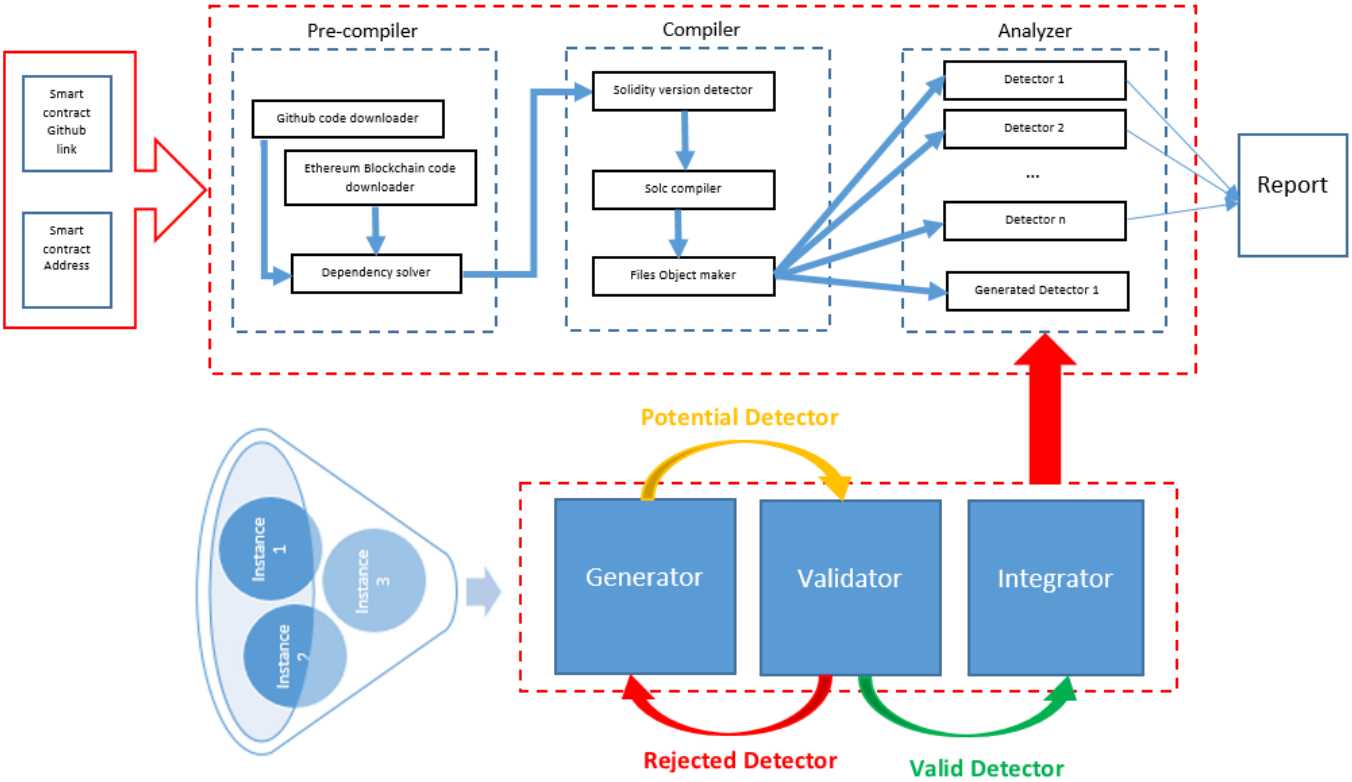

Figure 1. SmartLLMSentry Framework Design

Upon receiving the input Figure 1, the pre-compiler diligently undertakes the task of retrieving the specified codebase. This not only includes the primary smart contract but also extends to encompass all associated libraries, packages, and relevant code dependencies. The comprehensive inclusion of these elements ensures a self-contained and cohesive environment for subsequent compilation stages. The goal is to preemptively address any potential compilation challenges arising from dependencies, thereby enhancing the efficiency of the overall analysis process.

Moving forward, the compiler Figure 1, as the core processing unit, takes charge of the compilation process. Beyond the conventional compilation task, it plays a pivotal role in generating crucial artifacts that form the basis of subsequent analyses. Specifically, the compiler extracts both the Abstract Syntax Tree (AST) and the Control Flow Graph (CFG) from the compiled code. These representations provide a high-level abstraction of the smart contract's structure and the sequence of control flow, offering valuable insights into the code's intricacies.

The extracted AST and CFG, now enriched with semantic information, are then seamlessly transmitted to the static analyzer Figure 1. This component constitutes the heart of SmartSentry, employing static analysis techniques such as AST and control flow analysis and dataflow analysis. The static analyzer meticulously examines the received artifacts, conducting an in-depth analysis to detect potential security vulnerabilities. It scrutinizes the code for patterns indicative of common vulnerabilities, potential exploits, and deviations from best coding practices. The analyzer has been systematically designed with a focus on modularity, adhering to a structured approach that isolates each vulnerability's detection mechanism from others within SmartSentry. This deliberate separation of detectors ensures a modular and flexible architecture, facilitating seamless integration and scalability for future enhancements.

The segmentation of vulnerability detectors Figure 1 allows for targeted improvements or the addition of new detectors without necessitating extensive modifications to the existing framework. This design rationale is founded on the principle of providing an adaptable framework where individuals can effortlessly construct detectors tailored to specific vulnerabilities. Leveraging the built-in functionalities for AST analysis or dataflow analysis, stakeholders have the capability to construct specialized detectors in accordance with the unique requirements of distinct vulnerabilities. This modular design philosophy not only enhances the extensibility and versatility of the framework but also fosters a collaborative environment conducive to continual advancements in smart contract security analysis.

The second part is responsible for a continues and automated enhancement of the framework and it is also built upon 3 other components connected directly to the Analyzer Figure 1. Once a new vulnerability is detected in the wild, a number of vulnerable code instances are sent to the Generator. This component is responsible for creating detectors for specific vulnerabilities. It receives a set of instances representing a particular vulnerability and utilizes these instances to generate a detector tailored to identify that vulnerability. The generator is essential for producing initial candidate detectors based on real-world data, ensuring that the detectors are relevant and applicable to the specific vulnerabilities being addressed.

Following the generation of detectors, the validator assesses their performance by evaluating their accuracy using the same instances provided to the generator Figure 1. The validator is critical for ensuring the reliability of the detectors. If a detector achieves an accuracy rate below 80%, it is deemed inadequate and rejected. The generator is then tasked with producing a new detector to meet the accuracy threshold. This iterative validation process is vital for maintaining high-quality detection capabilities and preventing false positives or negatives.

Detectors that surpass the 80% accuracy threshold are accepted by the validator and subsequently passed to the integrator Figure 1. The integrator's role is to incorporate these validated detectors into the SmartSentry framework. This component ensures that new, high-performing detectors are seamlessly integrated into the existing system, enhancing the overall capability of SmartSentry. To facilitate debugging and maintenance, the integrated detectors are labeled with the term "generated," indicating their origin and allowing for easier identification and troubleshooting of any issues.

B. Prompt Design

This section outlines the prompts we have designed to improve ChatGPT's performance in detecting software vulnerabilities. For clarity, we denote each prompt as Px, where x represents the specific components of the prompt. Each component x will be detailed as we introduce and explain the corresponding prompt design for the first time.

TABLE I. LIST OF USED TRAINING PROMPTS

Code	Prompt
P_b	Write the if condition to detect this instruction.
P_{rb}	You are a smart contract security auditor. write the if condition to detect this instruction.
P_{rcb}	You are a smart contract security auditor. Using Solidity-ast and typescript, write the if condition to detect this instruction. The output should only contain the if condition.
P_{rcbi}	You are a smart contract security auditor. Using Solidity-ast and typescript, write the if condition to detect this instruction. The output should only contain the if condition. Keep in mind that The following ast structures could have different values depending on their nodeType: Expression.nodeType rightExpression.nodeType leftExpression.nodeType leftHandSide.nodeType rightHandSide.nodeType

1) Basic Prompting

Firstly, to conduct vulnerability detection via ChatGPT, it is essential to have a basic prompt (Pb). We use the following basic prompt in this study, and we ask ChatGPT to generate the require if condition that should be injected in SmartLLMSentry Analyzer component to be able to detect this vulnerability in any other source code.

Following OpenAI's gpt-best-practices document [10], we further propose the role-based basic prompt Prb to remind ChatGPT of its job (i.e., smart contract vulnerability detection) so that it focuses on the vulnerability issue:

As the generated if condition will be included into our previously developed framework, we needed to give more context information to gpt model to further optimize its output and focus only on the if condition.

2) Prompting with Auxiliary Information

In Solidity, the AST structure of multiple nodes can vary significantly based on the nodeType. Through extensive testing, we observed that ChatGPT does not consistently adhere to the correct Solidity AST structure. Therefore, we decided to incorporate additional information regarding the Solidity AST structure into our prompt. Specifically, we augmented the Prompt with auxiliary information about the AST structure of Solidity source code to improve its accuracy and reliability in generating and interpreting Solidity code.

IV. Dataset

To train our model and apply the prompts we developed, we required a suitable dataset. However, given that smart contract security is a relatively new field, and the vulnerabilities we selected are largely unexplored, we initially lacked the necessary data to train our model effectively. In this section, we explain the various steps involved in building the dataset and how we addressed the challenges encountered during the process. This includes our strategies for data collection, preprocessing, and augmentation, which were essential to overcoming the limitations of data scarcity in this emerging field.

A. Data Collection

The first step in developing our dataset involved collecting initial data from multiple sources. We gathered raw data from two primary repositories: GitHub and live smart contracts available on Etherscan. GitHub provided a valuable source of open-source smart contracts, while Etherscan offered insights into deployed contracts on the Ethereum network. This combination of sources allowed us to capture a diverse range of smart contracts and associated vulnerabilities.

To enhance and diversify our dataset, we implemented an additional strategy of injecting vulnerable code snippets into forged functions. By incorporating known vulnerabilities into these synthetic functions, we were able to artificially amplify the dataset and simulate various scenarios of interest. This approach not only increased the volume of data but also ensured that our dataset covered a broader spectrum of potential vulnerabilities, thereby enriching the training and testing phases of our model.

The dual approach of sourcing real-world data and augmenting it with synthetic examples enabled us to build a more comprehensive and robust dataset, addressing the challenges posed by the initial data scarcity in the field of smart contract security.

B. Data Pre-processing

In this study, we collected and utilized a dataset to train and evaluate our framework for detecting smart contract vulnerabilities through LLM prompt engineering. The data collection and preparation involved several critical steps to ensure the quality and effectiveness of our model.

First, we removed duplicate code snippets from the dataset to maintain its uniqueness and relevance. Given the constraints on input length imposed by ChatGPT, we carefully managed the size and format of our data. The dataset initially comprised 150 instances, which we divided into two subsets: 112 instances for training and 38 instances for testing. This partition allowed us to build and refine our model while reserving a separate set of data for rigorous evaluation.

Based on OpenAI's guidelines, which recommend a range of 50 to 100 instances for effective ICL, we structured our training data accordingly. We created two training groups: the first group included 100 instances, used to train the model initially. The second group comprised these 100 instances plus an additional 12 instances, totaling 112 examples, to investigate whether increasing the dataset size would improve the model's performance. The data was formatted into JSON Lines (JSONL) to ensure compatibility with ChatGPT’s input requirements. This format facilitated efficient data processing and integration with the model. By using this structured approach, we trained our model on the prepared data and evaluated its performance using the reserved test set.

V. Experimentation And Results Descussion

In this section, we report and analyze the experimental results inorder to answer the following research questions (RQ):

RQ1: Can ChatGPT generate valid detection code for specific vulnerabilities?

RQ2: How the amount of training data could affect the effectiveness of the model?

RQ3: Which version of chatgpt is best suited for smart contract vulnerability detection rule generation?

A. Experimental Settings

1) Finetunning Parameters

The ChatGPT fine-tuning platform provides several critical parameters that can significantly influence the model's final performance. Understanding and carefully configuring these parameters is essential for optimizing the model for specific tasks. The first parameter, Seed, is crucial for ensuring the reproducibility of the fine-tuning process. By setting a specific seed value, researchers can control the randomization involved in training, allowing for consistent results across different runs. The following tables present the different seeds used during our experimentation to reproduce the same exact results.

TABLE II. Seeds Used In Each Training For Dataset Size Of 100.

	Dataset size 100			
	Pb	***Prb***	***Prcb***	***Prcbi***
gpt3	184181018	1229186277	2050353472	1082851968
gpt4	1546849632	2143196420	1653381796	542758792

TABLE I. Seeds Used in Each Training for Dataset Size of 112

	Dataset size 112			
	Pb	***Prb***	***Prcb***	***Prcbi***
gpt3	317425969	1011665401	1553307650	294133873
gpt4	1692427035	1804209602	1109655604	956977286

The second parameter, **Batch Size**, determines the number of training examples used in one iteration of the model's learning process. A smaller batch size, enables the model to update more frequently, which can be beneficial for tasks requiring fine-grained adjustments. However, it also demands more computational resources and time. The third parameter, **Learning Rate Multiplier**, is a scaling factor applied to the base learning rate. This multiplier adjusts the speed at which the model learns during training. A higher learning rate multiplier, allows the model to converge more quickly, but it also risks overshooting the optimal solution, leading to suboptimal performance. Lastly, the **Number of Epochs** represents the total number of times the model will cycle through the entire training dataset. Setting the number of epochs to higher value indicates that the model will undergo multiple training cycles, helping it generalize better by repeatedly learning from the dataset.

Initial experiments indicate that the optimal configuration for our use case includes setting the number of epochs to 3, the batch size to 1, and the learning rate multiplier to 2. This configuration has shown to produce the best results in terms of model performance and accuracy in our specific application.

2) Used GPT versions

In our study, we have compared ChatGPT models effectiveness:

- gpt-3.5-turbo-1106
- gpt-4o-mini-2024-07-18

The choice of gpt models comes from the a scientific research performed by Wenpin et al. [64] that has clearly shown that Chatgpt outperform all the existing LLM models both opensource and closed source solutions in code generation.

3) Evaluation Metrics

To evaluate the effectiveness of our LLM models, we will use the Exact Match (EM), which is a commonly used metric to evaluate the effectiveness of an LLM model in generating valid code. However, we define the Exact match of two code snippet as the situation where both code has the exact same logic or the exact same syntax.

$$\text{Exact Match (EM)} = \frac{\text{Number of Exact Matches}}{\text{Total Number of Examples}} \text{x100}$$

Number of Exact Matches: Count the number of generated code snippets that exactly match the expected output code snippets.

Total Number of Examples: The total number of code snippets evaluated.

The total number of examples in our experimentation test inputs is **38**.

Here are the results of our experimentations:

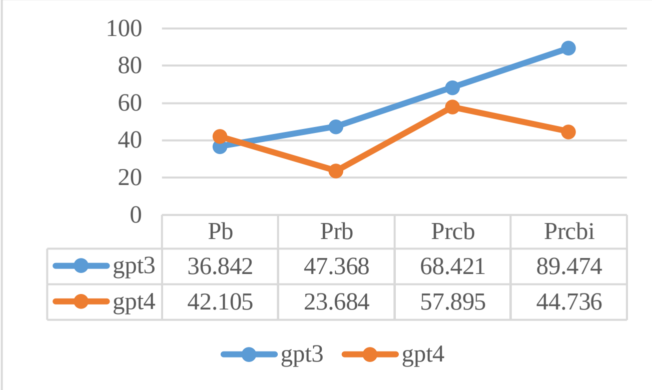

Figure 1. EM of both trained models with different Prompts and 100 dataset inputs.

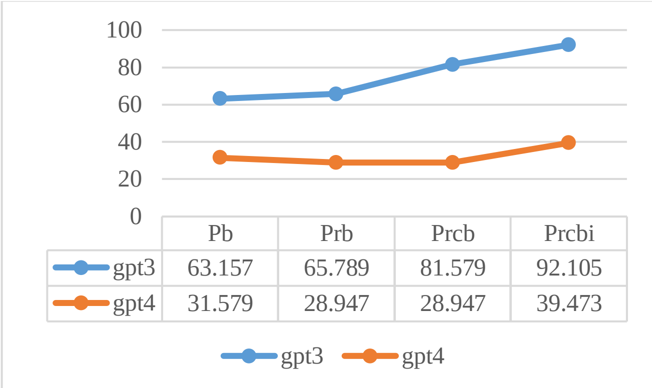

Figure 2. EM of both trained models with different Prompts and 112 dataset inputs.

The results presented in Figures 2 and 3 illustrate the performance of GPT-3 and GPT-4 in terms of EM accuracy across different dataset sizes and prompt types. In Figure 2, which evaluates the models with a dataset of 100 instances, GPT-3 achieved an EM score of 36.8% for prompt type Pb, 47.4% for Prb, 68.4% for Prcb, and 89.5% for Prcbi. In contrast, GPT-4's EM scores were lower, with 42.1% for Pb, 23.7% for Prb, 57.9% for Prcb, and 44.7% for Prcbi.

Figure 3 shows the results for a larger dataset of 112 instances. GPT-3's performance improved significantly, achieving EM scores of 63.2% for Pb, 65.8% for Prb, 81.6% for Prcb, and 92.1% for Prcbi. Conversely, GPT-4's performance was notably poorer, with EM scores of 31.6% for Pb, 28.9% for Prb, 28.9% for Prcb, and 39.5% for Prcbi.

B. Effectiveness of finetunned GPT models (RQ1)

The data reveal that GPT-3 consistently outperforms GPT-4 across all prompt types and dataset sizes. Even with additional training data, GPT-4's performance did not improve and, in fact, declined, suggesting that simply increasing the dataset size did not enhance its accuracy. Notably, GPT-4 did outperform GPT-3 with a dataset of 100 instances and a basic prompt. Nevertheless, under the specific experimental conditions and dataset configurations employed, GPT-3 exhibited superior exact match accuracy compared to GPT-4. This indicates that GPT-3 is more effective at leveraging available data to produce accurate results, while GPT-4 may need further refinement or adjustment to improve its performance.

C. The training data volum impact (RQ2)

The impact of increasing the training dataset on both GPT-3 and GPT-4 models is evident from the data provided. With a dataset of 100 instances, GPT-4 achieved higher EM accuracy compared to GPT-3 for a basic prompt. However, when the dataset size was increased to 112 instances, GPT-3's EM scores improved significantly across all prompt types and reached 92,1% EM, demonstrating its ability to effectively utilize more data for enhanced accuracy. In contrast, GPT-4's performance deteriorated with the larger dataset, as evidenced by lower EM scores across all prompt types. This decline suggests that simply increasing the dataset size did not benefit GPT-4's performance and may have revealed or exacerbated existing limitations within the model. These findings indicate that while GPT-3 showed a positive correlation between dataset size and performance, GPT-4's effectiveness was negatively impacted by the additional data.

D. The most suitable version? (RQ3)

Based on the results obtained from our experimentation, GPT-3 is the most suitable model for our use case, particularly when additional data is available during the training phase. The data demonstrate that GPT-3 consistently outperforms GPT-4 in terms of EM accuracy across various prompt types and dataset sizes. With a larger dataset, GPT-3's performance improved significantly, showcasing its ability to leverage additional data effectively to enhance accuracy. In contrast, GPT-4's performance declined with increased dataset size, indicating that it may have limitations in handling larger datasets or may require further optimization to achieve comparable results.

Given these observations, GPT-3's superior performance and its positive response to increased data make it a better fit for scenarios where extensive training data can be utilized. GPT-4, while initially promising, did not demonstrate the same level of robustness or improvement with additional data, making GPT-3 the preferred choice for our specific use case.

VI. Threats of Validity

A. Version of ChatGPT

The results presented in this paper are based on experiments conducted with two specific versions of ChatGPT. Given that ChatGPT is an actively evolving platform, it is important to acknowledge that the findings and conclusions drawn here are limited to the performance characteristics of these particular versions. As OpenAI continues to update and refine ChatGPT, subsequent versions may exhibit different behaviors, capabilities, or performance metrics. Therefore, the conclusions drawn from this study might not be applicable to future iterations of the model or to older versions that were not assessed in our experiments.

Updates to the model may include improvements in architecture, training techniques, or data handling, which could significantly alter performance outcomes. Consequently, findings relevant to the versions tested in this study may become outdated or inaccurate as newer versions are released. Similarly, insights derived from the tested versions might not fully account for changes that could affect the model's effectiveness in different contexts or applications.

B. Different Solidity parser library

Another significant threat to the validity of this study arises from the reliance on a specific Solidity parser library for analyzing smart contracts. The choice of parser can substantially influence the accuracy and completeness of the contract analysis due to variations in the implementation and features of different parser libraries.

In this study, we used a particular Solidity parser library called "solidity-ast-0.4.52" to process and analyze the smart contracts. However, there are several other available Solidity parser libraries, each with its own methodologies for parsing and interpreting Solidity code. These libraries may differ in their handling of syntax, support for various Solidity versions, and the extent of features they offer. Consequently, the results obtained using one parser might not be directly comparable to those obtained with another.

C. Vulnerability Types

A notable threat to the validity of our results is the limited focus on only five specific types of vulnerabilities, chosen randomly. While these types provided valuable insights into ChatGPT's performance, the model's effectiveness might vary with different vulnerabilities. Given the diverse nature of smart contract vulnerabilities, including reentrancy attacks, integer overflows, and other issues, ChatGPT's performance could differ significantly when applied to other types not covered in this study. The model may show better results with vulnerabilities that align more closely with its training data or prompt design. Conversely, novel or complex vulnerabilities could present challenges not captured by our selected types. Therefore, while our findings are informative, future research should explore ChatGPT's performance with a broader range of vulnerabilities to assess its robustness and adaptability across different types.

VII. Conclusion

LLMs with advanced capabilities have made substantial impacts across various domains. This paper investigates the effectiveness of prompt-enhanced ChatGPT for detecting vulnerabilities in smart contracts, a crucial aspect for ensuring blockchain security and fostering trust. We developed several specialized prompts for vulnerability detection, incorporating additional contextual information, and focused on five types of vulnerabilities that, to our knowledge, had not been previously explored in the scientific literature. These vulnerabilities were selected randomly to minimize bias, and a dataset was constructed for both training and testing the model.

Our findings indicate that the trained model achieves a high accuracy rate of 91.1% in exact match scenarios when provided with sufficient information. However, the results also reveal that GPT-4 is less effective for our specific use case compared to GPT-3, with GPT-4 showing reduced accuracy in generating detection rules, even with an increased dataset.

While the results are promising and demonstrate the potential of LLMs and in-context training for vulnerability detection, further improvements are necessary. The current model's generated rules are not fully automated in the framework and still require some expert intervention. Future research will aim to explore additional types of vulnerabilities to further evaluate and enhance the model's effectiveness in diverse contexts.

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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.

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

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The Relationship Between Avatar Identification Factors and Vicarious Pleasure: The Moderating Role of Affect Intensity in the Metaverse

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***Abstract*— This study investigated the connection between avatar identification factors, sharing intentions, and the influence of vicarious pleasure. Additionally, it explored the moderating effect of affect intensity on this relationship. For this, data was collected from 228 college students in South Korea through a survey. This study used hierarchical regression. The findings revealed several key points. Firstly, participants who perceived greater similarity identification, wishful identification, and embodied presence in their avatars within the metaverse platform reported higher satisfaction with their avatars. Secondly, participants who experienced a higher sense of embodied presence in their avatars were more inclined to share their avatars due to the vicarious pleasure they derived from it. Lastly, the positive correlation between perceived embodied presence and vicarious pleasure was stronger for participants with higher affect intensity in the metaverse platform. This study is the first to examine the integral model of avatar identification factors in the metaverse platform.**

***Keywords*— Avatar identification, similarity identification, wishful identification, embodied presence, vicarious pleasure, affect intensity, intention to share**

I. Introduction

Due to the spread of COVID-19, the concept of "untact" has become a common part of our daily lives. This involves non-face-to-face interactions, with schools and companies replacing traditional classes and workspaces with online and telecommuting options. With the rise of the fourth industrial revolution, new technologies such as artificial intelligence and virtual reality have further infiltrated our daily lives, providing highly advanced non-face-to-face environments. These technologies are leading the way in the development of the metaverse, which is a 3D virtual world that allows people to engage in everyday and economic activities through avatars. The metaverse is an extension of the real world, and it represents a transcendent reality where people can interact in a virtual space [1, 2].

Metaverse users view their avatars as equals to themselves and indirectly participate in avatar activities [3]. Fashion-sensitive users consume a variety of fashion items and express their characteristics through avatars, forming virtual communities and blurring the boundaries between reality and virtuality [4, 5]. To increase user awareness and drive product sales, companies are developing strategies to offer a variety of metaverse experiences that encourage users to share their experiences with others [6, 7]. To understand the potential and usability of the metaverse, it is essential to understand the metaverse from the user's perspective. Avatars are an important element of the metaverse, and user perceptions of avatars are considered important in forming attitudes toward the metaverse, such as vicarious enjoyment [8].

Theoretical understanding of avatars in the context of the metaverse includes social psychology and identity formation perspectives [9], cultural studies and representation perspectives [10], and marketing and consumer behavior perspectives [11]. In particular, the psychology of users who intend to share their avatars in the Metaverse is also very important in terms of Metaverse's marketing. However, there is a lack of research in this area.

With this theoretical perspective, this study aims to examine how users react to avatar identification when utilizing branded items in the metaverse. The study focuses on identifying the factors that influence avatar identification and how they impact vicarious pleasure experienced by users. Additionally, the study aims to examine how vicarious pleasure mediates the connection between avatar identification and the intention to share avatars. Lastly, since communication is a crucial aspect of the metaverse such as Second Life, Minecraft, World of Warcraft, etc, the study explores how users' affect intensity affects the relationship between avatar identification and vicarious pleasure.

II. Theoretical Background and Hypothesis Development

A. Metaverse and avatars

The integration of advanced information and communication technology and virtual implementation technology into the metaverse is transforming it into a space where consumers can engage in daily, economic, and cultural activities, driving innovation [12, 13]. Retail companies are interested in understanding the metaverse to stay competitive, and research in this area has expanded from exploring the initial concept of the metaverse to investigating new conceptualizations, case studies, and marketing applications based on technological advancements. As the ecosystem of the metaverse grows, it is replacing a part of daily life and is considered an extension of reality. The metaverse is defined as an expansive fusion world that combines real and virtual spaces through realistic technology [12]. It is a three-dimensional virtual space where avatars engage in creative,

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economic, and interactive activities [14], and is distinct from the comprehensive cyberspace that reflects all online activities, as it allows for value creation through social, economic, and cultural activities [13].

According to Forster [15], avatars were originally represented in various forms such as animals, humans, and abstract shapes. However, as online interactions became more diverse and to facilitate smooth communication between people, avatars became popularized in a more human-like form. Nowak and Rauh [16] define an avatar as a computer-generated image that represents a user in online interactions. Users of metaverse platforms often decorate their avatars to reflect their physical appearance and fashion style [12], as they tend to express themselves through their avatar's appearance and fashion style to gain favor [17]. While avatars may reflect a user's actual appearance, they can also be represented differently from reality to allow for deviation or vicarious satisfaction [18]. Zepeto, a metaverse platform, recognizes the user's face through a camera to create an avatar similar to their actual appearance but also allows for modification of features such as appearance, gestures, and fashion to create unique avatars. Fuschillo et al. [19] found that users with positive emotions tend to create avatars that reflect their actual appearance, considering them as mascots that reflect themselves. In contrast, users who seek to escape from the monotony of daily life tend to express their avatars in an idealized form, as mascots that represent their ideal self-image. Avatars thus fulfill the desire for anonymity in cyberspace and the desire to reveal oneself [12], with users forming a deep attachment to their avatars and considering them as part of themselves, resulting in a sense of identity [20].

B. Hypotheses development

Identification is the act of comprehending and empathizing with a situation from someone else's viewpoint [21]. A person can achieve identification by creating both cognitive and emotional connections with a particular object, which creates a feeling of identification [22]. They can also perceive themselves as actively participating in the object's situation, resulting in complete engagement [23]. Recent studies examining identification in media suggest that the factors that contribute to an individual's perception of identification can be divided into three categories: similarity identification, wishful identification, and embodied presence [24].

People can experience satisfaction through vicarious experiences of objects that they cannot achieve directly, as noted by [25]. This positive reaction to indirect experiences is referred to as vicarious satisfaction, and it has been suggested that user-avatar identification is an important condition for users to experience vicarious satisfaction [26]. When users identify with objects in the media, they internalize the object's goals, feel a sense of realism in the object's challenges, and experience vicarious satisfaction in the object's rewards [26]. Media viewers who emotionally identified with celebrities were able to vicariously satisfy their desires through media consumption and had a positive attitude toward vlogs [27]. Van Looy et al. [28] argued that user-object identification through similarity can enhance the perception of vicarious experience and create intimacy. Vicarious satisfaction is measured by what reality show viewers feel toward non-celebrity participants and how viewers strongly perceive the experience of non-celebrity participants and experience vicarious satisfaction by identifying with similar non-celebrities [37].

Examining prior research on the desire for identification and surrogate satisfaction, Hefner et al. [29] claimed that when identification occurs through the desire for similarity, users experience positive emotions by indirectly experiencing the idealized features of the target. Users feel surrogate satisfaction when they decorate their avatars to reflect their desired appearance [30]. When a metaverse user's avatar reflects an ideal image, it provides a low-cost way to fulfill their dreams, resulting in surrogate satisfaction [31]. Previous studies suggest that virtual reality users experience vicarious satisfaction by identifying with the target as if they were one entity [32]. The target's movement and high interaction produce a sense of physical coherence, leading the user to mistake themselves as being present in a specific situation [28]. Furthermore, indirect vicarious experience is enhanced when a digital environment provides a multisensory experience [26]. User reactions to avatar manipulation found that as the interaction between the user and the game increases, the user considers their avatar as a surrogate existence and experiences vicarious satisfaction [33]. Based on these findings, we hypothesize that external embodiment, desire for identification, and presence will positively influence vicarious satisfaction.

H1: Similarity identification will have a positive (+) effect on vicarious pleasure.

H2: Wishful identification will have a positive (+) effect on vicarious pleasure.

H3: Embodied presence will have a positive (+) effect on vicarious pleasure.

According to Zhang et al. [34], individuals tend to share positive or negative aspects of their purchasing experiences with friends and acquaintances. With the increasing variety of communication channels such as social media, people are now able to share information more easily than before [35]. The behavior of sharing information, which has a great influence on other people's product purchase decisions, is continuously addressed in the IT and marketing fields [36], and vicarious satisfaction is suggested as a leading factor. The objective of this research is to examine how avatar identification impacts the intention to share. Previously, a hypothesis was posited that the identification of avatars would enhance the level of vicarious pleasure. The present study aims to investigate whether vicarious pleasure mediates the relationship between avatar identification and intention to share.

People perceive vicarious experiences through others positively, leading to vicarious satisfaction, positive evaluation of the experience, and intentions to engage in future behaviors [37]. Previous studies have shown that when users of media content experience vicarious satisfaction, it positively influences word-of-mouth intentions through attitudes and satisfaction towards the content [38]. Vicarious satisfaction experienced through avatars in live broadcasting positively influenced word-of-mouth intentions [39]. Therefore, in this study, it is argued that vicarious pleasure based on empathy and positive response will affect positive intention to share. This study previously hypothesized that avatar identification would have a positive effect on vicarious pleasure. Furthermore, the study contends that vicarious pleasure would positively influence the intent to share. Considering the foregoing discussion, this paper suggests that vicarious pleasure will serve as a mediator between avatar identification and the intention to share.

H4: Vicarious pleasure will have a mediating effect on the relationship between similarity identification and the intention to share avatars.

H5: Vicarious pleasure will have a mediating effect on the relationship between wishful identification and the intention to share an avatar.

H6: Vicarious pleasure will have a mediating effect on the relationship between embodied presence and the intention to share avatars.

Furthermore, this study endeavors to explore the possibility of diverse effects of avatar identification on vicarious pleasure, contingent on the characteristics of users, through an exploratory investigation. Affect intensity refers to the strength of emotional responses individuals experience in reaction to emotional stimuli. Larsen [40] introduced this concept and developed a measurement tool for it. Affect intensity is a personal trait that indicates how intensely individuals experience emotions toward a specific object. Groups with high and low affect intensity react differently to the same emotional stimulus, with high groups consistently exhibiting stronger affective responses. Early studies on affect intensity focused on its conceptual independence, validity, and reliability [42]. Larsen et al. [42] analyzed the differences between high and low affect intensity groups in response to positive and negative emotional stimuli. Individuals with high affect intensity experienced stronger emotional responses to both positive and negative stimuli than those with low affect intensity. They also tended to be more friendly, active, alert, and emotionally responsive. Larsen & Diener [43] examined self-reported affect intensity and compared evaluation values from colleagues and high school. Since its introduction, affect intensity has been studied in many fields such as psychology, marketing, and advertising. Understanding users' affective responses is crucial in understanding consumer behavior, especially in affective products such as games.

In the metaverse, users with higher levels of emotional reactivity tend to feel a stronger emotional connection with their avatars, which plays a crucial role in increasing their sense of feeling in the virtual world [44]. This emotional connection is largely influenced by the user's perception of similarity with their avatar. Emotionally reactive users feel a greater sense of empathy with their avatar, and this empathy has a positive impact on their sense of presence and satisfaction. Therefore, if emotionally reactive users perceive a greater similarity with their avatars, it can have a positive effect on their sense of presence and satisfaction in the metaverse, ultimately making their experience more enjoyable and satisfying.

Moreover, people generally prefer avatars that resemble themselves, which is related to their sense of identity [45]. Emotionally reactive users are also more likely to form a stronger identity connection with their avatars, which enhances their self-confidence and positive self-image, leading to greater satisfaction with their virtual identity. Therefore, when emotionally reactive users tend to create avatars that resemble themselves, it is likely to have a positive impact on their sense of presence and satisfaction, ultimately enhancing their experience of identity in the metaverse.

In addition, embodied presence refers to the feeling of existence that users experience through their avatars in the metaverse. This feeling creates a sense of actually being present in the virtual world, which can contribute to users' satisfaction with their virtual identity. Especially for emotionally reactive users, their avatars can provide a stronger sense of embodied presence, which can further enhance their sense of presence and satisfaction in the metaverse. Therefore, it can be argued that emotionally reactive users in the metaverse are more likely to experience a higher sense of embodied presence through their avatars, ultimately contributing to their sense of satisfaction and well-being. Therefore, in this study, the affect intensity of metaverse service users is also intended to examine the moderating effect between avatar identification and vicarious pleasure.

H7: The influence of similarity identification that users perceive on vicarious pleasure will depend on users' level of affect intensity.

H8: The influence of wishful identification that users perceive on vicarious pleasure will depend on users' level of affect intensity.

H9: The influence of embodied presence that users perceive on vicarious pleasure will depend on users' level of affect intensity.

The research model of this study is presented in Figure 1.

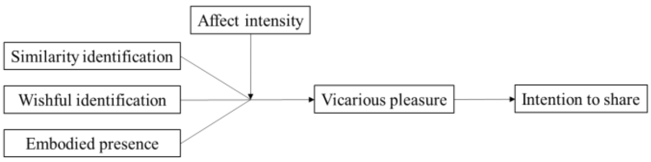

FIGURE I. RESEARCH MODEL

III. METHODOLOGY

A. Sample

This study sample consists of 228 college students with previous experience engaging in metaverse platforms such as Second Life, Minecraft, World of Warcraft, etc. The sample consists of undergraduate and graduate students in business, social science, and engineering programs in Korea. The criteria for participation in the study include past engagement in the metaverse and a minimum age of 18 years. Though the sample is considered one of convenience, college students represent a significant subset of a major participant's segment that focuses on active users.

B. Data collection and instrumentation

The study's objective was to identify the connection between avatar identification factors, sharing intentions, and the influence of vicarious pleasure. Additionally, it explored the moderating effect of affect intensity on this relationship. These factors can be identified by measuring the participants' perceptions of metaverse platforms. The survey research method is very useful in collecting data from many individuals in a relatively short period and at a lower cost. Hence, for the current study, the questionnaire survey was used for data collection. All participants received a paper-and-pencil questionnaire with an accompanying letter that explained the purpose of the survey, emphasized voluntary participation, and guaranteed confidence. Participants were asked to fill out the questionnaire and put it back into an envelope collected by the researcher.

The questionnaire employed psychometric measurement [46]. Similarity identification was measured using six items from the scale developed by Van Looy et al. [28]: "The appearance and behavior of my Zepeto avatar seem to be similar to that of my real-life self." Wishful identification was measured using five items from the scale developed by Van Looy et al. [28]: “It would be desirable if I could become like my Zepeto avatar in appearance.” Embodied presence was measured using six items from the scale developed by Van Looy et al. [28]: “I feel like my Zepeto Avatar within Zepeto.” Affect intensity was measured using twenty items from the scale developed by Larsen et al. [40]: "I get upset easily." Vicarious pleasure was measured using five items from the scale developed by Yang [47]: “I am happy to see the various experiences of avatars in Zepeto and feel vicarious satisfaction.” Intention to share avatars was measured using five items from the scale developed by Zhang et al. [34]: “I am planning to share my Zepeto avatar, which is adorned with fashion brand items, on social media.”.

IV. RESULTS

A. *Verification of reliability and validity*

The validity of variables was verified through the principal components method and factor analysis with the varimax method. The criteria for determining the number of factors is defined as a 1.0 eigenvalue. This study applied factors for analysis only if the factor loading was greater than 0.5 (factor loading represents the correlation scale between a factor and other variables). The reliability of variables was judged by internal consistency as assessed by Cronbach's alpha. This study used surveys and regarded each as one measure only if their Cronbach's alpha values were 0.7 or higher.

B. *Common method bias*

As with all self-reported data, there is the potential for the occurrence of common method variance (CMV) [48]. To alleviate and assess the magnitude of common method bias, this study adopted several procedural and statistical remedies that Podsakoff et al. [49] suggest. First, during the survey, respondents were guaranteed anonymity and confidentiality to reduce the evaluation apprehension. Further, we paid careful attention to the items' wording and carefully developed our questionnaire to reduce the item ambiguity. These procedures would make them less likely to edit their responses to be more socially desirable, acquiescent, and consistent with how they think the researcher wants them to respond when answering the questionnaire [49]. Second, this study conducted Harman's one-factor test on all of the items. Principal components factor analysis revealed that the first factor only explained 34.9 percent of the variance. Thus, no single factor emerged, nor did one factor account for most of the variance.

Furthermore, the measurement model was reassessed with the addition of a latent common method variance factor [49]. All indicator variables in the measurement model were loaded on this factor. The common variance factor's addition did not improve the fit over the measurement model without that factor with all indicators remaining significant. These results do suggest that common method variance is not of great concern in this study.

C. *Relationship between variables*

Table 1 summarizes the Pearson correlation test results between variables and reports the degree of multi-collinearity between independent variables. The minimum tolerance of 0.832 and the maximum variance inflation factor of 1.202 show that the data analysis's statistical significance was not compromised by multi-collinearity.

TABLE I. VARIABLES' CORRELATION COEFFICIENT

	1	2	3	4	5
Similarity identification	1				
Wishful identification	-.033	1			
Embodied presence	.082	.031	1		
Affect intensity	.029	.024	.011	1	
Vicarious pleasure	.034**	.013**	.013**	.031*	1
Intention to share	.038*	.022*	.017**	.051**	.013**

*$p < .05$, **$p < .01$

D. *Hypothesis testing*

First, the effect of avatar identification on vicarious pleasure was analyzed. As shown in Table 2, as a result of first introducing demographic variables, it was found that sex is negatively related to vicarious pleasure (β = -.065, p < .01).

TABLE II. ANALYSIS RESULTS ON THE IMPACT OF AVATAR IDENTIFICATION ON VICARIOUS PLEASURE

	Vicarious pleasure	
	Model 1	Model 2
Sex	-.065*	-.053*
Age	-.026	-.014
Educational level	.023	.011
Similarity identification		.072**
Wishful identification		.054**
Embodied presence		.031**
Adj. R^2	.101	.142
F	4.613**	8.881**

*$p < .05$, **$p < .01$

In model 1, sex was coded as 1 for men, so the analysis results show that women are more likely to fall into vicarious pleasure than men. Second, in model 2, as a result of inputting three variables of avatar identification, it was found that all three variables of similarity identification (β = .072, p < .01), wishful identification (β = .054, p < .01), and embodied presence (β = .031, p < .01) had a positive effect on vicarious pleasure. Hypotheses 1, 2, and 3 were supported.

Second, to ensure that vicarious pleasure mediates the relationship between each of the variables of avatar identification, Baron & Kenny’s [50] steps for establishing mediation were followed. First, in model 1 of Table 3, all three variables of avatar identification should be correlated to share. As a result of the analysis, similarity identification (β = .051, p < .01), wishful identification (β = .034, p < .01), and embodied presence (β = .033, p < .01) have a positive effect on the intention to share. Second, in model 2 of Table 3, it was determined that all three variables of avatar identification are related to vicarious pleasure. This relationship is shown by the analysis results for the verification of hypotheses 1, 2, and 3 above. Third, in model 3 of Table 3, when similarity identification, wishful identification, and embodied presence were then entered into the model, vicarious pleasure was found to be positively related to the intention to share avatars, and some paths were statistically insignificant or other path coefficients decreased. As a result of the analysis, vicarious pleasure (β = .021, p < .01) was found to have a positive effect on intention to share. Among the variables of avatar identification, the effect coefficient and significance level of embodied presence decreased after vicarious pleasure was introduced (β = .018, p < .05). Thus, as shown in Table 3, there is sufficient empirical support to conclude that vicarious pleasure mediates the relationship between avatar identification variables and intention to share. On the other hand, vicarious pleasure did not mediate the relationship between other variables of avatar identification and intention to share. Therefore, only H6 was supported.

TABLE III. ANALYSIS RESULTS ON THE MEDIATING EFFECT OF VICARIOUS PLEASURE IN THE RELATIONSHIP BETWEEN AVATAR IDENTIFICATION AND INTENTION TO SHARE AVATAR

	Intention to share avatar		
	Model 1	Model 2	Model 3
Sex	-.071*	-.045*	-.029*
Age	-.042	-.038	-.023
Educational level	.071	.056	.047
Similarity identification		.051**	.031
Wishful identification		.034**	.021
Embodied presence		.033**	.018*
Vicarious pleasure			.021*
Adj. R^2	.091	.124	.154
F	4.001**	7.451**	9.851**

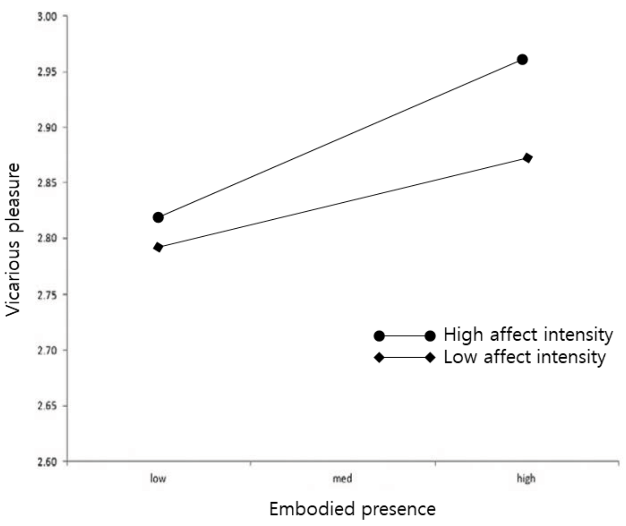

FIGURE 2. INTERACTION EFFECT

Lastly, model 3 of Table 4, consisting of moderators, shows the interactions between avatar identification variables and affect intensity on vicarious pleasure. Affect intensity positively affected the relationship between embodied presence and vicarious pleasure (β = .022, p < .01). Affect intensity was found to have no significance in the relationship between other variables of avatar identification and intention to share avatar (see Figure 2). Therefore, only H9 was supported.

TABLE IV. ANALYSIS RESULTS ON THE MODERATING EFFECT OF AFFECT INTENSITY IN THE RELATIONSHIP BETWEEN AVATAR IDENTIFICATION AND VICARIOUS PLEASURE

	Vicarious pleasure		
	Model 1	Model 2	Model 3
Sex	-.065*	-.053*	-.023*
Age	-.026	-.014	-.001
Educational level	.023	.011	.022
Similarity identification		.072**	.061**
Wishful identification		.054**	.036**
Embodied presence		.031**	.028**
Affect intensity			.014**
Similarity identification * Affect intensity			.022
Wishful identification * Affect intensity			.012
Embodied presence * Affect intensity			.022*
Adj. R^2	.101	.142	.194
F	4.613**	8.881**	12.665**

V. CONCLUSION

A. Discussion

The purpose of this study is to investigate the effect of avatar identification on the intention to share. To identify this relationship of influence, this study analyzed whether vicarious pleasure mediated the relationship between avatar identification and intention to share avatars and whether affect intensity regulated the relationship between avatar identification and vicarious pleasure. As a result of the analysis, first, similarity identification, wishful identification, and embodied presence, which represent avatar identification, all had a positive relationship with vicarious pleasure. That is, as expected, the more the user is similar to the avatar, wants to resemble the avatar, or has a greater sense of reality through the avatar, the more satisfied the user is with the avatar.

Second, among sub-variables representing avatar identification, only embodied presence increased the intention to share avatars through vicarious pleasure. On the other hand, the other two sub-variables had no mediating effect of vicarious pleasure for the intention to share. "Embodied presence" means that the user has direct control over their avatar, and their movements and actions are transmitted to the avatar. This makes the user's avatar feel more real, thus helping the user feel a real presence in the virtual world. This promotes "vicarious pleasure", which makes the user more satisfied in the virtual world. Thus, "embodied presence" can help increase users' intention to share their avatars. On the other hand, "similarity identification" and "wishful identification" mean that the user feels similar to their avatar, or that the avatar represents the state they would like to be in. These variables can strengthen the emotional connection between users and their avatars but do not directly influence users to increase their intention to share avatars in the virtual world. The reason for this is that "similarity identification" and "wishful identification" are related to the user's personal needs and self-identification. These factors may not be appropriate material to share with other users. On the other hand, an "embodied presence" is better for interacting more directly with other users, so it can be material that can be easily shared with other users.

Lastly, affect intensity positively moderates the influence relationship between embodied presence and vicarious pleasure among variables representing avatar identification. In other words, the more emotionally responded people are, the more satisfied they are with the realism of the avatar. Users with a higher level of emotional response in the metaverse can increase their vicarious satisfaction with the embodied presence they feel through their avatars than users who do not, which can have a positive effect. On the other hand, "similarity identification" and "wishful identification" are elements that allow you to be more satisfied in the virtual world through an avatar that is similar to you or wants to be you. Thus, these factors do not change their impact on vicarious pleasure in virtual worlds regardless of affect intensity. These results show that the various factors that increase vicarious pleasure in virtual worlds can act in different ways.

B. Research contributions and practical implications

For research contribution, this study is the first to examine the integral model of avatar identification factors in the metaverse platform. Despite growing practical importance, few quantitative studies on avatar identification factors affect participants' intentions to share. Given this situation, this study focused on participants' vicarious pleasure in the relationship between avatar identification and intention to share. This study shows that people who feel an embodied presence with an avatar want to share their avatars through their vicarious pleasure.

Second, this study is the first to investigate the moderating effect of affect intensity on the relation between avatar identification and vicarious pleasure in the metaverse. The results show that since people, who have more affect intensity, feel a more embodied presence through their avatar in the metaverse platform than any others, they are more satisfied in their avatar. Therefore, this study extends the metaverse study's scope by suggesting the study of the moderating effect on the relationship between avatar identification factors and vicarious pleasure.

Third, the findings of this study have the potential to enhance our theoretical understanding of the utilization, perception, and marketing of avatars in the metaverse. This, in turn, can inform the creation of more immersive and socially impactful virtual experiences. In particular, this study conducted a theoretical and empirical investigation into the role of avatars in the metaverse from the perspectives of identity formation from a social psychology perspective, self-expression from a cultural studies perspective, and marketing and consumer behavior.

For practical implications, first, the findings of this study highlight the importance of avatar identification in enhancing the intention to share avatars in the metaverse. Metaverse platform managers should focus on creating an environment where participants can experience similarity identification, wishful identification, and embodied presence with their avatars. One way to achieve this is by implementing a reputation system that rewards active participants with points or other incentives based on their interactions and contributions within the platform. This can encourage users to engage more deeply with their avatars and feel a stronger sense of identification with them. Additionally, the study reveals that the participants' affect intensity plays a significant role in enhancing the impact of embodied presence on vicarious pleasure. Metaverse platform managers should monitor and assess the effect intensity of participants based on their evaluation records. Those who exhibit high levels of activity in evaluating avatars are likely to experience higher affect intensity. Therefore, it is important to provide these users with opportunities to enhance their embodied presence in the metaverse, as this can lead to a greater sense of vicarious pleasure. In summary, metaverse platform managers should focus on promoting avatar identification and enhancing embodied presence to improve user experience and increase engagement. By understanding the factors that influence these aspects, managers can design more effective strategies to create a more immersive and enjoyable metaverse environment for their users.

Second, the results of this study offer specific solutions for leveraging the Metaverse as a marketing tool. For practical application, the study underscores the significance of avatar identification and examines, both theoretically and empirically, its role in fostering sharing intentions in the metaverse. Metaverse platform managers should concentrate on establishing an environment where participants can identify similarities with avatars, aspire to them, and feel physically present. One approach to achieve this physical presence is by implementing a reputation system that rewards active participants with points or other incentives based on their interactions and contributions within the platform. This can enable users to form deeper connections with their avatars and experience a stronger sense of identity. Furthermore, the study highlights the pivotal role of participants' emotional intensity in amplifying the impact of physical presence on virtual enjoyment. Metaverse platform managers should monitor and assess the strength of participants' influence based on their reputation records. Individuals demonstrating higher levels of activity in avatar reputations are likely to experience greater emotional intensity. Therefore, providing these users with opportunities to enhance their physical presence in the metaverse is crucial. This will enable them to experience greater pleasure. In conclusion, Metaverse platform administrators can enhance user experience and boost engagement by facilitating avatar identification and augmenting the sense of physical presence. By comprehending the factors influencing these aspects, managers can devise more effective strategies for their users.

C. Limitations and future research directions

This study applies a robust methodological approach to explore a new area, yet there remain opportunities for enhancement. While the findings offer several insights into participants' avatar identification in the metaverse, the following limitations should be acknowledged. First, as this research collected data from university students in South Korea, cultural differences may influence the findings. Future studies should consider expanding the sample to diverse countries and populations to enhance the reliability of these results. Second, given that all variables were measured simultaneously, it is uncertain whether their relationships are consistently stable over time. Although the survey questions were presented in reverse order from the analysis model to mitigate potential issues, causal relationships among the variables cannot be fully ruled out. Thus, future research should consider conducting longitudinal studies to investigate long-term relationships between these factors.

Moreover, this study examined perceived similarity identification, wishful identification, and embodied presence as avatar identification factors, with vicarious pleasure as a mediator and social distance as a moderator. However, considering the multifaceted characteristics of the metaverse, including additional moderating factors could further strengthen the study's academic and practical impact. For instance, platform sustainability may serve as an intrinsic motivation factor, while economic benefits could act as an extrinsic motivator. Additionally, social identity aspects, such as the interdependent self-view perceived by platform participants, may function as significant moderating factors.

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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.

CONFLICT OF INTEREST

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

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

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Software-Defined Metaverse (SDM) Architecture

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***Abstract*— The metaverse, a vast virtual shared space that integrates enhanced physical reality with persistent virtual environments, has the potential to revolutionize digital interaction by providing deeply immersive and interactive experiences. Leveraging cutting-edge technologies such as virtual reality (VR), augmented reality (AR), blockchain, artificial intelligence (AI), and cloud computing, the metaverse aims to harmonize the physical and digital worlds. However, existing metaverse architectures face significant challenges related to scalability, security, and efficiency. This paper introduces a novel Software-Defined Metaverse (SDM) Architecture, which uniquely addresses these challenges through a three-layered structure: the Application Layer, Control Layer, and Physical Layer. These layers are interconnected via standardized APIs, enabling efficient communication and data exchange. The architecture's innovative centralization of control within the Control Layer not only enhances resource management but also significantly improves performance, scalability, and user experience. The modular design of the SDM Architecture facilitates seamless integration with emerging technologies, ensuring adaptability and long-term sustainability. By addressing critical technical hurdles and providing a robust, scalable framework, this work lays a strong foundation for future developments in the evolving digital landscape, positioning the SDM Architecture as a key enabler for the next generation of digital experiences.**

Keywords*— *Metaverse, blockchain, security, SDM

I. Introduction

The concept of the Metaverse first emerged by Neal Stephenson in his 1992 science fiction novel Snow Crash [1]. In December 2021, the inaugural Metaverse Summit was held via live social media broadcast in China, drawing thousands of participants and marking a significant milestone in the global evolution of the Metaverse. This event, along with Facebook's rebranding to Meta, catalyzed a wave of innovation and entrepreneurship, leading to the emergence of hundreds of start-ups worldwide focused on developing Metaverse platforms and applications.

The Metaverse is characterized by several key features that define its essence and functionality [6]. Central to these is the creation of immersive experiences, made possible by advancements in VR, AR, blockchain, AI, and cloud computing. These technologies allow users to interact with digital environments and one another in ways that feel remarkably realistic [2,3,4,5]. This level of immersion is essential for simulating physical presence and interaction, which significantly enhances user engagement and satisfaction.

Interconnectivity and interoperability are fundamental to the metaverse, which is composed of interconnected virtual worlds and platforms. This interconnectedness allows for seamless movement and interaction across different environments, ensuring that users can access and utilize their digital assets, avatars, and identities consistently across various metaverse applications. Such interoperability is crucial for creating a cohesive and unified metaverse experience, where users are not confined to isolated platforms but can explore a vast, interconnected digital universe.

User-generated content is another significant aspect of the metaverse, empowering users to create, modify, and share their own content within the virtual environment. Platforms like Second Life, Roblox, and Minecraft exemplify this characteristic by enabling users to shape their digital spaces and experiences. This democratization of content creation fosters creativity and innovation, allowing the metaverse to evolve organically based on the contributions of its users.

The metaverse is designed to be persistent and synchronous, existing continuously regardless of individual user activity. This persistent digital universe ensures that changes and interactions occur in real-time, allowing users to engage with a dynamic and ongoing environment. Synchronous interactions enable users to communicate and collaborate in real-time, creating a vibrant and lively digital community that mirrors the continuous nature of the physical world.

Economic systems and digital assets play a crucial role in the metaverse, where users can buy, sell, and trade a variety of virtual goods [7]. These transactions are often underpinned by blockchain technology, which provides decentralized and secure ownership through non-fungible tokens (NFTs). The presence of robust economic systems allows for the creation of virtual marketplaces and economies, adding a layer of realism and functionality to the metaverse.

Social interaction is at the core of the metaverse experience, allowing users to communicate, collaborate, and socialize within virtual spaces [8]. The use of avatars, voice chat, and other interactive features enhances this social connectivity, enabling users to form communities and build relationships in

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the digital realm. This social aspect is essential for fostering a sense of belonging and engagement among metaverse users.

The integration of artificial intelligence (AI) and digital twins significantly enhances the functionality and realism of the metaverse [9]. AI powers intelligent virtual agents, providing dynamic interactions and responsive environments. Digital twins, which are digital replicas of physical entities, allow for the simulation and analysis of real-world objects and environments within the metaverse, bridging the gap between the digital and physical worlds.

Decentralization and the use of Web 3.0 technologies are key characteristics that distinguish the metaverse from traditional digital platforms [10]. Blockchain and decentralized networks ensure user control over data, digital identities, and assets, promoting greater transparency, security, and user autonomy. This decentralization is fundamental for building a trustless environment where users have full ownership and control over their digital presence.

The metaverse is accessible through a diverse range of devices, including VR/AR/MR headsets, smartphones, tablets, and traditional computers. This diversity in access points ensures that users can engage with the metaverse in various contexts and settings, making it more inclusive and versatile. The ability to access the metaverse through multiple devices enhances its usability and broadens its appeal to a wider audience.

The success of the metaverse hinges on scalability and performance, especially as it must support a vast number of concurrent users engaging in complex, dynamic interactions. However, despite advancements in creating immersive experiences, traditional metaverse architectures fall short in addressing several critical challenges. These architectures rely heavily on static networking frameworks and decentralized control, complicating management and optimization. This static nature creates integration barriers, hindering the incorporation of new and evolving technologies, such as AI-driven services and blockchain-based applications.

Absent an adaptive, scalable architecture, the metaverse is unlikely to meet the growing demands of users and developers. The motivation for this research stems from the fact that existing architectures struggle with maintaining high performance, ensuring security, and integrating cutting-edge technologies into a seamless framework. These issues not only limit user engagement but also prevent the metaverse from realizing its full potential as a next-generation digital ecosystem. A new, flexible approach is required to enable rapid technological advancements and provide a more efficient and secure infrastructure.

This paper proposes an innovative metaverse architecture called **software defined metaverse architecture (SDM)**, structured around three interconnected layers: the application layer, control layer, and physical layer.

The key contributions of our proposal include:

- Specialization and Efficiency: By separating the control layer from the application and physical layers, each layer can specialize in its functions, optimizing operations independently without impacting the others.
- Scalability and Flexibility: The modular control layer supports scalable resource management, allowing the metaverse to expand or contract as needed to accommodate millions of users and complex environments without significant manual intervention.
- Improved Performance: The dedicated control layer enhances performance by optimizing tasks such as space rendering, resource allocation, and virtual environment orchestration, resulting in reduced latency and a more responsive user experience.
- Enhanced Security: Isolation of the control layer allows for specialized security measures that contain potential threats, safeguarding the integrity of the entire metaverse ecosystem.
- Support for Diverse Technologies: The control layer integrates various technologies like AI, blockchain, and advanced rendering engines, fostering innovation and enabling the metaverse to effectively leverage emerging technologies.
- Centralized Control: Serving as the central hub, the control layer simplifies administration, ensures consistent policy enforcement, and enhances security by isolating critical functions from operational layers.

The rest of the paper is organized as follows: Section II outlines different techniques for software-defined solutions and their benefits. Section III reviews existing metaverse architectures, detailing their components and limitations. Section IV introduces our innovative architecture, which forms the core of our study, and offers a thorough breakdown of the proposed framework. Section V discusses the benefits and Comparative Analysis of the proposed architecture. finally, Section VI concludes the paper with a summary of the innovative aspects of our approach and provides a concise overview of the study's key contributions.

II. Background

The evolution of information technology (IT) infrastructure has undergone significant transformation in recent years, driven by the need for greater agility, scalability, and efficiency. Traditional IT environments, which heavily relied on specialized hardware for management and operation, often struggled with rigidity, high costs, and complexities in scaling. These challenges led to the development and adoption of Software-Defined Solutions (SDS), a paradigm shift that decouples the control and management functions from the underlying hardware, enabling more flexible and dynamic IT environments.

A. The Emergence of Software-Defined Networking (SDN)

Software-Defined Networking (SDN) was one of the earliest and most impactful innovations in the realm of software-defined solutions [11]. Before SDN, network infrastructure was tightly coupled with proprietary hardware, making it difficult to reconfigure networks or scale them efficiently. SDN introduced a new architecture that separates the control plane, which makes decisions about traffic routing, from the data plane, which forwards traffic to its destination. This separation allows for centralized management and dynamic adjustments to network traffic, improving overall network performance and reducing operational costs. The success of SDN has demonstrated the potential of software-defined approaches to revolutionize traditional IT infrastructure.

B. Expansion into Software-Defined Storage (SDS)

Building on the principles of SDN, Software-Defined Storage (SDS) emerged as a solution to the limitations of traditional storage systems, which were often inflexible and expensive [12]. SDS abstracts storage resources from the hardware, creating a virtualized pool of storage that can be dynamically allocated and managed by software. This approach not only optimizes storage utilization but also simplifies management, enabling organizations to efficiently scale their storage infrastructure as their data needs grow. The flexibility of SDS has made it a critical component in modern data centers, particularly in environments that demand rapid scaling and adaptation.

C. The Integrated Software-Defined Data Center (SDDC)

The concept of a Software-Defined Data Center (SDDC) represents the culmination of the software-defined paradigm, where all major components of a data center, including networking, storage, and compute resources are abstracted and controlled through software [13]. This integration allows for a fully virtualized data center infrastructure that can be managed and automated from a single platform. The SDDC model addresses the growing demands for agility in deploying and managing IT resources, enabling organizations to respond quickly to changing business needs while optimizing costs and resources. The adoption of SDDCs is a key driver in the shift towards cloud computing and hybrid IT environments.

D. Advancements in Software-Defined Wide Area Networking (SD-WAN)

As organizations expand globally, the need for efficient and cost-effective networking solutions has led to the rise of Software-Defined Wide Area Networking (SD-WAN) [14]. Traditional WANs, which relied on fixed, hardware-based systems, often struggled to meet the demands of modern, distributed workforces and cloud-based applications. SD-WAN addresses these challenges by using software to manage WAN connections, providing enhanced performance, security, and flexibility. It simplifies the management and operation of WAN by separating the networking hardware from its control mechanism. This technology enables organizations to optimize their network traffic over multiple types of connections, such as MPLS, broadband, and LTE, ensuring high availability and reliability.

E. The Role of Software-Defined Perimeter (SDP) in Security

The proliferation of remote work and the increasing sophistication of cyber threats have highlighted the need for more dynamic and secure access control mechanisms. The Software-Defined Perimeter (SDP) is a security framework that enforces a zero-trust model, granting access to network resources only after a user or device is authenticated and authorized [15]. Unlike traditional security models that rely on a fixed perimeter, SDP creates secure, encrypted connections on-demand, reducing the attack surface and protecting sensitive data from unauthorized access. As cyber threats continue to evolve, SDP represents a forward-looking approach to network security that aligns with the principles of software-defined solutions.

F. Software-Defined Access (SD-Access)

SD-Access is a network architecture approach that extends the principles of Software-Defined Networking (SDN) to the access layer of an enterprise network [16]. SD-Access is designed to simplify network management, enhance security, and improve the scalability and agility of network operations. It typically involves the use of software to automate network functions such as policy enforcement, segmentation, and access control.

G. Software-Defined Compute (SDC)

SDC is an approach within cloud computing and data center management that extends the principles of software-defined networking (SDN) to the computational resources of a data center [17]. SDC abstracts and automates the management of compute resources, such as CPUs, memory, and storage, through software rather than traditional hardware management methods.

Software-defined technologies, including SDN, SDS, SDDC, SD-WAN, SDP, SD-Access, and SDC all share the common goal of abstracting and automating traditional IT infrastructure, allowing for more flexible, efficient, and dynamic management of resources as shown in table I. However, each technology focuses on different aspects of IT infrastructure.

TABLE I. BENEFITS OF SOFTWARE-DEFINED TECHNOLOGIES.

Technology	Scalability	Centralized Management	Flexibility	Efficiency	Performance	Cost Reduction
SDN	✔	✔	✔	✔	✔	✔
SDS	✔	–	✔	✔	–	✔
SDDC	–	✔	✔	✔	✔	✔
SD-WAN	✔	✔	✔	✔	✔	✔
SDP	–	✔	–	–	✔	✔
SD-Access	✔	✔	✔	–	–	✔
SDC	✔	–	✔	✔	–	✔

key
✔ = The technology meets the criterion.
– = The technology does not specifically address the criterion.

In summary, Software-defined technologies share several common advantages that enhance the efficiency and effectiveness of IT infrastructure management. Primarily, these technologies enable significant automation and orchestration, streamlining tasks that were previously manual and thereby accelerating deployments, simplifying management, and reducing operational costs. They also support scalability, allowing resources to be dynamically added or removed with minimal reconfiguration, which facilitates handling growth or fluctuations in demand. Cost efficiency is another notable advantage, as the abstraction and virtualization of hardware diminish the reliance on costly, specialized equipment, leading to reduced capital and operational expenditures. Additionally, these technologies foster agility and flexibility, permitting rapid adaptation to evolving business needs through software-based updates to policies and configurations without physical infrastructure changes. Centralized management through a unified software interface enhances visibility and simplifies control across the entire infrastructure. Furthermore, improved security is achieved through the automation and centralized enforcement of security policies, minimizing the risk of human error and ensuring more consistent application of security measures.

These solutions empower organizations to adapt quickly to changing demands, ensuring that their operations remain efficient, secure, and capable of supporting future growth and innovation. Inspired by these solutions, we apply the concept of software-defined solutions to design metaverse architecture and leverage these benefits.

III. Related Work

The concept of the metaverse has evolved significantly over the years, influenced by advancements in technology, cultural trends, and various academic and industry-driven efforts. Below is a comprehensive overview of the related work on the metaverse.

In [18], The authors proposed an architecture for the metaverse called AIB-Metaverse, which seamlessly integrates Blockchain, AI, Digital Twin, AR/VR/MR, Cloud/Edge computing, and networking technologies. This architecture aims to help users regain full control of their data, enable smart decision-making, and provide ubiquitous immersive experiences. AIB-Metaverse leverages Web 3.0 technology to be accessible via various devices, including VR/AR/MR headsets and smartphones. However, some devices have limited computing, storage, and networking capabilities, making them unable to handle the intensive rendering required for high-quality metaverse videos. Additionally, the decentralized control of AIB-Metaverse complicates management and optimization efforts.

In [19], This work aims to propose a novel framework called MetaSlicing, designed to manage and allocate various resources effectively for Metaverse applications. By recognizing that Metaverse applications often share common functions, the framework first groups applications into clusters known as MetaInstances. Within a MetaInstance, shared functions allow multiple applications to use the same resources simultaneously, significantly improving resource utilization. To address the real-time nature and dynamic, uncertain resource demands of the Metaverse, the framework incorporates a semi-Markov decision process and introduces an intelligent admission control algorithm to maximize resource utilization and enhance Quality-of-Service (QoS) for end-users. however, As the number of Metaverse applications and users grows, managing MetaInstances and ensuring efficient resource allocation could become increasingly difficult.

In [20], The study seeks to create a cybersecurity model for a Roblox-based Metaverse architecture framework, with applications in internationalization, educational value chains, and online and e-learning education. It utilizes the Interpretivist Paradigm, which includes subjectivist epistemology, relativist ontology, naturalist methodology, and balanced axiology. The research incorporates both qualitative and quantitative methods within an experimental design. The resulting cybersecurity model is a Bayesian Network (BN), a directed acyclic graph paired with a probability distribution function, designed for multivariate analysis. These BNs allow us to reason from evidence to hypotheses with regards to cybersecurity issues.

In [21], This work aims to propose a novel blockchain-based framework called MetaChain, designed to address emerging challenges in the development of Metaverse applications, particularly security and privacy concerns. By utilizing smart contracts, MetaChain manages and automates complex interactions between Metaverse Service Providers (MSPs) and Metaverse users (MUs) effectively. The framework also supports transactions among MUs without requiring a trusted authority, enabling the smooth transfer and exchange of digital assets via blockchain. To enhance efficiency, we propose implementing a sharding mechanism that creates shards based on MUs' demands, such as one shard per region or application. This approach allows MSPs to dynamically allocate resources to each shard according to specific demands.

In [22], The cross-chain transaction model HCNCT, designed for the Metaverse environment, addresses critical issues in digital content and digital asset interactions between different blockchains. HCNCT introduces a notary mechanism that builds upon the atomicity and decentralization features of the original HTLC (Hashed Time-Lock Contract) scheme. This model leverages cryptographic techniques such as key agreement and verifiable secret sharing to ensure a secure cross-chain transaction process. By mitigating the vulnerabilities of HTLC, particularly its susceptibility to time-out transaction attacks, and addressing the centralization problems associated with traditional notary mechanisms, HCNCT offers a robust solution for secure and decentralized digital asset exchanges.

In [23], The authors provide a thorough analysis of cutting-edge studies on the fusion of Blockchain and Artificial Intelligence (AI) within the Metaverse. This survey explores digital currencies, AI applications in virtual worlds, and blockchain-empowered technologies, showcasing how these innovations are reshaping the Metaverse. By examining these areas, the survey offers valuable insights into the potential and challenges of integrating AI and Blockchain, underscoring the need for collaborative research efforts between academia and industry.

In [24], The authors propose a two-factor authentication framework that combines chameleon signatures with biometric-based authentication. To tackle the issue of disguise in virtual spaces, they introduce a chameleon collision signature algorithm that verifies the avatar's virtual identity. To address impersonation in the physical world, they create an avatar identity model that merges the player's biometric template with the chameleon key, facilitating the verification of the avatar's physical identity. Furthermore, they design two decentralized authentication protocols based on this identity model to ensure consistency between the avatar's virtual and physical identities. Security analysis shows that this framework guarantees the consistency and traceability of the avatar's identity.

In [25], The authors present a comprehensive survey of the Metaverse, focusing on key challenges and potential solutions for building a secure and privacy-preserving virtual environment. The survey provides critical insights and guidelines for understanding and mitigating security and privacy threats. It covers the fundamentals of the Metaverse, including its architecture, characteristics, enabling technologies, and existing prototypes. It also examines security and privacy threats across seven aspects: authentication and access control, data management, privacy, network, economy, governance, and physical/social effects, highlighting critical challenges. Additionally, the survey reviews state-of-the-art countermeasures from both academic and industry perspectives and evaluates their feasibility. Finally, it outlines future research directions for developing a secure, privacy-preserving, and efficient Metaverse.

Table II presents a comparative analysis of various metaverse architecture frameworks, emphasizing the techniques utilized, the benefits they provide, and the challenges they face. This comparison seeks to illuminate how different technologies and methodologies influence the development and operation of metaverse environments.

The development of the Metaverse presents several significant challenges that must be addressed to ensure its success. Scalability is a major concern, as device limitations and the complexity of resource management in large-scale environments hinder the efficient handling of high-quality rendering and resource allocation. Security and privacy also pose critical issues, particularly in decentralized environments where ensuring robust cybersecurity and protecting user data is inherently complex. The decentralized nature of the Metaverse further complicates management and optimization efforts, making coordination and monitoring difficult. Additionally, the seamless integration of emerging technologies such as VR, AR, AI, blockchain, and cloud computing is challenging due to their unique requirements and substantial resource demands. Enhancing user experience is another key challenge, as it requires sophisticated technology to create immersive experiences and maintain the consistency and traceability of avatars' virtual and physical identities. Cross-chain interactions introduce further complexity, as enabling secure exchanges between different blockchains involves overcoming interoperability and coordination challenges. Moreover, implementing effective security measures, including authentication, access control, and comprehensive threat mitigation strategies, is essential for maintaining Metaverse security. Finally, the rapid pace of technological advancements necessitates continuous adaptation and collaborative research efforts to address emerging challenges and ensure the Metaverse's evolution. Addressing these challenges is crucial for establishing a secure, immersive, and efficient Metaverse, providing a robust foundation for future advancements in this dynamic digital landscape.

TABLE II. RELATED WORK COMPARISON

Ref	Techniques Used	Advantages	Drawbacks
[18]	Blockchain Technology, Digital Twin Technology, VR, AR, and MR Networking Technologies.	User Data Control. Smart Decision-Making. Web 3.0 Accessibility.	Complex Management and Optimization. High Resource Requirements. Scalability Challenges.
[19]	Technique involves grouping Metaverse applications with common functions into clusters called MetaInstances.	Improved Resource Utilization. Improved Quality-of-Service (QoS).	Scalability Challenges. Computational Overhead. Complexity in Managing MetaInstances.
[20]	The cybersecurity model is constructed as a Bayesian Network and Integration with 6G Technologies.	Support for 6G Technologies. Application in Education and Internationalization.	Complexity of Implementation. High Dependence on Accurate Data. Resource-Intensive. Scalability Challenges.
[21]	The integration of blockchain technology, sharding, smart contracts, and game theory into a framework.	Efficient Resource Management. Security and Trust. Attraction of More Users and Resources.	Potential Scalability Limits. Incentive Mechanism Complexity. Complexity of Implementation. Resource Consumption.
[22]	This technique involves locking transactions with a cryptographic hash. A group of notaries is employed to oversee and facilitate cross-chain transactions.	Enhanced Security. Improved Cross-Chain. Transaction Efficiency. Mitigation of Time-Out Transaction Attacks.	Scalability Concerns. Performance Overhead. Dependence on Notaries. Complexity of Implementation.
[24]	Chameleon Collision Signature Algorithm and Biometric-Based Authentication.	Enhanced Security. Decentralized Authentication. Traceability and Verifiability.	Decentralized Protocol Challenge. Resource Intensive. Biometric Data Vulnerability.

IV. PROPOSED ARCHITECTURE

Inspired by Software Defined Solutions (SDSs), our proposed architecture for the metaverse is structured into three fundamental layers: The Application Layer, Control Layer, and Physical Layer. Each layer contains specific components essential for the functionality and efficiency of the metaverse as shown in figure 1. Below are the detailed descriptions of each component within these layers.

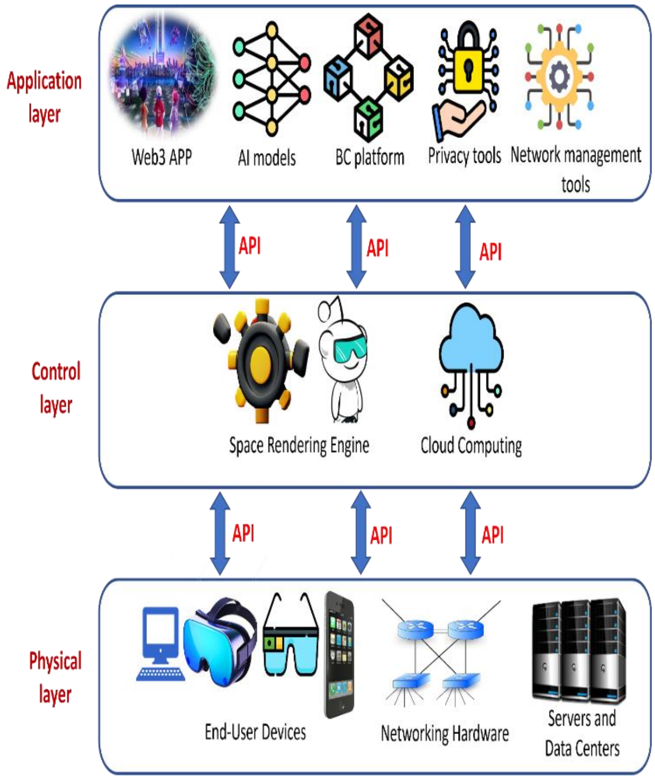

Fig. 1. THE PROPOSED SOFTWARE DEFINED METAVERSE ARCHITECTURE.

A. Application Layer

The Application Layer includes the services and tools that users interact directly. It encompasses:

- Web3 Applications
  - Function: Provide decentralized applications (dApps) that leverage blockchain technology.
  - Features: Enable decentralized interactions, smart contracts, and secure peer-to-peer transactions.
  - Examples: Decentralized finance (DeFi) platforms, decentralized social networks, NFT marketplaces.
- AI Models
  - Function: Deliver intelligent behaviors and predictions within the metaverse.
  - Features: Natural language processing, computer vision, predictive analytics, and personalized user experiences.
  - Examples: Virtual assistants, recommendation systems, automated content generation.
- Blockchain Platforms
  - Function: Ensure secure and transparent transactions and data integrity.
  - Features: Immutable ledgers, decentralized consensus mechanisms, smart contracts.
  - Examples: Ethereum, Hyperledger, Polkadot.
- Privacy Tools
  - Function: Safeguard user data and ensure compliance with privacy regulations.
  - Features: Data encryption, anonymization, consent management, privacy-preserving computation.
  - Examples: Zero-knowledge proofs, homomorphic encryption, GDPR-compliant tools, secure multi party computation, Differential privacy, and Distributed learning techniques such as federated learning, split learning, and blind learning.
- Network Management Systems
  - Function: Ensure seamless connectivity and optimal performance of the network.
  - Features: Traffic management, network monitoring, performance optimization, fault detection and recovery.
  - Examples: SDN controllers, network performance monitoring tools, load balancers.

B. Control Layer

The Control Layer serves as the backbone of the architecture, managing and optimizing the virtual environment's performance and scalability. It includes:

- Space Rendering Engine
  - Function: Render 3D environments and objects in real-time.
  - Features: High-performance graphics rendering, real-time environment updates, support for various graphics APIs.
  - Examples: Unity, Unreal Engine, proprietary metaverse rendering engines.
- Cloud Computing
  - Function: Provide scalable computational resources and storage by Utilizing a hybrid cloud approach to distribute the workload between public clouds, private clouds, and edge computing resources..
  - Features: On-demand resource allocation, scalable infrastructure, data storage and retrieval, AI model training and inference support.
  - Examples: Amazon Web Services (AWS), Google Cloud Platform (GCP), Microsoft Azure.

▪ *Efficient Resource Utilization in the Control Layer*

To efficiently utilize resources in the Control Layer, the following strategies can be implemented:

- Space Rendering Engine Optimization
  - Dynamic Level of Detail (LoD) Rendering: Adjusts the complexity of 3D models based on the user's viewpoint, reducing the computational load for

distant objects while enhancing detail for those nearby.

- Selective Rendering: Utilizes techniques such as occlusion culling to render only the visible parts of the scene, further optimizing resource usage.
- Efficient Asset Management: Involves caching frequently used assets locally or on edge servers and prefetching assets based on predicted user actions to minimize load times and bandwidth consumption.
- Parallel and Distributed Rendering: Leverages multiple GPUs and edge servers to handle rendering tasks, reducing latency and bandwidth usage.
- Compression Techniques: Reduces asset sizes without significantly impacting visual quality.

- Cloud Computing Optimization
  - Autoscaling: Implements dynamic resource allocation to adjust the number of active servers based on current demand, using services like AWS Auto Scaling, Google Cloud Autoscaler, or Azure Scale Sets.
  - Predictive Scaling: Utilizes machine learning to predict usage patterns and preemptively adjust resources.
  - Containerization and Microservices: Deploys applications in containers via platforms like Kubernetes and breaks them down into smaller, independently deployable services for improved scalability and fault tolerance.
  - Serverless Computing: Uses Function as a Service (FaaS) platforms such as AWS Lambda, Azure Functions, or Google Cloud Functions to run discrete pieces of code on-demand, eliminating the need to maintain idle servers.
  - Efficient Cloud Resource Usage: Optimizes resource usage by utilizing cloud-native tools for reserved instances for predictable workloads and spot instances for transient, non-critical tasks.
  - Load Balancing: Ensures even distribution of incoming traffic across servers, preventing overloading and ensuring optimal performance.
- Integration and Communication Optimization
  - Efficient API Design: Employs lightweight communication protocols such as gRPC, and HTTP/2 to minimize latency and overhead.
  - API Rate Limiting and Throttling: Ensures fair resource distribution and prevents abuse.
  - Data Compression and Edge Caching: Reduces bandwidth usage and server load by compressing data transmitted between layers and storing frequently accessed data closer to users.
- Continuous Monitoring and AI-Driven Optimization
  - Continuous Monitoring: Utilizes tools like Prometheus, Grafana, or cloud provider monitoring services to continuously track resource usage and identify bottlenecks.
  - Performance Metrics Tracking: Monitors key metrics such as CPU/GPU utilization, memory usage, and network bandwidth to optimize resource allocation.
  - AI-Driven Optimization: Uses predictive analytics based on historical data and AI-based anomaly detection to proactively manage resources and identify inefficiencies or potential issues.

By implementing these strategies, the Control Layer of a metaverse architecture can efficiently manage resources, ensuring a smooth, responsive, and scalable user experience. These measures collectively address the high resource demands inherent in maintaining a metaverse, leveraging advanced techniques in rendering, cloud computing, integration, and monitoring to achieve optimal performance and scalability.

C. Physical layer

The Physical Layer encompasses the necessary hardware infrastructure to support the metaverse's operations. It includes:

- End-User Devices
  - Function: Provide users with access to the metaverse.
  - Features: High-performance graphics processing, immersive user interfaces, connectivity to the metaverse network.
  - Examples: VR headsets, AR glasses, smartphones, PCs.
- Networking Hardware
  - Function: Enable data transmission and connectivity within the metaverse.
  - Features: High-speed data transmission, low-latency communication, reliable network connectivity.
  - Examples: Routers, switches, wireless access points.
- Servers
  - Function: Handle computational tasks and data processing for the metaverse.
  - Features: High processing power, scalable infrastructure, support for AI model inference and rendering tasks.
  - Examples: High-performance computing servers, GPU servers, dedicated metaverse servers.
- Data Centers

- Function: Provide centralized storage and processing capabilities.
- Features: High availability, redundancy, scalable storage solutions, security features.
- Examples: Colocation data centers, cloud data centers, edge data centers.

D. Inter-Layer Communication

- Standardized APIs
  - Description: Application Programming Interfaces that facilitate communication between the layers.
  - Functions: Ensure interoperability and seamless data exchange across different components of the architecture.
  - Types:
    - **Blockchain integration Protocols**: Enable secure transactions and data integrity between blockchain platforms and other components such as Ethereum Smart Contracts, IPFS (Interplanetary File System).
    - **OpenFlow Protocols**: Manage network traffic and ensure efficient routing and resource allocation.
  - Other Protocols: Facilitate various functionalities such as authentication, data synchronization, and analytics.
- Examples: OAuth (for authentication), WebSocket (for real-time data synchronization), RESTful APIs (for general communication), JSON (JavaScript Object Notation).

E. Case Studies: Workflow Examples for the Proposed Metaverse Architecture

To further illustrate the functionality and interaction between the layers in the proposed metaverse architecture, consider the following case studies. The first, Enhancing Educational Outcomes through Virtual Lab Simulations in the Metaverse, demonstrates how immersive virtual lab environments provide students with safe, cost-effective opportunities for conducting experiments, enhancing their learning experience. The second, attending a Virtual Business Meeting, examines how virtual meetings improve communication and collaboration among remote teams, allowing organizations to optimize operations and promote inclusivity in the modern digital workspace. Collectively, these case studies emphasize the pivotal role of virtual technologies in fostering innovation across various sectors.

1. Case Study 1: Enhancing Educational Outcomes through Virtual Lab Simulations in the Metaverse

Traditional laboratory experiments in education face financial constraints, particularly due to the high cost of chemical materials and specialized equipment. This limitation restricts the variety of experiments students can conduct, hindering their learning experiences. Virtual lab simulations in the metaverse offer a transformative solution by providing immersive and interactive environments where students can safely explore a wide range of experiments without the associated costs as shown in figure 2. This case study will highlight how these simulations enhance educational outcomes by increasing experiment variety and providing engaging, accessible, and cost-effective learning opportunities.

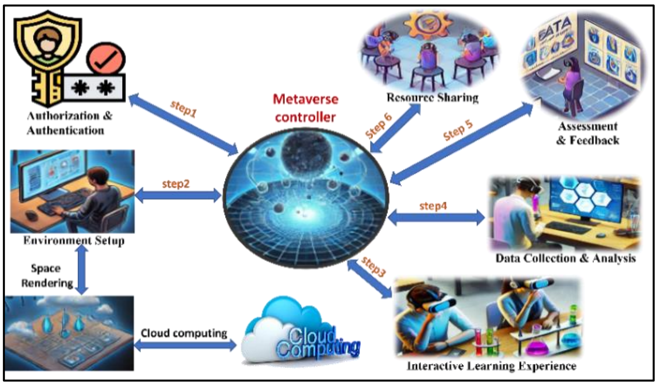

Fig. 2. THE VIRTUAL LAB SIMULATIONS IN THE METAVERSE.

Step 1: Authorization and Authentication

- User Device (Physical Layer): Students log in via VR headsets, tablets, or computers.
- API Call (Control Layer): Each device sends a request to the metaverse server to access the virtual lab environment.
- Application Layer (Web3 Apps): A decentralized authentication service verifies student identities securely.

Step 2: Environment Setup and Rendering

- Control Layer: The Space Rendering Engine receives user requests to render the virtual lab environment with interactive simulations, while Cloud Computing allocates the necessary resources for rendering and user interactions.

Step 3: Interactive Learning Experience

- Application Layer: Simulation Tools provide interactive models for real-time manipulation, fostering immersion, while Collaboration Features allow students to work together on experiments, sharing insights and findings seamlessly.
- Control Layer: Data Synchronization Services to ensure all interactions and data are synchronized for all users, and APIs facilitate communication between user devices and the simulation engine to enhance the experience.

Step 4: Real-Time Data Collection and Analysis

- Application Layer: Data Management Tools collect experimental data for real-time analysis, while Visualization Tools present results through charts and graphs to enhance understanding.

- Control Layer: Data Processing Services process and store experimental data securely for later retrieval and analysis.

Step 5: Assessment and Feedback

- Application Layer: Assessment Tools offer quizzes based on virtual lab experiments, and a Feedback Mechanism provides immediate performance feedback to enhance learning outcomes.
- Control Layer: APIs manage the integration of assessment tools with the lab environment, ensuring smooth functionality.

Step 6: Post-Lab Review and Resources

- Application Layer: Resource Sharing allows students to access additional learning materials, videos, and articles related to the lab experiments. Discussion forums facilitate discussions among students and instructors to reflect on the lab experience.
- Control Layer: Data Storage Services archive lab results and learning resources for future reference and study.

2. *Case study 2: Attending a Virtual Business Meeting*

This case study examines the benefits of attending virtual business meetings, which have revolutionized corporate communication and collaboration in today's interconnected world. By eliminating travel costs and time, virtual meetings enhance productivity and flexibility for employees, allowing them to participate from anywhere. Additionally, these meetings foster inclusivity by enabling diverse stakeholders to engage, leading to richer discussions and innovative solutions. Equipped with advanced features such as screen sharing and real-time collaboration tools, virtual meetings promote engagement and information retention. Overall, this case study highlights how virtual meetings streamline operations and contribute to a culture of collaboration and innovation within organizations.

Step 1: User Access and Authentication

- User Device (Physical Layer): The user logs into the metaverse using a VR headset, smartphone, or computer.
- API Call (Control Layer): The user's device sends a request to the metaverse server to access the virtual meeting room.
- Application Layer: A decentralized authentication service verifies the user's identity securely.

Step 2: Environment Setup and Rendering

- Control Layer: The Space Rendering Engine receives the request and begins rendering the virtual meeting room environment, while Cloud Computing allocates the necessary computational resources to manage the rendering and interaction load, ensuring scalability.

Step 3: Real-Time Data Synchronization and Collaboration

- Application Layer: Network Management Tools ensure smooth data flow and real-time synchronization of user actions, audio, and shared documents, while Privacy Tools protect the data being shared and discussed during the meeting.
- Control Layer: Data Synchronization Services ensure that all user actions, audio, and shared documents are synchronized across all participating devices, and standardized APIs manage communication between user devices and the space rendering engine.

Step 4: Secure Document Sharing and Collaboration

- Application Layer: Via the Blockchain Platform, when users share documents or sensitive data, the blockchain ensures secure and immutable transactions, while Privacy Tools protect personal data and shared documents during the meeting.
- Control Layer: Blockchain protocols manage secure data sharing, integrating smoothly with rendering and data synchronization services.

Step 5: Network Monitoring and Optimization

- Application Layer: Network Management Tools continuously monitor network performance to optimize data flow and reduce latency.
- Control Layer: OpenFlow protocols manage the network traffic, ensuring optimal routing and resource allocation.

Step 6: Post-Meeting Actions

- Application Layer: Provide decentralized services such as recording the meeting, storing shared documents securely, and allowing follow-up actions.
- Control Layer: APIs ensure that recorded content and stored documents are integrated and securely accessible post-meeting

V. Advantages And Comparative Analysis Of The Proposed Architecture

We outline the key benefits of the proposed Software-Defined Metaverse (SDM) Architecture and compare its features with existing architectures. By highlighting the unique advantages and improvements of the SDM architecture, we demonstrate how it addresses the limitations of previous models and enhances overall efficiency, security, and user experience within the metaverse.

Advantages of the Proposed Architecture:

- Modularity: The separation into Application, Control, and Physical Layers allows for modular development and maintenance. Each layer can be independently updated or scaled without affecting the others.
- Centralized Control: Simplifies management and enhances control.
- Scalability: Cloud computing in the Control Layer ensures that resources can be dynamically allocated to meet demand, making the architecture highly scalable.

- Security: Integration of blockchain platforms and privacy tools ensures secure and transparent transactions, as well as protection of user data.
- Interoperability: Standardized APIs and protocols (like blockchain protocols and OpenFlow) facilitate seamless communication between layers and components.
- Performance Optimization: The Control Layer's space rendering engine and network management systems optimize performance, ensuring smooth user experiences.
- Future-Readiness: The architecture's design allows for easy incorporation of emerging technologies and tools.

We compared this architecture with other architectures, as shown in table III, and concluded that centralized control simplifies management and enhances control. The high programmability of the architecture provides greater flexibility and fosters innovation. Efficient scaling is achieved by streamlining the network scaling process. Additionally, centralized security ensures consistent and comprehensive security measures. Lastly, dynamic data management optimizes data processes and improves user experiences.

TABLE III. COMPARISON BETWEEN TRADITIONAL ARCHITECTURE AND PROPOSED SDM ARCHITECTURE

Traditional Architecture	**SDM Architecture:**
Decentralized Control	Centralized Control
Rigid Infrastructure	Highly Programmable
Complex Scaling	Efficient Scaling
Dispersed Security Management	Centralized Security
Static Data Management	Dynamic Data Management

VI. CONCLUSION

The comprehensive framework presented in this paper addresses the technical challenges of creating a scalable, secure, and efficient metaverse. By structuring the architecture into three fundamental layers Application, Control, and Physical layers. the proposed architecture provides a robust framework for facilitating decentralized interactions, secure transactions, intelligent behaviors, and seamless connectivity. The Application Layer integrates essential services and tools, the Control Layer ensures optimized performance and resource management through space rendering and cloud computing, and the Physical Layer provides the necessary hardware infrastructure. Standardized APIs facilitate inter-layer communication, promoting modularity and adaptability to emerging technologies.

In our future work, we will focus on evaluating real-world examples to assess the flexibility and efficiency of this framework in practical applications. Ultimately, this framework establishes a solid foundation for future developments in this evolving digital landscape. By providing a robust and immersive user experience, it enables the ongoing integration of emerging technologies, propelling the metaverse toward a secure and innovative future.

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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.

CONFLICT OF INTEREST

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

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

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Application of Prompt Engineering Techniques to Optimize Information Retrieval in the Metaverse

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Abstract— **Prompt engineering techniques are instructions that enable large language models (LLMs) to solve real-world problems more effectively. These techniques enhance the capabilities of LLMs to generate accurate and efficient responses. Our study examines the challenge of acquiring comprehensive and efficient information in the metaverse through the application of various prompt engineering techniques. The main objective is to improve the accuracy and effectiveness of metaverse-related responses by leveraging LLM capabilities. In this study, 100 questions were generated using GPT, GEMINI, QWEN, and MISTRAL language models focusing on the metaverse. Our experiments indicated that responses often included unrelated information, highlighting the need for prompt engineering techniques. We applied knowledge-based, rule-based, few-shot, and template-based prompt engineering techniques to refine the responses. The performance of GPT, GEMINI, QWEN, and MISTRAL models were evaluated based on criteria including accuracy, timeliness, comprehensiveness, and consistency. Our findings reveal that prompt engineering techniques significantly enhance the efficacy of LLMs in providing improved information retrieval and response generation, aiding users in efficiently acquiring information in complex environments like the metaverse.**

Keywords— Prompt engineering, large language models, metaverse, information retrieval, response generation

I. INTRODUCTION

The metaverse represents both physical and digital environments, integrating augmented and virtual realities [1]. Within this space, users engage in a variety of activities, ranging from social interactions to commercial transactions and work through unique digital representations known as avatars. Consequently, user experiences in the metaverse are shaped by information retrieval and orientation strategies that facilitate personalized interactions. This digital environment holds the potential to significantly transform how individuals interact online and access information. However, the metaverse's dynamic nature and the extensive sharing of information among users pose challenges in accessing information within this environment. Information in virtual settings is often dispersed and unstructured, complicating the retrieval of accurate and reliable data. Additionally, the rapid increase in virtual interactions contributes to information pollution and uncertainty in the information access process. The substantial time and effort users must invest to locate specific information may decrease the metaverse's effectiveness as an efficient information acquisition platform.

Large language models (LLMs) and prompt engineering techniques are pivotal tools for enhancing information access in the metaverse. LLMs, trained on extensive datasets, effectively process information within complex and diverse environments such as the metaverse. Prompt engineering is a method designed to ensure these models respond appropriately to user queries. By crafting precise prompts, information retrieval in the metaverse can be significantly optimized. Consequently, LLMs and prompt engineering offer essential solutions to the challenges faced in the metaverse's information acquisition process.

Our main object of study is to extract meaningful and accurate Metaverse data using LLMs such as GPT, GEMINI, QWEN, and MISTRAL which are top ranked in benchmarks. The Generative Pre-trained Transformer (GPT) is recognized for its efficiency in processing large volumes of text-based information [2]. The GEMINI language model, an artificial intelligence tool used in natural language processing tasks, prioritizes user experience and delivers responses with high knowledge-based accuracy [3]. On the other hand, Qwen model, has been noted for its innovative architecture that supports various applications, including natural language-based applications [4]. This model's foundation in pre-trained weights allows it to leverage existing knowledge while adapting to new tasks effectively. Mistral, has been recognized for its performance on the MMLU benchmark, attributed to its innovative two-stage knowledge distillation process which enhances its understanding and generation of human-like text [5]. This duality of strengths and weaknesses underscores the importance of ongoing research to refine these models, particularly in areas requiring high precision. All models have demonstrated success in understanding and interpreting natural language without employing prompt engineering techniques.

Prompt Prompt engineering techniques are employed to ensure that models generate responses in the desired format, aligning with specific knowledge patterns or user requirements. Queries leveraging these techniques are crafted within defined constraints, providing templates or data elements to LLMs [6]. Implementing these strategies in large language models can yield accurate and comprehensive responses to inquiries. Within this framework, various prompt engineering approaches are utilized, including knowledge-based, rule-based, few-shot, and template-based methods. This study also examines the consistency of these models in delivering answers to diverse questions within a given context.

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Our experiments have demonstrated that prompt engineering techniques significantly enhance the retrieval of Metaverse-related information using large language models. Our contributions are as follows:

- Extending literature on the prompt engineering in the Metaverse
- Establishing a foundation for enhancing user experiences in virtual environments.
- Advancing discussions on LLM adaptability in dynamic digital spaces.
- Improving access to accurate information in the Metaverse.
- Solving information overload for users through optimized prompts.
- Support for diverse use cases like education, events, and business interactions.
- Applying specific prompt techniques to enhance data precision in LLMs.
- Providing a framework for evaluating accuracy, comprehensiveness, timeliness, and consistency.

II. Related Work

Prompt engineering techniques are recognized for their role in enhancing the capabilities of large language models, particularly in the domain of knowledge discovery. The Metaverse, with its vast and intricate datasets, presents significant challenges in efficiently searching and extracting knowledge. In response, research efforts have concentrated on exploring the use cases of the Metaverse, examining the application of prompt engineering techniques in large language models, and conducting experiments to assess their performance comprehensively.

Huang [7] highlighted the potential applications of AI technologies in the educational context, emphasizing the necessity of prompt engineering for effective knowledge acquisition. His findings indicate that the methods employed significantly influence the quality of questions and responses. Huang also stated that employing combined prompt engineering techniques with ChatGPT technology in education improves the teaching process for both learners and tutors. Conversely, Tassoti [8] explored the broader application of new technologies in education, noting a lack of focus on specific teaching challenges. He determined that the 5S method, used in AI applications, generates responses that are more effective and of higher quality compared to the traditional question-and-answer approach. The 5S method comprises five steps: Set the Stage, Be Specific, Simplify Your Language, Structure the Output, and Share Feedback.

The application of prompt engineering techniques in large language models has a significant and positive impact on improving performance. Notably, few-shot prompts have been observed to outperform traditional data augmentation methods by a substantial margin in scenarios with limited samples [9, 10]. In their study, Gao et al. [11] determined that few-shot prompts were more advantageous for the GPT-3 model compared to data augmentation without prompt engineering, resulting in a performance improvement of nearly 30% for each task. Overall, prompt engineering techniques contribute to enhancing the efficiency of large language model systems. Wang et al. [12] and Shin et al. [13] emphasized the importance of these techniques in quickly comprehending various knowledge classifications, as well as in synthesizing and generating new knowledge. Despite these benefits, concerns persist regarding the limitations of integrating different prompt engineering techniques [14].

In a vast universe like the Metaverse, the application of prompt engineering techniques can yield more effective and interactive outcomes. Users who generate their own content within the Metaverse can benefit from the question-answering and scenario evaluation capabilities of large language models. Elsadig et al. [15] noted the complexity of the Metaverse and underscored the importance of integrating prompt engineering techniques to enhance AI system performance as the Metaverse advances. Haque et al. [16] investigated the Metaverse's role in education, highlighting the benefits of using these techniques with large language models to improve the learning process. Sun et al. [17] explored the potential applications of the Metaverse in plastic surgery, compiling research on its medical applications up to 2022. Their findings emphasize the Metaverse's promise as a tool in plastic surgery, though they call for further research and evaluation. Lee and Kwon [18] examined methods for integrating brands into the Metaverse, stating that marketing strategies developed using prompt engineering techniques have increased brand visibility.

III. Methodology

The research methodology was structured to examine the effectiveness of large language models (LLMs) and the impact of performance enhancement techniques in efficiently delivering accurate data within the Metaverse environment. Prompt techniques were used for this purpose. Prompt engineering is a method used in natural language processing to optimise the performance of large language models. It involves the design and construction of customised prompts that elicit appropriate and correct responses [19]. In our study, 4 different prompt engineering techniques were examined and their effects on performance were analysed. These techniques are knowledge-based, rule-based, few-shot and template-based. Knowledge-based prompting is a way of using information from specific sources to extend the knowledge of the language model and to focus on specific topics [20]. Rule-based prompting is a technique used to control the language model according to a set of rules. These rules determine the type of text that the language model produces for a given task or topic. In developing the rules for our rule-based prompting technique, we employed a systematic approach that began with establishing clear criteria and objectives that would guide the rule creation process. We aimed to ensure that each rule would maximize the relevance, neutrality, and informativeness of responses within the context of the metaverse. Our primary source of domain knowledge included an extensive review of existing metaverse literature, complemented by insights gained from datasets and consultations with subject matter experts. These inputs were crucial in grounding the rules in current understanding and practical relevance to real-world applications. For instance, the rule that answers should not exceed two paragraphs was based on established communication practices that balance detail and conciseness. Additionally, the rule that stipulates responses be based solely on metaverse information while maintaining neutrality ensures the accuracy and objectivity of the output. We complemented this with an iterative refinement process, where rules were subjected to pilot testing to iron out ambiguities and enhance their effectiveness. This comprehensive methodology ensured that our rule-based framework was robust and capable of producing precise and contextually appropriate responses. A few-shot prompting is a technique used so that language models can understand new tasks or classes with only a few examples [21]. The main purpose of template-based prompts is to help language models to produce text that conforms to a particular structure or format [22]. The approach comprised the following steps:

- Question formulation
- Response collection without prompt engineering
- Response collection with prompt engineering
- Performance evaluation

TABLE I. RESPONSES FROM GPT, GEMINI, QWEN AND MISTRAL WITHOUT APPLYING PROMPT ENGINEERING

Question	GPT	GEMINI	QWEN	MISTRAL
What types of events are organized in simulation?	Social events, educational seminars, concerts, competitions, trade fairs and various interactive games are often organized in simulations. Events can often have a variety of themes that users can interact with, experience and learn from.	Simulations are a powerful tool that can be used in many different fields by mimicking real-world situations. Therefore, there is a wide range of types of activities that can be organized. Simulation technologies are rapidly developing and being used in many fields. In this way, it is possible to create more effective learning, better decision making and more efficient business processes.	This Physics simulation team activity is designed to help students understand classical mechanics. They are introduced to models of the motion of objects at rest and uniform linear motion due to unbalanced forces. In addition, they experience vertical jump and ballistic motion through a cricket ball back into the hole.	Simulations are invaluable across various fields, serving numerous purposes that enhance training, research, decision-making, entertainment, and more. In sectors like aviation, medicine, and military operations, they provide safe environments for trainees to practice and develop skills. In research and development, simulations allow for testing theories and prototypes without the need for physical models.
What are the most popular virtual sports or competitive games on virtual platforms?	Popular virtual sports and competitive games include soccer, basketball, racing games and fighting games. Games often offer multiplayer and competitive features, allowing players to compete in real time.	Virtual sports have gained immense popularity, especially with professional gaming leagues called e-sports. Games such as "League of Legends", "Dota 2", "Counter-Strike: Global Offensive" are followed by millions of players. Sports simulations and racing games are also very popular.	The most popular virtual sports or competitive games include titles such as football (soccer), basketball, tennis, and various racing games. These games allow players to compete online against friends or others worldwide, offering an engaging way to experience sports in a virtual environment. Additionally, esports has gained significant popularity, with competitive gaming tournaments for games like League of Legends, Fortnite, and Call of Duty drawing large audiences.	Fortnite, developed by Epic Games, is a widely popular online multiplayer battle royale game where up to 100 players compete to be the last one standing on a shrinking island, available on PC, console, and mobile platforms. League of Legends (LoL), created by Riot Games, is a renowned multiplayer online battle arena (MOBA) game, known for its vibrant esports scene and millions of players engaged in professional leagues and tournaments.
Which virtual beauty saloons or spas are available?	Virtual beauty salons and spa centers offer beauty and grooming services in virtual environments. Users can experience virtual beauty services and receive digital spa treatments.	Some platforms have virtual beauty salons and spas where you can change the look of your avatar. In these centers, you can get a haircut, apply makeup, get skincare and try on different outfits.	Virtual beauty salons and spas are increasingly popular as they allow individuals to explore new beauty treatments and services from the comfort of their homes. These platforms offer a variety of services, such as virtual spa treatments, which deliver facials, massages, and body treatments directly to clients, often through advance bookings for at-home delivery or specific locations.	Several virtual beauty salons and spas have emerged, offering innovative services to clients. GlamSquad provides a mobile beauty service and features GlamSquad Live, where users can book virtual makeup and hair tutorials with professional stylists. Paintbox, known for its nail artistry, offers virtual nail art classes through its Paintbox at Home platform, allowing users to learn intricate designs from home.
How is security and privacy ensured in virtual platforms?	Security and privacy are ensured through methods such as encryption, user authentication, privacy settings and protection of user data. Platforms generally offer various security measures to protect users' privacy.	Security and privacy on virtual platforms is ensured by strong encryption methods and user agreements. However, it is important to protect your personal information and choose reliable platforms.	Security and privacy are paramount on virtual platforms, particularly concerning users' personal information and online activities. Two-Factor Authentication (2FA) adds an extra layer of security by requiring users to verify their identity with a password and a code sent to their device. Secure communication protocols, such as HTTPS, ensure that data transmissions are protected from eavesdropping, while regular security audits help identify and address vulnerabilities over time.	Ensuring security and privacy on virtual platforms involves several key strategies, including data encryption to protect information at rest, in transit, and during use; implementing strict access controls through multi-factor authentication and role-based permissions; designing a secure network architecture that minimizes the attack surface; and conducting regular security audits to identify vulnerabilities. Additionally, educating users on security best practices, collecting only essential data to reduce privacy risks, and using secure payment systems to protect financial information are crucial.

A. Question Formulation

In this step, 100 questions concerning Metaverse were formulated for large language models to address. These questions were crafted to cover current developments, usage, areas of interest, and applications of the Metaverse. The purpose was not only to acquire knowledge but also to enhance the analytical thinking capabilities of the large language models.

Sample questions in this study are as follows:

- What types of events are organized in the metaverse?
- What are the most popular virtual sports or competitive games in virtual platforms?
- Which virtual beauty salons or spas are available?
- How are security and privacy provided in metaverse?

B. Response Collection without Prompt Engineering

In this step, the questions were input into the GPT, GEMINI, QWEN, and MISTRAL models, and responses were collected without employing any prompting techniques. This step aimed to evaluate and compare the performance of language models that did not utilize prompt engineering techniques. Table I displays the responses generated by the GPT, GEMINI, QWEN, and MISTRAL models for sample questions, illustrating outcomes without the application of prompt engineering techniques.

C. Response Collection with Prompt Engineering

In the third step, responses were obtained by employing rule-based, knowledge-based, and template-based prompt engineering techniques to compare the performance of the language models. The goal is to enhance the performance of large language models by applying these techniques. Rule-based prompt engineering ensures that responses adhere to specific rules and are subject-specific [23]. This technique is beneficial in the Metaverse's complex and dynamic environment, helping to produce more consistent answers [24]. Knowledge-based prompt engineering restricts data to obtain responses solely related to the Metaverse [25]. Template-based prompt engineering is used to format responses in the desired manner. Utilizing these techniques together optimizes large language models to focus on certain topics and produce efficient and consistent results [26]. Figure 1 illustrates the prompt template created for information retrieval using knowledge-based, rule-based, and template-based prompt engineering methods. Table II shows the sample responses from GPT, GEMINI, QWEN and MISTRAL models with the prompt engineering techniques applied.

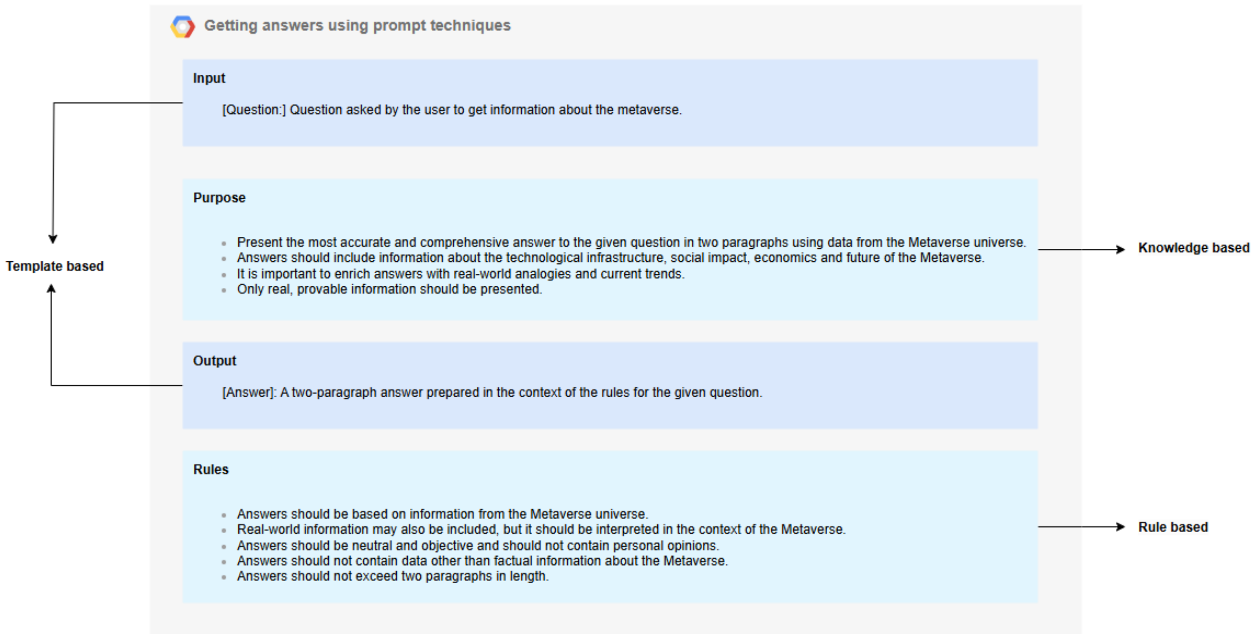


Fig. 1. PROMPT ENGINEERING TEMPLATE

D. Performance Evaluation

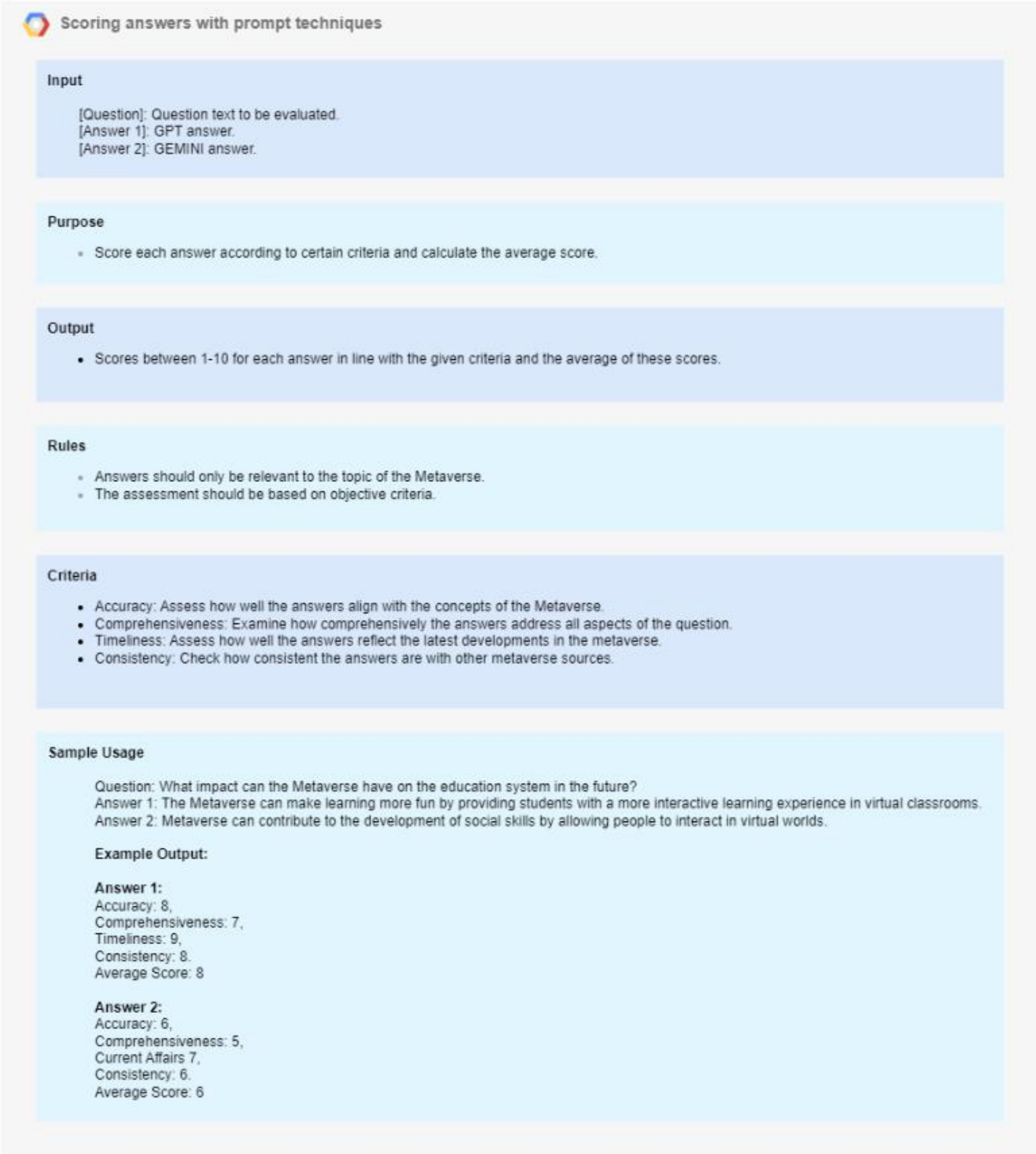
In the fourth section, the answers obtained using the techniques applied in the third section were analyzed and scored based on four categories: accuracy, comprehensiveness, timeliness, and consistency. The LLM-as-a-Judge method is used to analyse the responses of large language models. LLM-as-a-Judge involves an LLM evaluating the responses of another LLM against a given set of criteria. Since traditional human evaluations are slow and costly, evaluations using LLMs are an alternative solution. To evaluate the performance of different language models, the answers were analyzed separately for each model. This scoring system employed rule-based prompting, few-shot prompting, and template-based prompting techniques. Few-shot prompting is a method that enhances the performance and efficiency of large language models by providing examples on a specific topic, making model performance better [27]. This is particularly effective when fewer examples are provided through backpropagation [14]. Figure 2 illustrates a concise example where all three methods—few-shot prompting, rule-based prompting, and template-based prompting—are applied, along with their corresponding scoring.

TABLE II. RESPONSES FROM GPT, GEMINI, QWEN AND MISTRAL BY APPLYING PROMPT ENGINEERING TECHNIQUES

Question	GPT	GEMINI	QWEN	MISTRAL
What types of events are organized in simulation?	In the Metaverse, users can organize and participate in a variety of events. These events include a wide range of events, such as virtual concerts, art exhibitions, educational seminars, business meetings, social gatherings, sports competitions, and gaming tournaments. Especially during the COVID-19 pandemic, with real-world events being moved to the digital environment, such activities in the Metaverse have become more popular. For example, famous artists can reach their fans worldwide by giving virtual concerts, while companies can continue their business processes by holding virtual meetings with their global employees.	Metaverse provides a wide platform where users can interact in virtual environments by creating a digital copy of the real world through virtual reality and augmented reality technologies. Events organized on this platform offer new experiences by exceeding the boundaries of traditional events. Many different events, from educational seminars to virtual concerts, fashion shows to virtual meetings, can be held on metaverse platforms. Users can move freely in the virtual world with their own avatars, interact with other users and interact with virtual objects. This makes metaverse events more attractive for both participants and organizers.	In the metaverse, simulation events often include virtual training, social gatherings, and workshops. These events give users a chance to interact, learn, and practice skills in a digital environment.	Metaverse simulations organize events like virtual trainings, interactive social meetups, and collaborative sessions. Such events create a digital space for users to engage, learn, and experience activities similar to the real world.
What are the most popular virtual sports or competitive games on virtual platforms?	Popular virtual sports and competitive games on virtual platforms often provide users with interactive and dynamic experiences. These include virtual football, basketball and e-sports tournaments. Virtual sports events can be organized on platforms such as "VRChat", while social VR applications such as "Rec Room" and "Horizon Worlds" offer areas where users can play and compete in virtual sports games. In addition, popular battle royale games such as "Fortnite" and "Apex Legends" are among the main games where virtual competition is prominent.	The Metaverse pushes the boundaries of traditional sports and games, offering its users unique and interactive experiences. With virtual reality and augmented reality technologies, users can play sports in the virtual world, participate in tournaments, and compete with other players. Popular virtual sports include virtual football, basketball, racing, and fighting games. These games bring the excitement and competition of real-world sports to the virtual environment, attracting millions of users	In the metaverse, popular virtual sports and games include VR racing, simulated soccer, and virtual basketball. These games allow players to compete in lifelike, interactive environments.	On virtual platforms in the metaverse, competitive games like VR racing, soccer simulations, and multiplayer battle arenas are widely popular. These provide an immersive sports experience for users.
Which virtual beauty salons or spas are available?	There are various virtual beauty salons and spas in the Metaverse. These centers allow avatars to receive beauty treatments, makeup, hair styling, and relaxation services in a virtual environment. Users can experience these services to personalize their avatars' appearance and renew themselves in the virtual world. Virtual beauty salons help users express their virtual selves and express themselves through their avatars.	Some platforms feature virtual beauty salons and spas where users can change the appearance of their avatars, and services such as hair styling, makeup and skin care can be received.	In the metaverse, virtual beauty salons and spas provide services like avatar styling, virtual makeovers, and relaxation experiences. Users can personalize their avatars and enjoy immersive spa environments.	Virtual beauty salons and spas in the metaverse offer avatar customization, styling sessions, and calming digital environments for relaxation. These spaces help users personalize and unwind in a unique virtual setting.
How is security and privacy ensured in virtual platforms?	Security and privacy in virtual platforms are usually provided by advanced technology and protocols. Blockchain technology increases the security of ownership and transactions by encrypting and decentralizing user data. In addition, virtual platforms implement additional measures such as firewalls, encryption techniques, and regular security audits to protect user data. User authentication, two-factor authentication (2FA), and encryption are used to prevent unauthorized access and prevent data leaks.	While the metaverse offers its users a wide range of experiences, it also brings security and privacy concerns. In this virtual universe, users' data, identities, and digital assets must be protected. Platforms try to ensure security by encrypting users' personal information and preventing unauthorized access. In addition, account security is increased with methods such as multi-factor authentication. In terms of privacy, it is important for users to have control over what data they share.	In the metaverse, security and privacy are managed with encryption, user verification, and controlled data sharing to protect user information and interactions.	Virtual platforms in the metaverse enhance security through encryption, identity verification, and privacy settings. These measures help safeguard user data and maintain a secure environment for interactions.

Table III, IV, V and VI present the average scores, comparison of results with and without the application of prompt engineering techniques for responses generated by GPT, GEMINI, QWEN and MISTRAL language models respectively.

Results indicate that models employing prompt engineering techniques achieved higher average scores across all categories compared to models without such techniques. Prompt engineering enables models to generate more accurate, comprehensive, timely, and consistent responses. It is recognized as a critical tool for maximizing the potential of language models, allowing them to be better optimized for specific tasks and resulting in more accurate and useful outcomes. The results also demonstrate that language models can be utilized more effectively in Metaverse domains.


Scoring answers with prompt techniques

Input

[Question]: Question text to be evaluated.
[Answer 1]: GPT answer.
[Answer 2]: GEMINI answer.

Purpose

- Score each answer according to certain criteria and calculate the average score.

Output

- Scores between 1-10 for each answer in line with the given criteria and the average of these scores.

Rules

- Answers should only be relevant to the topic of the Metaverse.
- The assessment should be based on objective criteria.

Criteria

- Accuracy: Assess how well the answers align with the concepts of the Metaverse.
- Comprehensiveness: Examine how comprehensively the answers address all aspects of the question.
- Timeliness: Assess how well the answers reflect the latest developments in the metaverse.
- Consistency: Check how consistent the answers are with other metaverse sources.

Sample Usage

Question: What impact can the Metaverse have on the education system in the future?
Answer 1: The Metaverse can make learning more fun by providing students with a more interactive learning experience in virtual classrooms.
Answer 2: Metaverse can contribute to the development of social skills by allowing people to interact in virtual worlds.

Example Output:

Answer 1:
Accuracy: 8,
Comprehensiveness: 7,
Timeliness: 9,
Consistency: 8.
Average Score: 8

Answer 2:
Accuracy: 6,
Comprehensiveness: 5,
Current Affairs 7,
Consistency: 6.
Average Score: 6

FIG II. PERFORMACE EVALUATION PROMPT TEMPLATE

TABLE III. PERFORMANCE COMPARISON FOR GPT LANGUAGE MODEL

Category	GPT (without prompt engineering)	GPT (with prompt engineering)
Accuracy	7.17	9.2
Comprehensiveness	5.93	9.11
Timeliness	5.94	9.03
Consistency	6.88	9.16

TABLE IV. PERFORMANCE COMPARISON FOR GEMINI LANGUAGE MODEL

Category	GEMINI (without prompt engineering)	GEMINI (with prompt engineering)
Accuracy	6.13	9.14
Comprehensiveness	4.75	9.23
Timeliness	5.14	9.12
Consistency	6.4	9.03

TABLE V. PERFORMANCE COMPARISON FOR QWEN LANGUAGE MODEL

Category	QWEN (without prompt engineering)	QWEN (with prompt engineering)
Accuracy	5.2	7.8
Comprehensiveness	3.58	6.45
Timeliness	3.16	6.9
Consistency	5.4	7

TABLE VI. PERFORMANCE COMPARISON FOR MISTRAL LANGUAGE MODEL

Category	MISTRAL (without prompt engineering)	MISTRAL (with prompt engineering)
Accuracy	6.36	8.1
Comprehensiveness	4.36	7.2
Timeliness	4	7.1
Consistency	5.49	7.34

IV. Conclusion

One of the significant challenges in the Metaverse is accessing accurate and reliable information due to its complex and dynamic nature. Ensuring that users receive precise, comprehensive, timely, and consistent information is essential for effective engagement and decision-making within this virtual environment. This study evaluated the potential of prompt engineering techniques to enhance information retrieval in the Metaverse using large language models, specifically GPT, GEMINI, QWEN, and MISTRAL. By analyzing responses to Metaverse-related questions, we experimented with various prompt engineering methods, including rule-based, knowledge-based, template-based, and few-shot prompting. Our results highlighted improvements in accuracy, comprehensiveness, timeliness, and consistency. GPT demonstrated enhancements of 28.31% in accuracy, 53.63% in comprehensiveness, 52.02% in timeliness, and 33.14% in consistency. GEMINI showed even greater improvements, with 49.10% in accuracy, 94.32% in comprehensiveness, 77.43% in timeliness, and 41.09% in consistency. QWEN demonstrated enhancements of 50% in accuracy, 80.17% in comprehensiveness, 118.35% in timeliness, and 29.63% in consistency. MISTRAL showed enhancements of 27.36% in accuracy, 65.14% in comprehensiveness, 77.5% in timeliness, and 33.61% in consistency. These findings underscore the effectiveness of prompt engineering in refining the outputs of large language models to provide accurate and detailed information about the Metaverse. Future work could focus on developing more adaptive and context-specific prompt engineering methods tailored to the unique requirements of the Metaverse. Additionally, incorporating human evaluation metrics alongside automated assessments may enhance the robustness of performance evaluations.

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Authors` contributions

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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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Data Availability

The dataset used in this study is publicly available at “Metaverse dataset”, Mendeley Data, V1, doi: 10.17632/br68w4gn43.1

Ethical Statement

In this article, the principles of scientific research and publication ethics were followed. This study did not involve human or animal subjects and did not require additional ethics committee approval.

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Exploring University Teachers' Perceptions of Metaverse Integration in Higher Education: A Quantitative Study from China

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***Abstract*—Understanding these perceptions is crucial for successful adoption and implementation, particularly in the context of higher education institutions in Jiangsu Province, China, as little is known about university teachers' perceptions of these technologies and their potential applications in educational settings. This study employed a quantitative research approach, collecting data through a questionnaire sent to 389 university teachers from institutions offering Bachelor's programs. The data were analyzed using SPSS 26, applying statistical techniques such as independent sample t-tests, Analysis of Variance (ANOVA), and factor analysis to examine the influence of demographic variables on teachers' perceptions. The analysis revealed that demographic factors, including teachers' age, academic qualifications, years of teaching experience, and attitudes toward new educational technologies, significantly influenced their perceptions of the application of Metaverse technologies in higher education. The findings contribute to the growing body of knowledge on technology acceptance in educational contexts and offer practical implications for policymakers and educators aiming to integrate innovative technologies into teaching and learning practices.**

***Keywords*— University teachers, Metaverse, Perception of Metaverse, Higher education**

I. INTRODUCTION

Since 2021, Metaverse has become the focus of the global technology community, with major technology companies joining the Metaverse industry by establishing Research and Development departments, acquiring unicorn companies in Metaverse-related industries, and investing in Metaverse companies. At the same time, there has been a surge of academic research on Metaverse-related theories. The rapid development of network technology, human-computer interaction, and artificial intelligence has given birth to Metaverse and further promoted the digital transformation of all aspects of people's material lives [1].

Metaverse has been used for various purposes, including social networking, online gaming, education, and training. It can be used to create virtual worlds that mirror the real world, or it can be used to create entirely new and imaginary worlds. According to academics, one of the most important uses of Metaverse will be in education in the future [2], though Metaverse is still a new concept in the field of education. Metaverse in education can be thought of as an upgraded educational environment that combines components of the real and virtual educational environments with Metaverse-related technologies, which has enabled students to feel engaged as if they are in a real-world educational environment as a result. From this vantage point, it is clear that integrating Metaverse into education can open up a wide range of amazing learning opportunities for students [2]. This is because Metaverse can create a new educational environment [3] that combines elements of the virtual and physical educational environments. Thus, because of Metaverse, educational institutions will be able to provide students and staff with a 360-degree experience and, of course, will be much more flexible and adaptable to unforeseen circumstances [4].

Metaverse has not yet received widespread attention from educational researchers in China since June 2022; using China National Knowledge Infrastructure as the data source, a total of 372 papers with "Metaverse" as the keyword were retrieved, among which papers on the educational Metaverse accounted for approximately 10% [5]. How to integrate deeply into the educational teaching process remains an important proposition in educational research. An important prerequisite is the university teachers' perceptions of Metaverse as well as their acceptance of Metaverse and its related technologies used in their learning and teaching settings. This paper is intended to explore university teachers' perceptions of Metaverse and conduct a questionnaire survey on the current situation and development needs of Metaverse applied in higher education institutions taking teacher groups in Jiangsu, China, as the research sample. This study explores an important yet under-researched area by examining university teachers' perceptions of Metaverse technologies in higher education. By adopting a quantitative approach and focusing on Jiangsu Province, the research offers a unique perspective, particularly through its analysis of demographic factors influencing these perceptions. The findings contribute to the understanding of technology acceptance in educational settings and offer practical insights to support the integration of Metaverse technologies in higher education, both within China and internationally.

II. LITERATURE REVIEW

In 2021, Metaverse became an international buzzword and thus became known as the Year of Metaverse. In recent years, information technology has been fully applied in education, and the integration of technology and education has become increasingly close; however, problems such as insufficient

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interactivity and contextualization in online teaching, poor interaction between teachers and students in offline teaching, and incomplete recording of learning data have still not been effectively addressed. Metaverse is a comprehensive integration of information technology, depicting a panoramic view of the vision of the future information technology revolution. The emergence of Metaverse has naturally become a topic of lively discussion in the field of education. It is important to analyze academic research on Metaverse and to explore its application in the field of education to provide a reference for future reform and innovation in higher education.

The use of Metaverse in numerous fields is growing in popularity because of the potential advantages it offers. Teachers of different levels have shown interest in the application of Metaverse or its enabling technologies in their teaching activities. Mustafa found that teachers have a strong interest in Metaverse, though their knowledge of it is low, and that the majority of them are aware of the potential for using Metaverse in the classroom and for educational purposes [6]. According to Aydin, EFL (English as a Foreign Language) teachers primarily have favorable attitudes toward using Metaverse as a setting for teaching and studying foreign languages and that comparatively, to individuals with MA and Ph.D. degrees, BA holders were more optimistic about the value of Metaverse for comprehending ideas and expressing opinions [7].

For teachers, the knowledge, attitude, and awareness scores of male and female teachers on the concept of Metaverse do not differ significantly. Compared to teachers younger than 31 and older than 40, teachers between the ages of 31 and 40 expressed greater confidence in their ability to use Metaverse in their lesson plans to achieve specific learning objectives [8].

Researchers have also studied what factors have played mediating roles in the teachers' perceptions of the application of Metaverse in education.

- **Perceived Ease of Use (PEU)**. The degree to which people believe their productivity will increase and they will exert less effort when utilizing the technology in issue is referred to as perceived ease of use [8]. Teachers' attitudes about using AI technologies to help teaching are positively influenced by their PEU [9].
- **Perceived Usefulness (PU).** The extent to which users believe they will benefit and perform better as a result of using the technology in question is known as perceived usefulness [10]. According to [11], teachers' PU toward applying AI technologies to support teaching are positively affected by their perceived ease of use.
- **Self-Efficacy (SE)**. Self-efficacy is a term used to describe one's assessment of one's own technological proficiency [12]. According to [13], teachers' attitudes toward implementing particular technologies in the classroom are typically influenced indirectly by their SE. The SE of university teachers would improve their perceptions of usability and usefulness while incorporating AI technology into instruction was less of a concern for teachers who had greater SE [14].

Other variables that may influence the perception and application of Metaverse and its enabling technologies in education include effort expectancy, facilitating conditions [15], perceived enjoyment, and perceived cyber risks [16], perceived benefit, readiness [17], perceived complexity, perceived ubiquity, perceived value [18], and trialability, observability, compatibility, and users' satisfaction [19].

Scholars also conducted quantitative and qualitative research to explore the relations between variables of university teachers' understanding of using Metaverse or Metaverse-related technologies in higher education. Teo noted that ATU (Attitude towards AI) was influenced by the interplay of PU (Perceived Usefulness), PEU (Perceived Ease of Use), and subjective norms, which in turn encouraged teachers to use technology [20].

The effectiveness of using Metaverse in education depends on teachers' attitudes and perspectives as well as their knowledge of it. As they have become increasingly aware that it is helpful to apply Metaverse to education, this research is designed to make a quantitative study of how university teachers perceive Metaverse and its application in higher education based on literature.

A. *Significance of the Study*

Metaverse has now gained great attention since 2021 and has been applied in various fields. Scholars started to conduct research on the application of this technology in higher education. Much of the research has focused on opportunities, challenges, possible risks, and limitations of Metaverse in higher education [21-24]. They also focused on factors affecting the application of Metaverse in universities and colleges and the specific application of Metaverse in certain disciplines, including social science, medical science, and Engineering [25-28]. A greater number of research has been done concerning the United States [29, 30], the United Kingdom [31], Japan [32-34], South Korea [35, 36], Brazil [37], Spain [38], and China [39]. In terms of research objects, researchers have conducted research concerning university teachers' readiness for Metaverse, and sustainable learning of teachers. The research objects of this research are university teachers who had experiences with Metaverse-related technologies applied in their teaching and learning in Nanjing, Jiangsu Province, where new technologies in higher education have been attached great importance to and are supported by students and teachers, as well as administrations.

B. *Research Limitations*

This research has contributed to understanding Metaverse applied in higher education in China's context, but it still has several limitations. The specific target populations of this study are full-time teachers teaching undergraduate students in only a province in China instead of nationwide. The sample size for this research, 389 teacher respondents out of 120,236 full-time teachers, is adequate rather than large enough, which fails to provide enough statistical power to detect meaningful differences. Besides, this study has adopted a questionnaire concerning university teachers without integrating qualitative data; therefore, essential questions ---- the WHY questions or HOW questions, for example ---- may remain unanswered or unexplored.

III. Research Methods

This paper will use quantitative research methods. Quantitative research uses sampling techniques to gather statistically meaningful data from current and future clients [40].

A. Determination of Sample Size

A substantial sample size that accurately represents the target market is used when conducting quantitative research. The specific target populations of this study are full-time teachers teaching undergraduate students in Jiangsu Province. According to the statistics from the Jiangsu Bureau of Statistics (2023), there were 116,615 full-time teachers in 2021 and 123,856 full-time teachers in 2022 in Jiangsu Province, as shown in Table I. An average number of the two years was used to calculate the sample size.

Table I. Numbers Of Undergraduate Students And Teachers In Jiangsu Province In 2021 And 2022 (Jiangsu Bureau Of Statistics (2023))

Year	Full-time Teachers
2021	116,615
2022	123,856
Average	120,236

To determine the sample size for the large population proportion, Cochran created equation (1) [41]. Large populations are best suited for the Cochran formula, which determines the critical sample size for the necessary degree of precision, confidence level, and estimated fraction of the attribute present in the population [42].

$$n_0 = \frac{z^2 \cdot p \cdot (1-p)}{e^2} \quad (1)$$

Where e = Margin of error (percentage in decimal form); p = population proportion (assumed as 50% or 0.5); and z = z-score.

$$n = \frac{n_0}{1+\frac{n_0 - 1}{N}} \quad (2)$$

Where n_0 = sample size computed using the formula for ideal sample size, and N = the size of the population.

The sample size for the teachers' scale is 384 when z = 1.96, p = 0.5, e = 0.05, and N = 120,236. This research found that 389 questionnaires for the teachers' scale were usable. The completed forms were transcribed into the Statistical Package of Social Science 26 (SPSS).

The results of this study are most applicable to regions with similar technological and institutional contexts with Jiangsu Province, a leader in economic and educational development, but may not fully capture the diversity of experiences and attitudes across China or in other countries.

B. Data Collection

Another critical component of quantitative research is using closed-ended questions that are especially created to support the study's goals. In research, a questionnaire is a formal collection of inquiries intended to elicit participant data. It is employed to gather quantitative or qualitative information about participants' beliefs, actions, or traits [40]. The questionnaire designed in this research, "A Study on the Perception of College Teachers regarding the Application of Metaverse in Education", consists of 49 questions, focusing on investigating college teachers' understanding of the application of Metaverse in higher education and their utilization of Metaverse technology in teaching. The questionnaire was structured to integrate original and literature-based questions seamlessly. 12 original questions were designed to capture specific aspects of the research that were not addressed in existing literature. To ensure the reliability and comparability of the data, the other questions were adapted from validated scales found in the literature. For example, questions 16 and 41 were taken from [43].

The questionnaire includes two sections. Section 1 concerns demographic variables for the respondents' backgrounds; Section 2 was designed with 49 closed-ended questions on a 5-point Likert scale, anchored from 1 (strongly disagree) to 5 (strongly agree).

To distribute the data collection instruments via the Internet, invitations were sent to potential participants via email through Wenjuanxing (www.wjx.cn), an online survey tool that allows users to create, publish, and analyze surveys in China.

IV. Results And Findings

A. Analysis of Descriptive Statistics

Description statistics offer concise descriptions of the sample and the observations that have been recorded. These summaries could be sufficient for a specific investigation or serve as the foundation for the initial data description in a more thorough statistical analysis [44].

Table II, Table III, and Table IV show teacher respondents' statistics. As is shown in Table IV.1, the sample showed a more significant number of female (240) than male (149) respondents, representing a ratio of 61.70% and 38.30%, respectively. This gender imbalance reflects the broader teaching workforce in Jiangsu Province. The majority of respondents (54.8%) were aged 40-49 years, 21.60% were aged between 30-39 years old, accounting for the majority of the sample, while 15.40% of the respondents were over 50 years old, and only 8.20% were under 29 years old.

Table II. Frequency Of Teachers' Gender And Age (N=389)

Category	n	%
Gender		
Male	149	38.30%
Female	240	61.70%
Age		
under 29 years old	32	8.20%
30-39 years old	84	21.60%
40-49 years old	213	54.80%
Over 50 years old	60	15.40%

According to Table III, Most respondents hold the title of Lecturer (35.0%) or Associate Professor (29.0%), indicating a balanced representation of mid-level academic staff. A slight majority of respondents (54.8%) hold a Master's degree, while

45.2% have a Doctorate, suggesting a highly educated sample. Over half of the respondents (51.9%) work in regular colleges or universities, while fewer are affiliated with prestigious ‘Double First-Class’ institutions (15.4%).

TABLE III. BACKGROUND INFORMATION OF THE TEACHER RESPONDENTS (N=389)

Category	n	%
Professional Rank and Title		
Professor	78	19.5%
Associate Professor	113	29.0%
Assistant Professor	44	11.3%
Lecturer	136	35.0%
Highest Academic Qualification		
Doctor	176	45.2%
Master	213	54.8%
Higher Educational Institutions They Work with		
‘Double First-Class’ Educational Institutions	60	15.4%
Educational Institutions with ‘Double First-Class’ Disciplines	127	32.6%
Normal Colleges or Universities	202	51.9%
Years of Teaching		
0-5 years	42	10.8%
6-10 years	39	10.0%
11-15 years	87	22.4%
16-20 years	138	35.5%
Over 21 years	83	21.3%
0-5 years	42	10.8%

Note. ‘Double First-Class’ educational institutions refer to universities or colleges in China that are part of the *Double First-Class Initiative*, a national strategy launched by the Chinese government in 2015. The initiative aims to develop a group of world-class universities and disciplines by improving the quality of higher education and research in China (Minister of Education).

Table IV shows how teacher respondents were familiar with Metaverse-related technologies. Teachers are most familiar with Virtual Reality (55.3%), followed by Artificial Intelligence (47.8%) and the Internet of Things (47.6%). Familiarity with Metaverse technology is relatively low (36.5%), indicating that while some teachers are aware of the concept, it is not yet widely understood or adopted. Emerging technologies like Blockchain (15.9%) and GameFi (14.7%) have the lowest familiarity, suggesting a need for further training.

TABLE IV. TEACHERS’ FAMILIARITY WITH METAVERSE-RELATED TECHNOLOGIES

Technology	Very Familiar + Familiar (n=389)
VR (Virtual Reality)	215 (55.3%)
AI (Artificial Intelligence)	186 (47.8%)
IoT (Internet of Things)	185 (47.6%)
Metaverse	142 (36.5%）
AR (Augmented Reality)	98 (25.2%)
Digital Twins	80 (20.6%)
Cloud computing	74 (19.0%)
High-performance computing	70 (18.0%)
Blockchain technology	62 (15.9%)
Gamefi	57 (14.7%)

B. Exploratory Factor Analysis (EFA)

The researcher intends to determine the number of factors of university teachers’ perception of Metaverse. The main objectives of EFA include reducing the number of variables, examining the structure or relationship between variables, detecting and assessing the unidimensionality of a theoretical construct, and evaluating the construct validity of a scale, test, or instrument [45]. The suitability of the respondent data for factor analysis should be evaluated using several tests before the factors are extracted. Bartlett’s Test of Sphericity [46] and the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy [47] are two examples of these tests. When the cases-to-variable ratio is smaller than 1:5, the KMO index, in particular, is advised. The KMO index ranges from 0 to 1, with a value of 0.50 being appropriate for factor analysis. To be appropriate, factor analysis requires a substantial ($p<0.05$) Bartlett’s Test of Sphericity [48, 49]. Factor analysis helped the researchers identify the main constructs (e.g., benefits, effectiveness, challenges) that define teachers’ perceptions. This analysis provided a deeper understanding of how teachers conceptualize Metaverse technologies and their applications in higher education, aligning with the study’s goal of exploring perceptions in a systematic and data-driven manner.

The KMO Measure of the Sampling Adequacy coefficient is .97, the sample size is good enough for factor analysis, and Bartlett’s Test of Sphericity is significant (Chi-square = 16689.64, $p = .00 < .05$) confirmed that the data has patterned relationships. Ten questions were eliminated from the study as factor loadings and eigenvalues were used as the relationship between the factors and the research questions is very weak, and the factors cannot effectively extract information from them. Then, a Varimax rotation was applied to achieve a simpler and more interpretable factor structure, assuming that the factors are uncorrelated. The Varimax rotation model was fit to three factors as after rotation, the factor loadings revealed a clear structure, with each item loading strongly on a single factor and minimal cross-loadings. Three factors have been extracted, and 45.26% of the item variance was accounted for by factor 1, 15.73% by factor 2, and 9.45% by factor 3. 3 variables together account for 70.44% of the variation.

The removed questions are 7 (Metaverse educational platforms provide sufficient safety measures that make me feel at ease while using them for educational purposes.), 8 (I have no concerns that Metaverse educational platforms will distribute my data without my permission.), 17 (I appreciate the realism of the virtual environment (avatars and scenery) on Metaverse.), 19 (Access to Metaverse platforms can be expensive.), 33 (Metaverse educational platforms enhance the quality of my student’s learning.), 36 (Using Metaverse in education makes my students’ learning easier.), 38 (When Metaverse platforms used, my students feel fully engaged in the learning process and can experience it with all their senses.), 43 (Metaverse educational environments increase my students’ motivation to learn.), 44 (I believe that my students are ready for Metaverse in education.), 45 (I believe that my school is ready for Metaverse in education.), and 47 (My students can benefit more from Metaverse education than traditional education because the former is more flexible for them.).

The results of factor analysis on teachers’ perception of Metaverse in education are presented in Table V.

A measurement’s consistency is evaluated by reliability. A measurement instrument’s internal consistency and credibility can be evaluated using a variety of metrics. Cronbach’s alpha [50] was utilized to assess each factor’s reliability. If a factor’s

Cronbach alpha is at least 0.70, it is regarded as dependable. The scale of Cronbach's alpha for Teachers' Perception of the Metaverse in the Education dimension is 0.97, both indicating a high reliability.

TABLE V. FACTOR ANALYSIS RESULTS

Variables and Measurement Items	***Factor Loading***	***Cronbach's Alpha***
Benefits of Metaverse		0.98
BOM 1	0.764	
BOM 2	0.739	
BOM 3	0.712	
BOM 4	0.764	
BOM 5	0.791	
BOM 6	0.770	
BOM 7	0.807	
BOM 8	0.793	
BOM 9	0.634	
BOM 10	0.777	
BOM 11	0.638	
BOM 12	0.630	
BOM 13	0.653	
BOM 14	0.711	
BOM 15	0.712	
BOM 16	0.728	
BOM 17	0.716	
BOM 18	0.641	
BOM 19	0.664	
BOM 20	0.684	
BOM 21	0.714	
BOM 22	0.611	
BOM 23	0.633	
BOM 24	0.384	
BOM 25	0.782	
BOM 26	0.782	
BOM 27	0.753	
BOM 28	0.777	
Variables and Measurement Items	***Factor Loading***	***Cronbach's Alpha***
BOM 29	0.785	
Effectiveness of Metaverse		0.87
EOM 1	0.767	
EOM 2	0.792	
EOM 3	0.718	
EOM 4	0.550	
EOM 5	0.520	
Challenges of Metaverse		0.85
COM 1	0.783	
COM 2	0.793	
COM 3	0.674	
COM 4	0.620	

C. Comparative Analysis

The independent sample t-test compares the means of two samples from unrelated populations. This suggests that different samples are adding points to each group. By using t-tests, the researchers were able to assess whether specific groups (e.g., male vs. female teachers or Master's vs. Doctorate holders) differ significantly in their perceptions.

An independent sample t-test was run to see if gender plays a statistically significant role in teacher's understanding of Metaverse, and the results show that males and females are significantly different in their understanding of five items of the scale (Table VI). Statistics showed that female teachers (M=2.78, SD=0.83) found joining a Metaverse educational platform easier than male teachers (M=2.60, SD=0.89). It was statistically easier for female teachers (M=2.88, SD=0.94) to become skilled at using a Metaverse educational platform than male teachers (M=2.65, SD=0.94). More female teachers (M=2.40, SD=0.83) than male teachers (M=2.15, SD=0.89) assume that they will use Metaverse educational platforms. Compared with female teachers (M=3.46, SD=0.99), male teachers (M=3.74, SD=1.03) cannot distinguish the virtual world on Metaverse from the real world. Female teachers (M=2.46, SD=0.91) feel more than male teachers (M=2.22, SD=0.94) that their students could become addicted to the digital games on Metaverse. Female teachers found it easier to join and become skilled at using Metaverse educational platforms compared to male teachers. Female teachers were more likely to assume they would use Metaverse platforms in their teaching. Male teachers, however, found it harder to distinguish between the virtual and real worlds in Metaverse. Female teachers expressed more concern about students potentially becoming addicted to digital games on Metaverse.

TABLE VI. INDEPENDENT SAMPLES T-TESTS ON GENDER VS FIVE ITEMS IN THE SCALE

Item	**Gender**	***n***	***M***	***SD***	**t-test**		
					t	*df*	*p*
1	Male	149	2.60	0.89	-2.10	387	0.037
	Female	240	2.78	0.83			
2	Male	149	2.65	0.94	-2.37	387	0.018
	Female	240	2.88	0.94			
9	Male	149	2.15	0.89	-2.84	387	0.005
	Female	240	2.40	0.83			
18	Male	149	3.74	1.03	2.73	387	0.007
	Female	240	3.46	0.99			
41	Male	149	2.22	0.94	-2.48	387	0.014
	Female	240	2.46	0.91			

An independent sample t-test was run to see if the teachers' academic qualifications make a statistically significant difference. As is shown in Table VI, there are statistically significant differences for the 26 items as the p-values are less than 0.05. For items 41 and 42, teachers with a Doctor's Degree had higher mean scores than teachers with a Master's Degree. For the other 24 items, teachers with a Master's Degree had higher mean scores than teachers with a Doctor's Degree.

TABLE VII. INDEPENDENT SAMPLE T-TESTS ON ACADEMIC QUALIFICATIONS VS. 26 ITEMS IN THE SCALE

Item	**Academic qualification**	***n***	***M***	***SD***	**t-test**		
					t	***df***	***p***
4	Doctor	176	2.16	0.98	-5.897	387	0.000
	Master	213	2.74	0.95			
5	Doctor	176	2.17	1.00.	-5.985	387	0.000
	Master	213	2.77	0.99			
6	Doctor	176	2.46	0.96	-7.092	387	0.000
	Master	213	3.14	0.93			
9	Doctor	176	1.99	0.88	-6.959	387	0.000
	Master	213	2.56	0.75			
10	Doctor	176	2.12	0.95	-6.333	387	0.000
	Master	213	2.72	0.91			
11	Doctor	176	2.13	0.92	-4.805	387	0.000
	Master	213	2.56	0.86			
12	Doctor	176	1.98	0.89	-5.635	387	0.000
	Master	213	2.48	0.87			
16	Doctor	176	2.95	1.00	-2.180	387	0.030
	Master	213	3.17	0.99			
20	Doctor	176	2.06	0.87	-5.697	387	0.000
	Master	213	2.55	0.84			
21	Doctor	176	2.32	0.81	-6.471	387	0.000
	Master	213	2.86	0.84			
22	Doctor	176	2.38	0.85	-6.926	387	0.000

Item	Academic qualification	n	M	SD	t-test		
					t	df	p
	Master	213	2.99	0.88			
23	Doctor	176	2.51	0.93	-5.781	387	0.000
	Master	213	3.07	0.99			
24	Doctor	176	2.15	0.98	-6.793	387	0.000
	Master	213	2.84	1.01			
25	Doctor	176	2.15	0.95	-7.171	387	0.000
	Master	213	2.87	1.03			
26	Doctor	176	2.14	0.98	-7.052	387	0.000
	Master	213	2.87	1.04			
27	Doctor	176	2.18	1.00	-6.438	387	0.000
	Master	213	2.85	1.06			
28	Doctor	176	2.22	0.97	-6.549	387	0.000
	Master	213	2.89	1.03			
31	Doctor	176	2.32	0.81	-5.736	387	0.000
	Master	213	2.81	0.88			
34	Doctor	176	2.49	1.01	-5.354	387	0.000
	Master	213	3.05	1.04			
35	Doctor	176	2.67	1.07	-5.024	387	0.000
	Master	213	3.20	1.02			
37	Doctor	176	2.60	0.98	-5.846	387	0.000
	Master	213	3.19	1.02			
41	Doctor	176	2.48	0.90	2.140	387	0.033
	Master	213	2.28	0.93			
42	Doctor	176	2.94	0.90	3.538	387	0.000
	Master	213	2.61	0.92			
46	Doctor	176	2.42	0.94	-6.510	387	0.000
	Master	213	3.06	1.00			
48	Doctor	176	2.24	0.89	-4.425	387	0.000
	Master	213	2.63	0.87			
49	Doctor	176	2.24	0.93	-5.636	387	0.000
	Master	213	2.79	0.97			

Independent sample t-tests were run with respect to each factor of the teachers' scale. In Table VIII, Levene's test shows that p-values for all 3 Factors are greater than 0.05, and group variances are equal. There is a statistically significant difference in Doctor teachers' and Master Teachers' perception of the Benefits of Metaverse, Effectiveness of Metaverse, and Challenges of Metaverse. Master teachers have better perceptions than Doctor teachers of the Benefits and Effectiveness of the Metaverse; Doctor teachers know the Challenges of the Metaverse statistically better than Master teachers. Teachers with Master's degrees perceived more benefits and effectiveness of Metaverse, while those with Doctoral degrees were more attuned to its challenges.

TABLE VIII. INDEPENDENT SAMPLE T-TESTS ON HIGHEST ACADEMIC QUALIFICATION VS. 3 FACTORS IN THE TEACHERS' SCALE

Factor	Academic Qualification	n	M	SD	t-test		
					t	df	p
BOM	Doctor	176	2.25	0.75	-7.363	387	0.000
	Master	213	2.82	0.76			
EOM	Doctor	176	2.84	0.81	-5.008	387	0.000
	Master	213	3.25	0.82			
COM	Doctor	176	2.65	0.69	2.228	387	0.026
	Master	213	2.49	0.73			

The study aims to explore how different demographic variables, such as age and teaching experience, influence teachers' perceptions of Metaverse. ANOVA allowed the researchers to determine whether teachers with varying levels of experience or from different age groups had significantly different perceptions of the benefits, effectiveness, and challenges of Metaverse. A one-way ANOVA test was run to see if different years of teaching play a statistically significant role in teachers' perception of Metaverse and their application of Metaverse in education. In Table IX, teachers with more years of teaching experience had a statistically better understanding of Metaverse and were more adept at applying it in their teaching. This suggests that experienced teachers may have a broader perspective on the potential benefits and challenges of Metaverse technologies.

TABLE IX. ONE-WAY ANOVA RESULTS BASED ON TEACHERS' YEARS OF TEACHING

	Years of Teaching (Years) M (SD)					F	Post hoc Analysis
	(1) 0-5 (n=42)	(2) 6-10 (n=39)	(3) 11-15 (n=87)	(4) 16-20 (n=138)	(5) Over 21 (n=83)		
3	2.86 (0.95)	3.00 (0.92)	3.02 (1.01)	2.95 (0.98)	3.51 (0.76)	5.718*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
4	2.33 (1.07)	2.46 (0.88)	2.38 (0.93)	2.25 (0.89)	3.06 (1.06)	10.171*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
5	2.33 (1.07)	2.54 (0.91)	2.45 (0.99)	2.21 (0.94)	3.11 (1.04)	11.313*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
6	2.67 (0.98)	2.72 (0.92)	2.86 (0.99)	2.56 (0.94)	3.40 (0.94)	10.616*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
9	2.07 (0.84)	2.38 (0.85)	2.23 (0.76)	2.08 (0.86)	2.83 (0.76)	12.522*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
10	2.40 (1.01)	2.56 (0.91)	2.36 (0.88)	2.16 (0.94)	2.99 (0.93)	10.734*	(1)<(5) (3)<(5) (4)<(5)
11	2.19 (1.04)	2.21 (0.86)	2.39 (0.84)	2.15 (0.81)	2.84 (0.93)	8.995*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
15	2.43 (1.09)	2.54 (0.88)	2.30 (0.92)	2.14 (0.90)	2.95 (1.11)	9.449*	(1)<(5) (3)<(5) (4)<(5)
20	2.31 (0.95)	2.41 (0.79)	2.23 (0.77)	2.07 (0.87)	2.84 (0.86)	11.404*	(1)<(5) (3)<(5) (4)<(5)
21	2.50 (0.99)	2.56 (0.91)	2.59 (0.79)	2.43 (0.78)	3.05 (0.88)	7.444*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
22	2.62 (1.01)	2.69 (0.92)	2.59 (0.87)	2.52 (0.87)	3.20 (0.84)	8.631*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
23	2.79 (1.07)	2.87 (0.89)	2.67 (0.94)	2.60 (0.92)	3.31 (1.05)	7.776*	(1)<(5) (3)<(5) (4)<(5)
24	2.52 (1.09)	2.54 (1.10)	2.37 (0.97)	2.27 (0.90)	3.13 (1.10)	10.445*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
25	2.31 (1.14)	2.36 (1.01)	2.46 (1.09)	2.35 (0.92)	3.17 (1.00)	10.315*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
26	2.40 (1.11)	2.36 (1.04)	2.49 (1.01)	2.28 (0.98)	3.18 (1.05)	11.014*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
27	2.45 (1.09)	2.51 (1.17)	2.46 (1.05)	2.25 (0.94)	3.20 (1.06)	11.615*	(1)<(5) (2)<(5) (3)<(5)

	Years of Teaching (Years)					F	Post hoc Analysis
	M (SD)						
	(1) 0-5 (n=42)	(2) 6-10 (n=39)	(3) 11-15 (n=87)	(4) 16-20 (n=138)	(5) Over 21 (n=83)		
							(4)<(5)
31	2.55 (0.92)	2.56 (0.91)	2.55 (0.85)	2.38 (0.81)	3.01 (0.86)	7.326*	(1)<(5) (3)<(5) (4)<(5)
32	2.50 (0.94)	2.44 (0.97)	2.48 (0.83)	2.28 (0.76)	2.95 (0.90)	8.339*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
37	2.93 (1.16)	2.97 (0.90)	2.84 (1.00)	2.68 (0.98)	3.39 (1.06)	6.449*	(3)<(5) (4)<(5)
41	2.19 (0.89)	2.41 (0.94)	2.28 (0.90)	2.62 (0.87)	2.12 (0.96)	4.789*	(3)<(4) (5)<(4)
46	2.81 (1.15)	2.79 (0.92)	2.68 (0.98)	2.50 (0.95)	3.29 (0.96)	8.689*	(3)<(5) (4)<(5)
48	2.48 (0.97)	2.49 (0.94)	2.32 (0.91)	2.28 (0.81)	2.86 (0.86)	6.219*	(3)<(5) (4)<(5)
49	2.55 (1.06)	2.62 (0.82)	2.45 (1.01)	2.31 (0.93)	2.99 (0.96)	6.771*	(3)<(5) (4)<(5)

*p < 0.05.

A one-way ANOVA test was run to see if teachers' different attitudes towards new technology play a statistically significant role in their perception of Metaverse and their application of Metaverse in education. In Table X, Levene's test of homogeneity of variances shows that the group variances are equal. Generally, teachers who like new technologies have a statistically worse understanding of Metaverse than those who are hesitant to use new technology and are not interested in new technologies in education.

TABLE X. ONE-WAY ANOVA RESULTS BASED ON TEACHERS' ATTITUDES TOWARD NEW TECHNOLOGIES

	Attitudes towards New Technology			F	Post hoc Analysis
	M (SD)				
	A (n=165)	*B (n=131)*	*C (n=93)*		
1	2.25 (0.77)	2.85 (0.73)	3.33 (0.70)	68.127*	A<B<C
2	2.25 (0.81)	3.02 (0.84)	3.44 (0.76)	71.432*	A<B<C
5	1.88 (0.80)	2.57 (0.82)	3.49 (0.86)	115.100*	A<B<C
6	2.30 (0.82)	2.89 (0.78)	3.71 (0.92)	85.590*	A<B<C
23	2.30 (0.70)	2.79 (0.91)	3.82 (0.81)	106.197*	A<B<C
35	2.42 (0.77)	2.98 (1.00)	3.89 (0.97)	78.298*	A<B<C
37	2.44 (0.76)	2.90 (0.98)	3.82 (0.99)	71.081*	A<B<C
41	2.73 (0.84)	2.38 (0.82)	1.71 (0.84)	44.248*	C<B<A
42	3.05 (0.87)	2.77 (0.86)	2.23 (0.87)	26.903*	C<B<A
46	2.22 (0.78)	2.76 (0.88)	3.75 (0.83)	102.488*	A<B<C

*p < 0.05.

Note. A. I like new technologies so I would look for ways to experiment with them.

B. I am hesitant to try out new technologies, but I will try them.

C. I am not interested in new technologies and only work on them as required.

Statistics in Table XI show that teachers' age has a statistically significant influence on their perceptions of the Benefits of the Metaverse (Factor 1), their perceptions of the Effectiveness of the Metaverse (Factor 2), and the Challenge of the Metaverse (Factor 3). For Benefits of Metaverse, teachers over 50 years old have a better perception than teachers from other age groups. For the Effectiveness of Metaverse, teachers over 50 years old have a better perception than teachers aged between 30 and 39 and teachers between 40 and 49. Teachers between 30 and 49 have a statistically better understanding than older teachers concerning the Challenges of Metaverse. Older teachers (over 50) are more optimistic about the benefits and effectiveness of Metaverse, possibly due to their broader experience and less direct engagement with its challenges. Teachers aged 30-49 are more critical, likely due to their active involvement in integrating technology into teaching and encountering practical challenges.

TABLE XI. ONE-WAY ANOVA RESULTS OF 3 FACTORS BASED ON TEACHERS' AGE

	Age (Years old)				F	Post hoc Analysis
	M (SD)					
	A < 29 (n=32)	B 30-39 (n=84)	C 40-49 (n=213)	D >50 (n=60)		
BOM	2.54 (0.92)	2.50 (0.80)	2.38 (0.67)	3.25 (0.81)	21.551*	A<D B<D C<D
EOM	3.34 (0.96)	3.09 (0.88)	2.85 (0.66)	3.64 (0.97)	17.068*	C<A B<D C<D
COM	2.48 (0.05)	2.51 (0.76)	2.71 (0.66)	2.18 (0.71)	9.771*	D<B D<C

*p < 0.05.

A one-way ANOVA test was run to see if different years of teaching play a statistically significant role in teachers' perception of Metaverse and their application of Metaverse in education. The results show that different years of teaching have played a significantly important role concerning 23 items in the scale, as shown in Table XII. Generally, teachers who teach for a longer time in college or university have a statistically better understanding of Metaverse and are better at applying Metaverse in their teaching.

TABLE XII. TUKEY POST-HOC TEST RESULTS OF DIFFERENTIATED QUESTIONS BASED ON TEACHERS' YEARS OF TEACHING

	Years of Teaching (Years)					F	Post hoc Analysis
	M (SD)						
	(1) 0-5 (n=42)	*(2) 6-10 (n=39)*	*(3) 11-15 (n=87)*	*(4) 16-20 (n=138)*	*(5) Over 21 (n=83)*		
3	2.86 (0.95)	3.00 (0.92)	3.02 (1.01)	2.95 (0.98)	3.51 (0.76)	5.718*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
4	2.33 (1.07)	2.46 (0.88)	2.38 (0.93)	2.25 (0.89)	3.06 (1.06)	10.171*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
5	2.33 (1.07)	2.54 (0.91)	2.45 (0.99)	2.21 (0.94)	3.11 (1.04)	11.313*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
6	2.67 (0.98)	2.72 (0.92)	2.86 (0.99)	2.56 (0.94)	3.40 (0.94)	10.616*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
9	2.07 (0.84)	2.38 (0.85)	2.23 (0.76)	2.08 (0.86)	2.83 (0.76)	12.522*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)

10	2.40 (1.01)	2.56 (0.91)	2.36 (0.88)	2.16 (0.94)	2.99 (0.93)	10.734*	(1)<(5) (3)<(5) (4)<(5)
11	2.19 (1.04)	2.21 (0.86)	2.39 (0.84)	2.15 (0.81)	2.84 (0.93)	8.995*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
15	2.43 (1.09)	2.54 (0.88)	2.30 (0.92)	2.14 (0.90)	2.95 (1.11)	9.449*	(1)<(5) (3)<(5) (4)<(5)
20	2.31 (0.95)	2.41 (0.79)	2.23 (0.77)	2.07 (0.87)	2.84 (0.86)	11.404*	(1)<(5) (3)<(5) (4)<(5)
21	2.50 (0.99)	2.56 (0.91)	2.59 (0.79)	2.43 (0.78)	3.05 (0.88)	7.444*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
22	2.62 (1.01)	2.69 (0.92)	2.59 (0.87)	2.52 (0.87)	3.20 (0.84)	8.631*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
23	2.79 (1.07)	2.87 (0.89)	2.67 (0.94)	2.60 (0.92)	3.31 (1.05)	7.776*	(1)<(5) (3)<(5) (4)<(5)
24	2.52 (1.09)	2.54 (1.10)	2.37 (0.97)	2.27 (0.90)	3.13 (1.10)	10.445*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
25	2.31 (1.14)	2.36 (1.01)	2.46 (1.09)	2.35 (0.92)	3.17 (1.00)	10.315*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
26	2.40 (1.11)	2.36 (1.04)	2.49 (1.01)	2.28 (0.98)	3.18 (1.05)	11.014*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
27	2.45 (1.09)	2.51 (1.17)	2.46 (1.05)	2.25 (0.94)	3.20 (1.06)	11.615*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
31	2.55 (0.92)	2.56 (0.91)	2.55 (0.85)	2.38 (0.81)	3.01 (0.86)	7.326*	(1)<(5) (3)<(5) (4)<(5)
32	2.50 (0.94)	2.44 (0.97)	2.48 (0.83)	2.28 (0.76)	2.95 (0.90)	8.339*	(1)<(5) (2)<(5) (3)<(5) (4)<(5)
37	2.93 (1.16)	2.97 (0.90)	2.84 (1.00)	2.68 (0.98)	3.39 (1.06)	6.449*	(3)<(5) (4)<(5)
41	2.19 (0.89)	2.41 (0.94)	2.28 (0.90)	2.62 (0.87)	2.12 (0.96)	4.789*	(3)<(4) (5)<(4)
46	2.81 (1.15)	2.79 (0.92)	2.68 (0.98)	2.50 (0.95)	3.29 (0.96)	8.689*	(3)<(5) (4)<(5)
48	2.48 (0.97)	2.49 (0.94)	2.32 (0.91)	2.28 (0.81)	2.86 (0.86)	6.219*	(3)<(5) (4)<(5)
49	2.55 (1.06)	2.62 (0.82)	2.45 (1.01)	2.31 (0.93)	2.99 (0.96)	6.771*	(3)<(5) (4)<(5)

*p < 0.05.

As shown in Table XIII, teachers' years of teaching have a statistically significant influence on their perception of all three Factors. Teachers with more than 21 years of teaching have a better perception of the benefits of Metaverse (Factor 1) than teachers with fewer years of teaching. Teachers with over 21 years of teaching experience have a statistically better understanding of Metaverse concerning its challenges (Factor 2) than teachers with only 0-5 years of teaching experience and teachers with 11-15 years of teaching. For Challenges of Metaverse (Factor 3), teachers with 16-20 years of teachers have a statistically better perception than Teachers with over 21 years of teaching experience.

TABLE XIII. ONE-WAY ANOVA RESULTS OF 3 FACTORS BASED ON TEACHERS' YEARS OF TEACHING

	Years of Teaching (Years) M (SD)					F	Post hoc Analysis
	A *0-5 (n=42)*	***B*** *6-10 (n=39)*	***C*** *11-15 (n=87)*	***D*** *16-20 (n=138)*	***E*** *Over 21 (n=83)*		
BOM	2.46 (0.89)	2.51 (0.74)	2.49 (0.73)	2.32 (0.70)	3.07 (0.80)	13.258*	A<E B<E C<E D<E
EOM	3.12 (1.00)	3.14 (0.72)	2.91 (0.84)	2.91 (0.84)	3.43 (0.91)	6.528*	C<E D<E
COM	2.43 (0.68)	2.60 (0.73)	2.49 (0.70)	2.73 (0.68)	2.41 (0.76)	3.299*	D>E

*p < 0.05.

Teachers' attitudes towards education-related new technologies have a statistically significant influence on their perception of the Benefits of the Metaverse (Factor 1), the Effectiveness of the Metaverse (Factor 2), and the Challenges of the Metaverse (Factor 3), as shown in Table XIV. As for the benefits of Metaverse and the Effectiveness of Metaverse, teachers who use new technology only upon request have greater means than teachers who are hesitant to use new technologies and teachers who like new technologies. In terms of the Challenges of Metaverse, teachers who like new technologies have better perceptions than teachers who use new technology only upon request, while teachers who are hesitant to use new technologies have the least understanding. Teachers hesitant to adopt new technologies had a better understanding of Metaverse's benefits, while tech-savvy teachers focused more on its challenges.

TABLE XIV. ONE-WAY ANOVA RESULTS OF 3 FACTORS BASED ON TEACHERS' ATTITUDES TOWARD NEW TECHNOLOGIES

	Attitudes Towards New Technologies M (SD)			F	Post hoc Analysis
	A *(n=165)*	***B*** *(n=131)*	***C*** *(n=93)*		
BOM	2.05 (0.58)	2.59 (0.65)	3.40 (0.60)	146.269*	A<B<C
EOM	2.67 (0.57)	3.02 (0.78)	3.83 (0.79)	81.056*	A<B<C
COM	2.83 (0.68)	2.60 (0.62)	2.04 (0.62)	44.555*	A>B>C

*p < 0.05.

Note. A. I like new technologies so I would look for ways to experiment with them.
B. I am hesitant to try out new technologies, but I will try them.
C. I am not interested in new technologies and only work on them as required.

V. DISCUSSION

This research is designed to find out how university teachers in China perceive Metaverse-related technologies and their application in higher educational institutions. Data collected through two questionnaires from 389 university teachers in Jiangsu Province, China, have been thoroughly analyzed quantitatively. Based on statistical analyses, several findings have been discovered.

The results show that male and female teachers have no statistically different perceptions of the Benefits of Metaverse and the Effectiveness of Metaverse. This differs from the findings in [50] when they conclude that male teachers know more about Metaverse and have more application of Metaverse than their female counterparts. According to [7], female teachers appeared to have a more positive perception of Metaverse's potential benefits for education. Gender makes no statistical difference in teachers' understanding of the Challenges of the Metaverse, which echoes the conclusion of [52] that there is no statistical difference between male and female teachers concerning what they know about and how they perceive Metaverse as well as their awareness scores. The lack of gender-based differences in this study suggests a shift in how both male and female teachers engage with emerging technologies like Metaverse. This could indicate that gender is becoming less of a determinant in technology adoption, possibly due to increased access to training and resources for both genders.

The results show that Master teachers have statistically better perceptions of the Benefits of Metaverse and the Effectiveness of Metaverse while Doctor teachers have statistically better perceptions of the Challenges of Metaverse. Reference [7] points out in his research that Ph.D. graduates feel more comfortable choosing Metaverse environments to fit their students' work. In contrast, MA graduates are more optimistic about Metaverse's utility for conceptual understanding and thought expression. This finding suggests that master's degree holders may focus more on the practical and immediate benefits of Metaverse, while Ph.D. holders, with their deeper engagement in research, maybe more attuned to the challenges and limitations. This highlights the need for tailored professional development programs that address the specific needs and perspectives of teachers based on their academic qualifications.

Teachers of different ages have statistically different understandings of the Benefits of Metaverse, Effectiveness of Metaverse, and Challenges of Metaverse. Teachers of 50 years and older have a better perception of the Benefits of the Metaverse than teachers of any other age; teachers between 40 and 49 years of age have the slightest understanding of the Effectiveness of Metaverse. Teachers between 30 and 49 have a statistically better understanding than older teachers concerning the Challenges of Metaverse. This contradicts [51], which concluded that age has a significant influence on the acceptance of Metaverse because younger people accept Metaverse more frequently and expect it to be implemented in schools sooner. The positive perception of older teachers toward the benefits of Metaverse may reflect their broader teaching experience and ability to see the potential long-term value of new technologies. Conversely, younger teachers' focus on challenges could stem from their familiarity with the practical limitations of emerging technologies. This divergence underscores the importance of addressing age-specific concerns and expectations when designing training and support programs for Metaverse adoption.

Teachers with more than 21 years of teaching have a better perception of the benefits of Metaverse (Factor 1) than teachers with fewer years of teaching. Teachers with over 21 years of teaching experience have a statistically better understanding of Metaverse concerning its Challenges (Factor 2) than teachers with only 0-5 years of teaching experience and teachers with 11-15 years of teaching. For Challenges of Metaverse (Factor 3), teachers with 16 – 20 years of teaching have statistically better perceptions than teachers with over 21 years of teaching experience.

The results show that teachers with different years of teaching have statistically different perceptions of the Benefits of Metaverse, the Effectiveness of Metaverse, and the Challenges of Metaverse. Basically, the more years of teaching teachers have, the better is their perception of Metaverse. Teachers who like new technologies and teachers who use new technology only upon request have a better understanding of Metaverse. Experienced teachers may have a broader perspective on how to integrate new technologies effectively, while mid-career teachers may be more critical of specific challenges due to their active engagement with evolving pedagogical practices. This highlights the need for differentiated training programs that leverage the strengths of experienced teachers while addressing the concerns of mid-career educators.

The results show that teachers who are hesitant to use new technologies have a better understanding of the Benefits and Effectiveness of Metaverse, while teachers who like new technologies have the best understanding of the Challenges of Metaverse.

In conclusion, demographic variables, attitudes, and institutional factors all play a critical role in shaping these perceptions. Addressing these factors through targeted interventions and further research will be essential for the successful integration of Metaverse technologies in higher education.

VI. Conclusion

The study has examined how university teachers in China perceive Metaverse and related technologies applied in higher educational institutions in China. By quantitative analyses of data collected through a questionnaire among university teachers in Jiangsu Province in China, this research answers the following questions: the impact of demographic variables on the impact of demographic variables on university teachers' perception of Metaverse used in Education, with the conclusion that teachers of different gender, academic qualifications, age, years of teaching, and attitudes towards education-related technologies have different perceptions of Metaverse.

A. Practical Implications

In recent years, Metaverse, as a potential platform to enhance teaching and learning experiences in higher educational settings, has gained great popularity. By employing quantitative research methods, researchers can gather empirical data to evaluate the effectiveness of Metaverse in higher education and identify areas for improvement.

University teachers can benefit from the study by learning more about how students view and use Metaverse technologies in higher education. This knowledge can help teachers modify their lesson plans and curriculum to better suit their students' requirements and preferences by offering engaging activities, real-world simulations, and hands-on learning experiences through integrating Metaverse tools and resources into their courses. On the other hand, the study's findings can help university instructors improve their professional development chances and increase their understanding of using Metaverse technology in their classrooms. Personalized student support, collaborative learning, and the successful integration of Metaverse tools into classes are all areas in which teachers can be trained. They can also promote peer-to-peer interactions, group projects, and conversations to strengthen learning outcomes.

In or to overcome barriers to Metaverse adoption, teachers can attend workshops and training sessions focused on Metaverse technologies to improve their technical skills and understanding of how to integrate these tools into their teaching practices. They can also engage in peer-to-peer learning and knowledge-sharing sessions. They may also learn how to integrate Metaverse tools with their teaching objectives, ensuring that the technology enhances learning outcomes rather than being used for novelty.

B. Implication for Future Research

Larger-scale studies can be conducted to explore further the perceptions of university teachers towards Metaverse in higher education in bigger areas in China, including a more diverse sample of participants from different regions and institutions. Qualitative research can also be made concerning how Metaverse potentially influences teaching and learning outcomes, such as student engagement, motivation, and academic performance. Even though Metaverse education is still in its infancy, it has a very bright future ahead of it since, in terms of resources, environment, and manner of instruction, it has significantly overcome the constraints of traditional blended learning and online education [30].

Future studies could concentrate on how Metaverse enables university teachers to shift from a single-teacher to a dual-teacher or even multi-teacher teaching model, as well as how Metaverse makes learning more convenient for students by offering a widely accepted and credible paradigm of wisdom learning in addition to a rich, immersive experiential learning process.

Solving the challenges and barriers university teachers face is another potential topic for future researchers in integrating Metaverse into their teaching and learning practices, and strategies to overcome these obstacles can be identified. The potential ethical and privacy concerns associated with using Metaverse in higher education can be explored, and related guidelines and best practices for ensuring the responsible and ethical use of this technology can be developed. The role of institutional support and resources in facilitating the adoption and implementation of Metaverse in higher education in China can be examined.

Before the concept of the education Metaverse became popular, the Chinese government had already provided strong support for applying core enabling technologies such as AI, VR, and AR in education. However, due to the futuristic nature of the educational Metaverse vision and the immaturity of existing related technologies, as well as the relatively simplistic nature of research and design in the educational application of core enabling technologies, the current conclusions of research in terms of validity, generalizability, etc., are limited. There is still a long way to go for the journey from theory to realizing the educational Metaverse.

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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.

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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DATA AVAILABILITY

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

ETHICAL STATEMENT

In this article, the principles of scientific research and publication ethics were followed. This study did not involve human or animal subjects and did not require additional ethics committee approval.

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