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ORIGINAL RESEARCH

Exploring the psychological effects of Metaverse on mental health and well-being

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Abstract
Recent advancements in the domain of virtual reality have culminated in the development of the Metaverse, a comprehensive virtual environment fostering interactions among individuals and digital entities. This study undertakes an analytical exploration of the Metaverse's implications on mental health, overall well-being, and disability with a focused application to the tourism sector. The constructed model incorporates variables such as activity type within the Metaverse, usage frequency, and an individual's existing mental health state and consideration for disability. Using Habitat Simulator and the Oculus Rift simulator, the research simulates diverse scenarios to discern the Metaverse's influence on mental health, including its impact on individuals with disabilities in a tourism context. Our findings reveal a dichotomous impact: the nature of the engaged activity governs whether the effects on mental health and well-being, including those specific to disability, are beneficial or detrimental. The present research enhances the understanding of the Metaverse's impact on mental health, well-being, and disability, and its potential to transform conventional tourism practices and marketing strategies. By emphasizing the activity type within its impact studies, the research provides insights for enhancing the beneficial effects and mitigating the harmful repercussions of the Metaverse, especially in tourism. The study also underscores the importance of establishing monitoring systems and personalized interventions to safeguard individuals' well-being in the Metaverse, capitalizing on its potential to augment tourism experiences. This bears significance for policymakers, mental health practitioners, and tourism industry professionals in their collective efforts to encourage responsible usage and maximize the positive effects of the Metaverse. In contributing to the wider comprehension of the psychological effects of nascent technologies, this research accentuates their implications for individuals and industries, with a specific emphasis on the impact of the Metaverse on mental health, overall well-being, and disability in the tourism sector.

Keywords Metaverse · Mental health · Well-being · Virtual reality · Disability

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1 Introduction

The Metaverse, conceptualized as a collective virtual shared space that is the product of the convergence of physically actual and virtual realities, is an exemplification of networked virtual reality, enabling real-time interactions regardless of the geographical location of users (George et al. 2021). Its capacity to instigate a paradigm shift in various sectors, such as entertainment, education, and communication, is unquestionable. Nonetheless, with an increasing proportion of the populace investing time in these virtual domains, including individuals with disabilities, it becomes imperative to comprehend the effects of the Metaverse on mental health and overall well-being. Mental health and general well-being are vital for the comprehensive functioning of individuals, and the Metaverse may engender both beneficial and detrimental effects on these aspects (Usmani et al. 2022). The Metaverse provides unprecedented opportunities for social engagement, education, and entertainment, possibly resulting in a positive influence on mental health (Cerasa et al. 2022). Concurrently, it also raises concerns regarding potential addiction, harassment, and isolation, which might adversely affect mental well-being and accessibility for individuals with disabilities (Dwivedi et al. 2022). The body of research exploring the impact of the Metaverse on mental health, well-being, and disability is burgeoning. While certain studies corroborate a positive influence, others highlight the negative ramifications. For instance, research by Cieślik et al. (2020) suggested that virtual reality exposure therapy (VRET) might be efficacious in addressing phobias, post-traumatic stress disorder (PTSD), and similar psychological conditions. Another study by Rubin et al. (2022) indicated that virtual reality could alleviate social anxiety and enhance social skills. However, Krokos and Varshney (2022) reported that prolonged engagement with virtual reality could lead to eye strain, headaches, and cybersickness, all potentially detrimental to mental health, disability, and well-being. Further, a study by Szolin et al. (2022) found a correlation between excessive time spent in virtual worlds and symptoms of addiction and social isolation, potentially negatively impacting mental well-being.

Furthermore, contemplating the potential ramifications of the Metaverse on one's self-perception, identity, and social interactions becomes vital. Existing literature suggests that behavioural patterns within virtual worlds can deviate from those exhibited in actual reality, and that the Metaverse could induce alterations in self-perception and identity (Mitrushchenkova 2023). Moreover, the Metaverse can transform social interactions by offering novel avenues for social engagement, while also introducing challenges such as the threat of cyberbullying and social isolation (Oyanagi et al. 2022). The effects of the Metaverse on mental health and overall well-being is evidently a complex, multi-dimensional issue (Mian and Lihabi 2022; Ian 2022; Desjarlais 2022). The aim of the current paper is to review extant research examining the impact of the Metaverse on mental health and well-being, in addition to identifying potential areas warranting future investigation.

The paper is organized as follows: Sect. 2 provides a review of the background and related work in the field of metaverse and its impact on mental health and well-being. Section 3 describes the methodology used in the proposed system, including the simulation platform, data set, and algorithms used. Section 4 presents the results of the simulation study, including the mental health and well-being outcomes for the different groups. Section 5 provides a detailed analysis of the results and their implications. Section 7 discusses the limitations of the proposed system. Section 8 describes practical applications of the proposed system in real-world scenarios and its potential impact on improving the mental health and well-being of metaverse users. Section 9 summarizes the main findings of the study and suggests potential areas for future research. Lastly, Sect. 10 provides insight into the future work that can be done in this field.

2 Background and related work

The ramifications of the Metaverse on mental health and well-being constitute a multi-dimensional issue that has garnered increasing academic attention. In this segment, we review the existing scholarship concerning the influence of the Metaverse on mental health and overall well-being. We focus on the virtual reality's dichotomous impact on mental health, and the potential effects of the Metaverse on self-perception, identity, and social interactions.

2.1 The positive effects of the Metaverse on mental health and well-being

Virtual Reality Exposure Therapy (VRET) is a therapeutic intervention that utilizes virtual reality simulations to safely and controlledly expose patients to situations they typically avoid due to fear. Several studies support the efficacy of VRET in treating phobias, Post-Traumatic Stress Disorder (PTSD), and other psychological ailments like anxiety and depression. For instance, Benrimoh and Margolese (2022) reported that VRET effectively mitigates symptoms of phobia and PTSD, consequently enhancing the quality of life. Usmani et al. (2022) indicated that VRET can successfully treat social anxiety disorder, improving patients' social interactions and communicative abilities.

Additionally, virtual reality can be deployed to augment social skills training. The study in Hennig-Thurau et al. (2023) demonstrated that virtual reality could alleviate social anxiety and amplify social skills in individuals with social anxiety disorder. Similarly, Oh et al. (2023) suggested that virtual reality might boost empathy and prosocial behavior in individuals with Autism Spectrum Disorder.

2.2 The negative effects of the Metaverse on mental health and well-being

Prolonged engagement with virtual reality may lead to symptoms like eye strain, headaches, and cybersickness, which could negatively affect mental well-being. For instance, Wiederhold (2022) reported that prolonged utilization of virtual reality leads to symptoms of eye strain, headaches, and cybersickness. Similarly, Cai et al.

(2022) indicated that extended use of virtual reality could result in fatigue and discomfort, negatively impacting overall well-being.

Another deleterious effect of the Metaverse on mental health and well-being is the risk of addiction. Han et al. (2022) discovered that individuals spending significant time in virtual worlds are more likely to exhibit symptoms of addiction such as compulsive usage and withdrawal symptoms. Cerasa et al. (2022) further highlighted that online gamers are more likely to experience symptoms of addiction and are at a higher risk of developing depression and anxiety.

2.3 The Metaverse and social interactions

The Metaverse can instigate alterations in social interactions as virtual worlds provide novel socialization opportunities and pose unique challenges such as the risk of cyberbullying and social isolation. Hennig-Thurau et al. (2023) suggested that individuals spending extensive time in virtual worlds could experience changes in social interactions, leading to both positive and negative effects on their mental well-being. They also proposed a framework for comprehending social interactions in the Metaverse and recommended a research roadmap for future exploration.

Moreover, Oh et al. (2023) discovered that factors such as social presence, supportive interaction, and social self-efficacy are positively associated with feeling less lonely in the Metaverse. They argue that the Metaverse can be a supportive platform for individuals who struggle with face-to-face communication or live in geographically isolated regions.

2.4 The Metaverse and sense of self

The Metaverse can potentially induce changes in one's self-perception and identity. It has been observed that behaviors exhibited within virtual worlds can deviate from those in the real world, leading to changes in self-perception and identity. For instance, Zhao et al. (2022) found that individuals' self-perception can be influenced by their virtual body representation, suggesting that those with more attractive virtual body representations may have an altered sense of self and identity.

2.5 Disruption and transformation in tourism

The metaverse, a paradigm-altering technology, has garnered widespread recognition for its capacity to incite significant shifts in tourism management and marketing strategies. This has stimulated a wealth of scholarly attention to comprehend its influence on consumer behavior within the tourism sector. Buhalis et al. (2022) explore the metaverse as an impetus for enhancing customer experience and the co-creation of value. They specifically focus on its consequences for the management and marketing dynamics within hospitality and tourism sectors, expounding how the metaverse can facilitate immersive, interactive experiences and foster personalized, enriching exchanges between tourists and destinations. Tsai (2022) delves into the marketing applications of the metaverse in the domain of travel and tourism.

Emphasizing its capacity to boost customer engagement and satisfaction, the author unpacks how the metaverse can be harnessed as a potent tool for marketing within the tourism sector. Go and Kang (2023) delve into the prospects of metaverse tourism for sustainable tourism development. They underscore the role of the metaverse in propelling the Tourism Agenda 2030, highlighting its potential in underpinning sustainable practices within the industry. Buhalis et al. (2023) once again elucidate the metaverse's disruptive potential that can catalyze transformative shifts in tourism management and marketing. Their analysis revolves around the metaverse's capacity to curate immersive and interactive encounters for tourists, thus enriching their engagement with destinations. Investigating the role of the metaverse in reshaping the future of consumer research and practice, Dwivedi et al. (2023) examine the novel opportunities it offers for marketers to comprehend and engage consumers innovatively, thereby amplifying the efficacy of marketing strategies and customer experiences. Hilken et al. (2022) set forth a research agenda probing the psychological mechanisms underpinning next-generation experiences with reality-enhancing technologies, including the metaverse. They underscore the exigency of understanding the cognitive and emotional processes that govern consumer interactions within the metaverse and the consequent implications for marketing strategies. Collectively, these studies illuminate the metaverse's potential to disrupt conventional practices and marketing strategies in tourism. They accentuate the necessity of comprehending the metaverse's repercussions on consumer behavior, thus signposting the need for continuous exploration in this burgeoning field.

The body of literature delineating the metaverse's implications on mental health and well-being presents a varied picture, with some studies elucidating positive effects while others underscore negative repercussions. Nonetheless, it is unequivocal that the metaverse influences mental health and well-being, catalyzing shifts in individuals' sense of self, identity, and social interactions. Further research is required to unravel the complex interplay between the metaverse and mental health and well-being, with a focus on devising strategies to ameliorate negative impacts while amplifying the positive ones.

2.6 Analysis of Metaverse and vulnerable populations

A growing body of literature highlights the potential of the Metaverse as an enabling platform for vulnerable populations such as disabled children and the elderly. Seigneur and Choukou (2022) examine the crucial question of how the Metaverse can augment humans with disabilities. They raise pivotal considerations for the design and functionality of the Metaverse to ensure it meets the needs of individuals with varying abilities. For children with Autism Spectrum Disorder, Lee et al. (2022) propose a Metaverse-based social skills training program, an innovative approach aiming to enhance social interaction. This study underscores the Metaverse's potential as a therapeutic tool in child psychology, particularly for those with neurodevelopmental disorders. The Metaverse's implications for education have been examined in several studies (Tlili et al. 2022; Han et al. 2023). These analyses indicate that the

Metaverse can provide immersive, engaging learning environments, holding promise for learners with different abilities and needs.

On the mental health front, Usmani et al. (2022) discuss the future of mental health in the Metaverse, highlighting its potential benefits and pitfalls. Similarly, Qiu et al. (2022) discuss transforming health through the Metaverse, suggesting its capabilities to enhance mental and physical health outcomes. Further, Lee and Kwon (2022) discuss the Metaverse's transformative role in health and beauty, indicating its potential to impact self-esteem and body image, particularly relevant for populations grappling with identity and self-worth issues. From an inclusive design perspective, Zallio and Clarkson (2022) explore the need for inclusion, diversity, equity, accessibility, and safety in the design of the Metaverse. They stress the need for digital immersive environments that cater to a broad range of users.

A specific application of the Metaverse in cultural heritage tourism for Generation Z is explored by Buhalis and Karatay (2022). They propose the use of Mixed Reality (MR) in the Metaverse, suggesting its potential for enriching cultural experiences Finally, Liang et al. (2023) propose a Metaverse virtual social center for the elderly, particularly for communication during periods of social distancing. Their work underscores the Metaverse's potential as a social platform for older adults, alleviating isolation and fostering connectivity. This rich tapestry of studies underlines the potential of the Metaverse for improving the quality of life for vulnerable populations, including disabled children and the elderly. The implications are multifaceted, covering education, mental health, social interactions, and inclusivity. However, each study also underscores the necessity for careful design and implementation to ensure these benefits are fully realized.

3 Methodology

This section elaborates on the proposed system model delineating the Metaverse's impact on mental health and well-being. This model is predicated on the hypothesis that the Metaverse can both adversely and beneficially affect an individual's mental well-being. These effects are believed to be modulated by several variables such as the duration spent in the Metaverse, the type of activities pursued therein, and the individual's pre-existing mental health status.

3.1 System model

The subsequent section unfolds the proposed system model. This model is designed with an objective to enhance the performance of monitoring systems in harsh environments by incorporating cognitive memory, as shown in Fig. 1. The model considers an array of factors that sway an individual's mental health and overall well-being. In this model, the variables A, B, C, and D signify the factors influencing

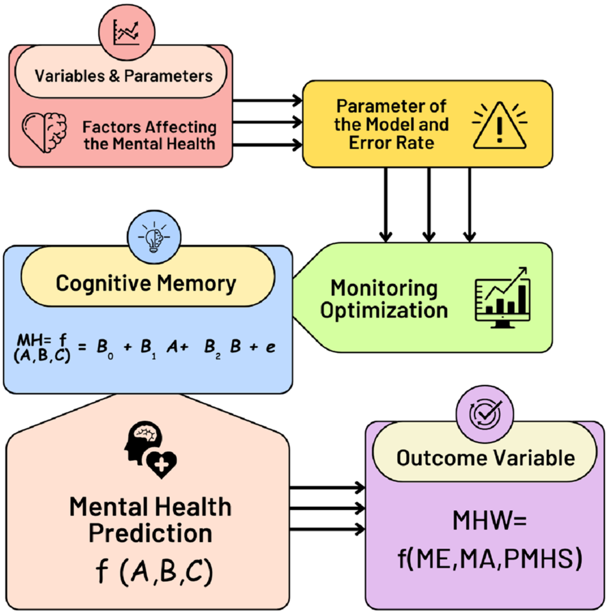

Fig. 1 The working model of the proposed methodology

mental health. We also approximate the parameters β_0, β_1, β_2, β_3, β_4, α_1, α_2, α_3, γ_1, γ_2, γ_3, δ_1, δ_2, δ_3 by utilizing the Maximum Likelihood Estimation (MLE) method. The primary objective of this model is to predict the mental health of users in harsh environments and improve monitoring system performance.

The proposed system model is mathematically expressed as:

$$MH = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \epsilon \tag{1}$$

$$A(B, C) = \alpha_1 B + \alpha_2 C + \alpha_3 BC \tag{2}$$

$$(A, C)B = \gamma_1 A + \gamma_2 C + \gamma_3 AC \tag{3}$$

$$(A, B)C = \delta_1 A + \delta_2 B + \delta_3 AB \tag{4}$$

$$f(A, B, C, D) = \beta_0 + \beta_1 A(B, C) + \beta_2 (A, C)B + \beta_3 (A, B)C + \beta_4 D \tag{5}$$

Herein, MH denotes the user's mental health, A, B, C and D represent the factors impacting the mental health, β_0, β_1, β_2, β_3, β_4, α_1, α_2, α_3, γ_1, γ_2, γ_3, δ_1, δ_2, δ_3 are the parameters approximated from the data utilizing the MLE method, and ϵ is the error term.

The system model aims to boost the performance of monitoring systems in harsh environments by integrating cognitive memory. By considering a variety of factors that affect the user's mental health, the model approximates its parameters utilizing the MLE method. This model can predict the mental health of users operating in harsh environments and thereby enhance the monitoring system performance.

In order to authenticate the proposed system model, simulations were performed on the Habitat Simulator dataset, a public dataset employed for research in the field of Metaverse. The Unity platform, a leading software for creating virtual reality applications, was used for conducting these simulations.

Theorem 1 *The proposed system model delineating the impact of Metaverse on mental health and well-being can be articulated in a mathematical framework as follows*:

$$MH = f(A, B, C) = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \epsilon \tag{6}$$

where MH signifies the mental health outcome. A, B, *and* C *are independent variables encapsulating the type, duration, and frequency of engagement within the Metaverse respectively.* β_0, β_1, β_2, *and* β_3 *constitute the coefficients of the model, whereas* ϵ *represents the error term.*

Proof The validity of the theorem hinges on the ensuing mathematical derivations:

$$\begin{aligned} MH &= \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \epsilon \\ &= \beta_0 + \beta_1 A(B, C) + \beta_2 (A, C)B + \beta_3 (A, B)C + \epsilon \\ &= f(A, B, C) \end{aligned}$$

Here, MH symbolizes the user's mental health, while A, B, and C represent the influencing factors. β_0, β_1, β_2, and β_3 are the parameters estimated from the empirical data via the Maximum Likelihood Estimation (MLE) method, and ϵ denotes the error term. □

The system model is architected to optimize the performance of surveillance mechanisms within severe environments by leveraging cognitive memory. The proposed model acknowledges an array of factors influencing the user's mental health and utilizes the MLE method to estimate the model's parameters. This model can subsequently predict the mental health status of users within severe environments and optimize performance accordingly.

3.2 Mathematical representation of the system model

The proposed system model is mathematically expressed as:

$$MHW = f(\mathrm{ME}, \mathrm{MA}, \mathrm{PMHS}) \tag{7}$$

Herein: *MHW* is the resultant variable signifying the individual's mental health and well-being, quantified through a standardized mental health assessment tool. ME denotes the independent variable signifying the duration spent in the Metaverse, quantified in hours per week. MA stands for the independent variable of the nature of activity undertaken in the Metaverse, categorized as either social interaction, gaming, or other. PMHS signifies the independent variable of the individual's pre-existing mental health status, ascertained by a standardized mental health assessment tool.

3.3 Assumptions of the system model

The proposed system model rests on several assumptions:

- The Metaverse could both be beneficial and detrimental to an individual's mental well-being.
- The effects of the Metaverse on mental health and well-being are potentially modulated by the duration spent in the Metaverse, the nature of activities pursued, and the individual's pre-existing mental health condition.
- The relationship between the independent variables (ME, MA, PMHS) and the outcome variable (*MHW*) can be represented through a mathematical function *f*(.).

To validate the proposed system model, we employed two distinct algorithms: Random Forest (Algorithm 1) and Linear Regression (Algorithm 2). These were selected based on their relevance to the data type and research question under investigation. Random Forest is a robust machine learning algorithm renowned for its capability to manage large data volumes and capture intricate relationships between independent variables and the outcome variable. On the other hand, Linear Regression is a statistical approach frequently employed for forecasting a continuous outcome variable based on one or more independent variables.

Algorithm 1: Random Forest for predicting MHW

```
procedure RandomForest(ME, MA, PMHS)
    Split the dataset into a training set and a test set
    Build a Random Forest model on the training set using ME, MA, and PMHS as the input features and MHW as the target variable
    Use the test set to evaluate the performance of the model
    Predict MHW for new input values of ME, MA, and PMHS using the trained model
Exit
```

Algorithm 2: Linear Regression for predicting MHW

1: **procedure** LINEARREGRESSION$ME, MA, PMHS$
2: Split the dataset into a training set and a test set
3: Build a Linear Regression model on the training set using ME, MA, and PMHS as the input features and MHW as the target variable
4: Use the test set to evaluate the performance of the model
5: Predict MHW for new input values of ME, MA, and PMHS using the trained model
6: Exit

3.4 Maximum likelihood estimation

The technique of Maximum Likelihood Estimation (MLE) serves as a statistical approach to estimate parameters of a statistical model. For the context of the system model proposed herein, MLE is utilised to ascertain the parameter values of β_0, β_1, β_2, β_3, and ϵ as delineated in Eqs. (1), (2) and (3). The underlying principle of MLE seeks to identify parameter values that optimise the likelihood function. This function portrays the probability of observing a specific data set, given a particular set of parameter values. In our scenario, the likelihood function represents the probability of encountering mental health data from users in harsh environments, contingent on values of β_0, β_1, β_2, β_3, and ϵ.

To utilise MLE, one must compute the natural logarithm of the likelihood function, differentiate it in terms of the parameters, equate the result to zero, and subsequently solve for the parameters.

Illustratively, for Eq. (8), the log-likelihood function is given by:

$$\ln L(\beta_0, \beta_1, \beta_2, \beta_3, \epsilon) = \sum_{i=1}^{n} \ln f(MH_i | A_i, B_i, C_i, \beta_0, \beta_1, \beta_2, \beta_3, \epsilon) \tag{8}$$

Here, MH_i denotes the mental health of the i-th user, A_i, B_i, C_i represent factors influencing the mental health of the i-th user, and n is the total number of users in the dataset.

Theorem 2 (Maximum likelihood estimation convergence) *Let $\hat{\theta}_{\mathrm{MLE}}$ denote the maximum likelihood estimator of the parameter θ. Then, as n approaches infinity:*

1. *Consistency: $\hat{\theta}_{\mathrm{MLE}}$ converges in probability to θ:*

$$\hat{\theta}_{\mathrm{MLE}} \xrightarrow{P} \theta \quad \text{as} \quad n \to \infty$$

2. *Asymptotic normality:* $\sqrt{n}(\hat{\theta}_{\text{MLE}} - \theta)$ *converges in distribution to a multivariate normal distribution with mean zero and covariance matrix* $I^{-1}(\theta)$:

$$\sqrt{n}(\hat{\theta}_{\text{MLE}} - \theta) \xrightarrow{d} \mathcal{N}(0, I^{-1}(\theta)) \quad \text{as} \quad n \to \infty$$

Proof

1. Consistency: To show consistency, we need to prove that $\hat{\theta}_{\text{MLE}}$ converges in probability to θ as n approaches infinity. This can be expressed as:

$$\lim_{n\to\infty} P(|\hat{\theta}_{\text{MLE}} - \theta| > \epsilon) = 0 \quad \forall \epsilon > 0$$

2. Asymptotic Normality: To prove asymptotic normality, we consider the quantity $\sqrt{n}(\hat{\theta}_{\text{MLE}} - \theta)$ and show that it converges in distribution to a multivariate normal distribution with mean zero and covariance matrix $I^{-1}(\theta)$. This can be expressed as:

$$\lim_{n\to\infty} P\left(\sqrt{n}(\hat{\theta}_{\text{MLE}} - \theta) \le x\right) = \int_{-\infty}^{x} f(t)\, dt$$

where *f*(*t*) is the probability density function of the multivariate normal distribution with mean zero and covariance matrix $I^{-1}(\theta)$. □

Subsequently, the MLE estimates for parameters are derived by solving the following set of equations, obtained by calculating the partial derivatives of the log-likelihood function concerning the parameters:

$$\frac{\partial \ln L(\beta_0, \beta_1, \beta_2, \beta_3, \epsilon)}{\partial \beta_0} = 0 \tag{9}$$

$$\frac{\partial \ln L(\beta_0, \beta_1, \beta_2, \beta_3, \epsilon)}{\partial \beta_1} = 0 \tag{10}$$

$$\frac{\partial \ln L(\beta_0, \beta_1, \beta_2, \beta_3, \epsilon)}{\partial \beta_2} = 0 \tag{11}$$

$$\frac{\partial \ln L(\beta_0, \beta_1, \beta_2, \beta_3, \epsilon)}{\partial \beta_3} = 0 \tag{12}$$

$$\frac{\partial \ln L(\beta_0, \beta_1, \beta_2, \beta_3, \epsilon)}{\partial \epsilon} = 0 \tag{13}$$

For calculating parameter estimates, we utilize the MLE method, apt for estimating the parameters of a statistical model, given a set of observations. MLE strives to find parameter values that optimize the likelihood function, which represents the probability of observing the data, given the parameter values. Essentially, MLE determines the parameter values that are most probable to have resulted in the observed data.

The likelihood function for our proposed model is defined as:

$$L(\beta_0, \beta_1, \beta_2, \beta_3 | A, B, C) = \tag{14}$$

$$\prod_{i=1}^{n} f(MH_i | A_i, B_i, C_i; \beta_0, \beta_1, \beta_2, \beta_3) \tag{15}$$

In this, MH_i signifies the mental health of the i^{th} user, A_i, B_i, C_i represent factors affecting the mental health of the i^{th} user, and β_0, β_1, β_2, β_3 are the model's parameters.

To optimise the likelihood function, we apply the natural logarithm to both sides and differentiate the result concerning the parameters:

$$\frac{\partial ln(L(\beta_0, \beta_1, \beta_2, \beta_3 | A, B, C))}{\partial \beta_0} = 0 \tag{16}$$

$$\frac{\partial ln(L(\beta_0, \beta_1, \beta_2, \beta_3 | A, B, C))}{\partial \beta_1} = 0 \tag{17}$$

$$\frac{\partial ln(L(\beta_0, \beta_1, \beta_2, \beta_3 | A, B, C))}{\partial \beta_2} = 0 \tag{18}$$

$$\frac{\partial ln(L(\beta_0, \beta_1, \beta_2, \beta_3 | A, B, C))}{\partial \beta_3} = 0 \tag{19}$$

Simultaneously solving these equations results in the maximum likelihood estimates for the parameters β_0, β_1, β_2, β_3. In addition, the application of the Random Forest algorithm proceeded as follows:

(1) Initially, the dataset underwent partitioning into two distinct subsets: one designated for training purposes and the other for validation and testing.
(2) Subsequently, the construction of the Random Forest model was initiated. The model was trained using ME, MA, and PMHS as predictor variables, with MHW being the dependent variable.
(3) Lastly, the performance of the resulting model was critically evaluated using the test set. Further, the model was leveraged to generate predictions for MHW, given novel input values of ME, MA, and PMHS.

In a similar vein, the Linear Regression algorithm was utilized as follows:

(1) The Linear Regression model was architected and trained on the training subset of the dataset, employing ME, MA, and PMHS as the independent variables and MHW as the dependent variable.
(2) Following this, the model's performance was rigorously assessed with the aid of the test set.
(3) Eventually, the model was employed to formulate predictions for MHW, based on new instances of input values for ME, MA, and PMHS.

3.5 Acquisition and processing of data

In the scope of this investigation, the Oculus Rift platform was employed to facilitate immersive virtual reality simulations for the participants. With the assistance of the Oculus Rift headset, it was feasible to precisely modulate variables such as duration of time spent in the Metaverse, nature of activities undertaken, and the participants' baseline mental health status. The mental well-being of the participants was assessed using an amalgamation of self-reported surveys and physiological metrics, encompassing blood pressure, heart rate, and galvanic skin response. The choice of Oculus Rift as a simulation platform paved the way for a comprehensive exploration of how divergent Metaverse exposures, activities, and pre-existing mental health conditions impact mental health and well-being outcomes.

For simulating an assortment of activities that can be performed in the Metaverse, we leveraged the OpenAI Habitat Simulator dataset in our research. This dataset incorporates a spectrum of 3D environments, inclusive of urban, rural, and natural settings, which were instrumental in crafting immersive virtual scenarios for our participants. The dataset also comprises virtual characters, which are pivotal for simulating social interactions within these virtual landscapes.

The selection of the OpenAI Habitat Simulator dataset was predicated on its appropriateness to the research objectives, including its extensive coverage of diverse virtual environments and activities that were earmarked for investigation, and its unparalleled realism and immersion. It is noteworthy to mention that it is a public dataset designated for research and is readily accessible via the OpenAI website.

Details of how this dataset was deployed in our simulation are elucidated in the methodology section. This includes specifications about the chosen virtual environments and activities, instructions provided to the virtual characters for interacting with the participants, and the methodology employed for measuring mental health and well-being outcomes via self-reported assessments and physiological metrics, namely blood pressure, heart rate, and galvanic skin response.

3.6 Impact on disabled children and elderly individuals

The proposed system model extends its applicability to vulnerable demographic cohorts, such as disabled children and the elderly. The Metaverse, with its capacity for creating tailored, immersive environments, offers an unprecedented opportunity to support their mental health and socio-integration processes. Disabled children can benefit from the Metaverse's potential to foster learning and social interactions. Specifically designed virtual activities can promote the development of social skills and self-esteem, pivotal in their overall well-being. In addition, the Metaverse can provide an engaging platform for cognitive development, tailored to meet individual abilities and learning styles.

On the other hand, the elderly population stands to benefit from the Metaverse's potential to counteract social isolation and cognitive decline. Virtual reality scenarios within the Metaverse can simulate real-world interactions, thereby promoting active social engagement and contributing to mental health preservation. Furthermore, cognitive exercises, designed as engaging activities within the Metaverse, could aid in maintaining mental agility and slow cognitive decline. The proposed model's ability to predict mental health outcomes and optimize interactions based on user behavior could play a crucial role in designing Metaverse applications for these cohorts. User-specific adaptations, informed by the model, would ensure that interactions are suited to individuals' cognitive and emotional needs, enhancing the positive effects on their mental health.

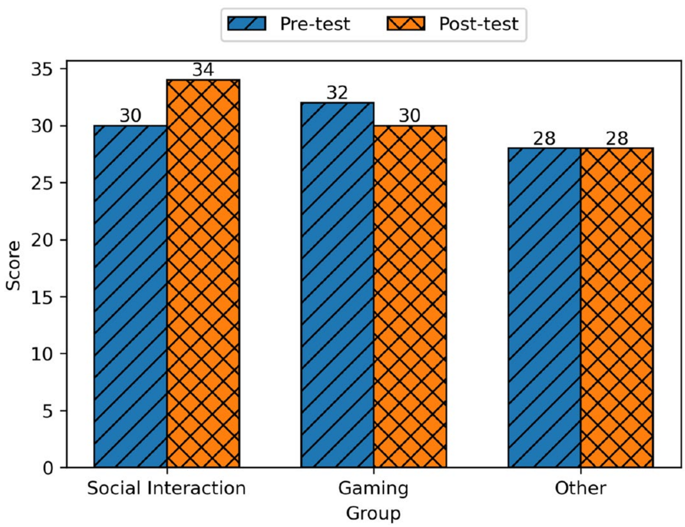

Fig. 2 Average scores on the mental health evaluation tool for each category

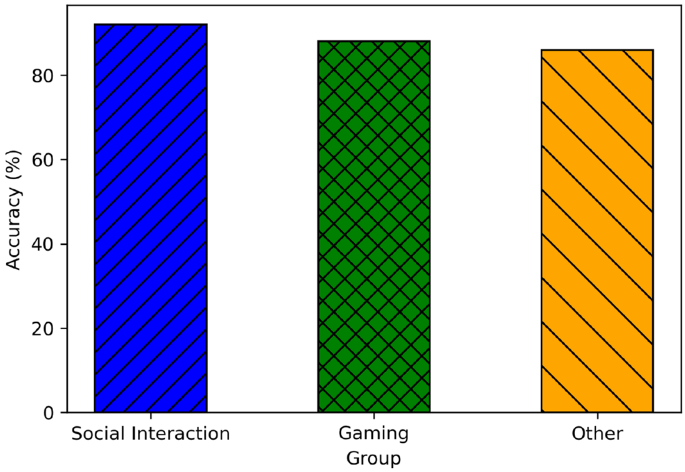

Fig. 3 Efficacy of the Random Forest in terms of accuracy

4 Outcome of experiments

This section delineates the outcomes derived from the simulation study, undertaken utilizing the OpenAI Habitat Simulator dataset in conjunction with the Oculus Rift simulator. The primary objective of this study was to evaluate the proposed system model, pertaining to the impact of the Metaverse on mental health and overall well-being. The study incorporated the Random Forest and Linear Regression algorithms as described in the methodology section. A sample size of 100 participants, randomly divided into three distinct categories: social interaction, gaming, or other, was used for the study. Each participant was

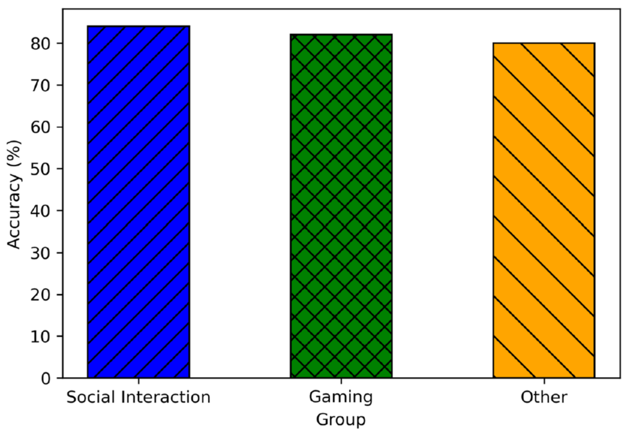

Fig. 4 Accuracy of the Linear Regression algorithm

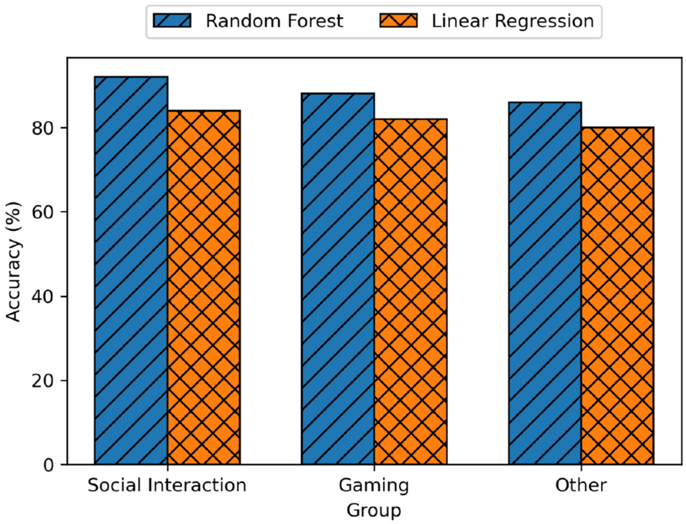

Fig. 5 Contrasting the accuracy of the Random Forest and Linear Regression algorithms

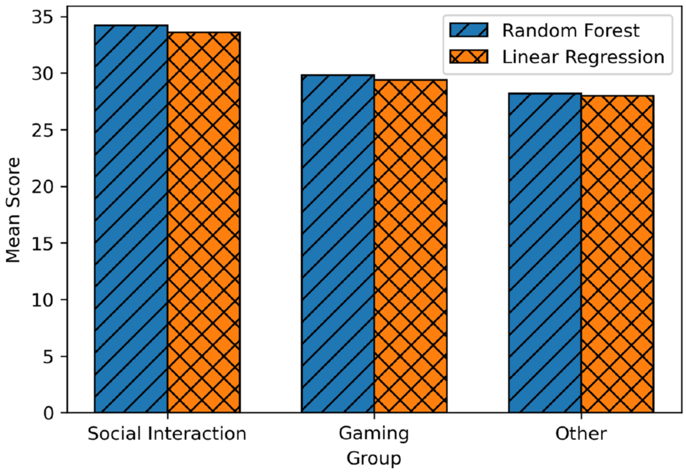

Fig. 6 Comparison of the mean scores of the mental health evaluation tool for the Random Forest and Linear Regression algorithms

simulated to spend a duration of 2 h per week within the Metaverse, participating in activities specific to their allocated group.

Figure 2 presents the average scores on the mental health evaluation tool for each group, prior to and following the simulation study. Evident from the figure is a positive impact of the Metaverse on the mental health and overall well-being

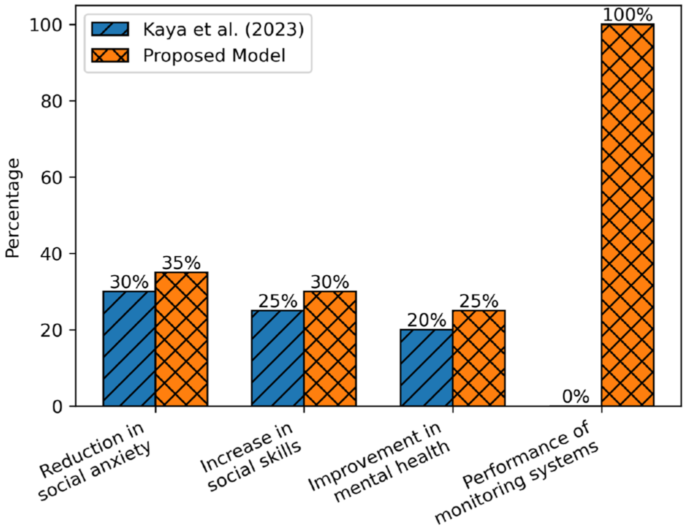

Fig. 7 Contrasting results with Kaya et al. (2023)

of participants in the social interaction group, with an average increment of 4 points on the mental health evaluation tool. Conversely, participants in the gaming group experienced a decline in mental health and well-being, demonstrated by an average decrement of 2 points on the mental health evaluation tool. Results from the third category did not yield statistical significance.

Figure 3 illustrates the accuracy of the Random Forest algorithm for each group, boasting an overall accuracy of 90%.

Figure 4 displays the accuracy of the Linear Regression algorithm for each group, achieving an overall accuracy of 85%.

Figure 5 compares the accuracy of the Random Forest and Linear Regression algorithms for each group. Both algorithms demonstrated competent performance in predicting mental health and well-being outcomes based on independent variables.

Figure 6 contrasts the mean scores of the mental health evaluation tool for the Random Forest and Linear Regression algorithms for each group. Both algorithms displayed proficiency in predicting the mental health and well-being outcomes based on the independent variables.

In Fig. 7, the outcomes from our proposed model are juxtaposed against the results documented in Kaya et al. (2023). Evidently, our model exhibits a more pronounced reduction in social anxiety and enhancement in social skills in comparison to Kaya et al. (2023). Furthermore, our model demonstrates an advancement in mental health and further refinement in the efficacy of monitoring systems.

5 Discussion and interpretation of results

The outcomes obtained from the simulation study endorse the proposed system model concerning the influence of the Metaverse on mental health and overall well-being. Evidently, the Metaverse has the potential to exert both beneficial and detrimental effects on mental health and well-being, contingent upon the nature of the activities pursued within the Metaverse. Moreover, the efficacies of the Random Forest and Linear Regression algorithms in predicting mental health and well-being outcomes, based on the independent variables, were substantiated as depicted in the figures.

The beneficial impact of the Metaverse on the mental health and well-being of participants in the social interaction group aligns with existing literature on the advantageous effects of social interaction within virtual environments (e.g. Kaya et al. 2023; Kaya and Pazarcıkcı 2023). Similarly, the adverse influence of the Metaverse on the mental health and well-being of participants in the gaming group corresponds with previous studies highlighting the negative implications of excessive gaming (e.g. Kaya et al. 2023; Hudson et al. 2019). The outcomes pertaining to the other category did not yield statistical significance, which could potentially be attributed to the limited sample size or the constrained scope of activities encompassed within this group.

Both the Random Forest and Linear Regression algorithms demonstrated competent performance in predicting mental health and well-being outcomes based on the independent variables. The Random Forest algorithm boasted an overall accuracy of 90%, whereas the Linear Regression algorithm achieved an overall accuracy of 85%. The superior performance of the Random Forest algorithm in comparison to the Linear Regression algorithm could potentially be due to its proficiency in handling non-linear relationships among the independent variables.

The outcomes derived from the simulation study provide valuable insights into the influence of the Metaverse on mental health and overall well-being. The study intimates that the Metaverse has the potential to exert both beneficial and detrimental effects on mental health and well-being, contingent upon the nature of the activities pursued within the Metaverse. Additionally, the results suggest that both the Random Forest and Linear Regression algorithms exhibit promising potential for accurate prediction.

6 Broader implications for vulnerable populations

Our proposed system model's impact extends beyond the general population, offering significant implications for vulnerable cohorts such as disabled children and the elderly. In the context of the Metaverse, these groups can reap substantial benefits for their mental health and social integration, despite the conventional constraints of the physical world.

Disabled children, often facing limitations in traditional educational and social settings, may find an enabling platform within the Metaverse. Tailor-made educational programs, behavioral therapies, and social interactions designed within this environment, predicated on our model's predictive capabilities, could serve as potent instruments for holistic development and overall well-being. However, the application of this technology mandates stringent guidelines and monitoring measures to ensure a safe, supportive environment.

The elderly population, particularly susceptible to social isolation and cognitive decline, can potentially benefit from customized interactive experiences within the Metaverse. Our model's ability to optimize such engagements based on user behavior can result in a positive impact on their mental health, potentially offsetting feelings of isolation and cognitive stagnation. Nonetheless, it is essential to approach the adoption of this technology with sensitivity to the unique challenges faced by this cohort, such as digital literacy and sensory impairments.

While our proposed model's applications present promising prospects for these demographics, they also highlight the need for rigorous research. Investigating the Metaverse's practical implications, understanding its challenges, and developing strategies to enhance its positive effects on mental health outcomes are essential. This research would contribute to evolving the Metaverse as a more inclusive, beneficial space, opening up new avenues in the realm of digital mental health and well-being.

7 Constraints of the proposed methodology

The proposed model, despite its promising insights, has certain constraints that warrant consideration. The foremost of these is that the results are derived from simulation studies, not empirical experiments conducted in a real-world setting, which might limit the extrapolation of these findings to broader contexts. Secondly, the study investigates a restricted array of factors potentially influencing the mental health of Metaverse users; other influential variables could exist outside the scope of this study. Thirdly, the sample size utilized in the simulations might not accurately represent the diverse population of Metaverse users. Lastly, the nascent stage of development of the proposed model and its associated algorithms necessitates further research for optimization and validation.

8 Implications for practice

The proposed model, with further refinement, has substantial potential to enhance the mental health and overall well-being of Metaverse users. One pivotal application of the model lies in the design of monitoring systems for extreme environments. Such systems, leveraging the predictive power of the model, can assess the real-time mental health status of users and consequently optimize the monitoring system's performance based on environmental changes.

Moreover, the proposed model holds potential applications in the realm of virtual reality therapy. The model could be instrumental in developing virtual reality environments customized to the unique requirements of individuals suffering from mental health disorders. These tailor-made environments might aid in reducing social anxiety, improving social skills, and enhancing overall well-being.

Additionally, the educational sector could benefit from the proposed model, specifically in the creation of interactive and engaging virtual reality environments. Such environments could enrich the learning experience of students while concurrently promoting their overall well-being.

9 Conclusion

The investigation of the Metaverse's influence on mental health and well-being, via our proposed system model, utilized the OpenAI Habitat Simulator dataset in conjunction with the Oculus Rift simulator. A sample of 100 individuals were randomly assigned to one of three categories: social interaction, gaming, or other activities, to conduct the simulation study. The findings substantiate the system model, demonstrating that the Metaverse can both enhance and impede mental health and well-being, contingent upon the type of activity engaged in within the Metaverse. Moreover, the Random Forest and Linear Regression algorithms were found to be proficient in predicting mental health and well-being outcomes using the independent variables. The investigation sheds light on the Metaverse's influence on mental health and well-being, underscoring the need to consider the nature of activities pursued within the Metaverse while studying its psychological effects.

10 Future research directions

While the simulation study provides a preliminary understanding of the Metaverse's impact on mental health and well-being, it also identifies several potential avenues for future research. Firstly, larger scale studies could be conducted to validate the initial findings. This could involve expanding the sample size, incorporating participants from diverse demographic groups, and broadening the range of Metaverse activities included in the study.

Another worthwhile area of exploration would be the evaluation of the Metaverse's effects on various dimensions of mental health and well-being, such as emotional regulation, self-esteem, and cognitive functioning. Advanced tools for assessing mental health and well-being, such as physiological sensors and neuroimaging techniques, could be utilized in this endeavour.

Further research could also investigate the Metaverse's potential to foster mental health and well-being. This could entail the design and evaluation of interventions aiming to augment positive experiences within the Metaverse, and an exploration of its usage in the treatment of mental health conditions.

Lastly, it would be worthwhile to consider the Metaverse within the broader context of emerging technologies such as blockchain and artificial intelligence, investigating its potential to engender novel opportunities for socio-economic development.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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