INTEGRATING AI AND OR FOR REAL-TIME OPTIMIZATION IN DIGITAL TWIN ECOSYSTEMS AND METAVERSE ENGINEERING

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Abstract:

Digital twins are essential in metaverse engineering as a foundation for optimization, simulation, and analysis. However, these digital replicas are vulnerable to malicious software, potentially compromising data and allowing unauthorized access. AI enhances digital twins by enabling them to learn from real-time data and make autonomous decisions. AI algorithms allow for simulating complex environments that react instantly to human input, creating immersive experiences. This article introduces an AI-based study to optimize digital twin ecosystems and metaverse engineering platforms in real-time (AI-DTE-ME). Realistic and interactive virtual worlds can be created by integrating metaverse technology with digital twins. Continuous data analysis allows digital twins to detect patterns, predict issues, and adapt processes dynamically. This capability brings the Metaverse to life, enabling the creation of intelligent, interactive digital objects. The study highlights the effectiveness of combining AI with operations research (OR) for the real-time optimization of Digital Twin ecosystems. The experimental results demonstrate that the proposed model achieves a high user interaction ratio of 90.2%, less service cost of 20%, allocation of resource ratio of 94.5%, and digital resource usage ratio of 97.3% compared to other existing models.

1 Introduction

The primary motivation for Digital Twins (DTs) is the need for feedback between physical systems in the real world and their digital counterparts in cyberspace. People increasingly turn to virtual events to mimic real-life events [1]. If one wants to know a whole life cycle, the only way is through whole-life monitoring that uses cyclic feedback. In this approach, it will be possible to guarantee digital consistency with the physical world

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throughout its life cycle [2]. It may undergo many simulations, analyses, data collecting, mining, and even AI applications built on digital models to ensure its appropriateness for actual physical systems. Observation, modelling, evaluation, and reasoning are the first steps in determining an intelligent system's intelligence [3]. "Metaverse" is an amalgamation of the words "verse," a diminutive form of the cosmos, and "meta," meaning beyond. Individuals may access and leave the virtual world using their digital personas, as described in the article [4]. Since this announcement, many academic and business communities have been interested in using the Metaverse to achieve sustainable development objectives. Even if the Metaverse will replace the Internet, the specifications of today's edge devices may not be enough to display high-definition 3D environments [5]. The accomplishments of the Metaverse as the future of the Internet hinges on users' ability to access it, much like how the Internet continues to enthral billions of people daily. Incorporating 6-G's tactile Internet, VR, and AR into the Metaverse will require the development of new modes of communication [6-7]. Additionally, next-gen portable network edges may help users with limited computational resources access the Metaverse when they are on the move, as there is a current trend away from bandwidth and other traditional metrics for communication towards computation-oriented interactions (COC) and different types of computation and communication system co-design [8-9]. Digital regions may allow users to interact deeper in the virtual world known as the Metaverse. Most people's online activities may be accessed via this ever-present network of three-dimensional virtual worlds [10]. Formerly limited to fantasies and video games, these ideas are now poised to revolutionize several industries, including consumer products, medical care, schooling, and economics.

The rapid advancement of the Metaverse and artificial intelligence (AI) technologies is teetering on the edge of a technical, societal, and economic catastrophe [11-12]. A new virtual universe, the Metaverse, is emerging due to the merging of the digital and physical realms. Theoretically, it will allow users to have more meaningful interactions with one another via more significant levels of immersion [13]. On the other hand, AI refers to robots' ability to do tasks often associated with human cognition, such as comprehending speech, processing images, and making decisions. More and more, physical structures in industry are integrating and interacting with digital networks. Complex and multi-informational simulation output may be acquired using digital twin technology, which allows for incorporating physical models, activities, and service data into a digital entity [14–15]. The industrial sector is an early adopter of Digital Twin technology, which allowed them to address the challenges of cyber-physical systems brought about by the proliferation of the Internet of Things (IoT). Digital twins (DTs) are digital model models of actual systems that allow interaction between the real system and its computerized version [16]. It can record physical parts and intangibles like business procedures and NFT transactions. Management of supply chains, smart cities, medical care, accessibility, and product development and production are some domains that use DTs [17]. Despite the increasing use of DTs in Cyber-Physical System (CPS) design, development, and operation, the existing variety of approaches has prevented an analytically based and focused user modelling approach. Workers directing collaboration in these areas are increasingly required to have digital design skills, and a centred around people engineering methodology for DTs of Metaverse/XR applications is becoming mandatory [18]. The study's overarching goal is to improve decision-making, open the door to predictive analytics, and smooth out interactions in digital twin ecosystems and metaverse engineering platforms via the integration of AI. This integration is critical for attaining scalable, adaptable, and efficient operations because of the importance of real-time feedback loops and optimization in these ecosystems. This method aligns with Industry 4.0 developments as it uses AI to power smart, networked systems that adjust to changing conditions and user needs.

The main contribution of the paper:

i) This study aims to illuminate the current situation of digital twins as they pertain to operation research, including their role in different domains, the difficulties they encounter, and their needs within this sector.

ii) This study explores the potential of artificial intelligence (AI) to create individualized content, enhance the realism and allure of virtual environments, and provide users with smart virtual assistants to help them navigate the Metaverse.

iii) Consequently, a potential trend that might promote the good expansion of the blockchain/AI-powered metaverse ecosystem is the production and sharing of intelligence via AI, which combines AI with metaverse technology.

Here is how the rest of the paper is structured. The context and relevant studies are presented in Section 2. In Section 3, the whole AI-DTE-ME procedure is detailed. To illustrate the specifics of the experiments and the outcomes of the simulations, Section 4 lays out a scenario. Section 5 concisely summarises the topic and suggestions for further research.

2 Related Survey

In [19], Fuzzy weighted spherical fuzzy rough sets with zero-inconsistency interval values (IvSFRS-FWZIC) and combined compromise solution (CoCoSo) are proposed and developed to reduce uncertainty in tool and transformation assessments. IvSFRS-FWZIC prioritizes digital twin features and other CPMMS components. Sensitivity, correlation, and comparison studies verify the method's applicability and robustness. Managers may find the recommended strategy helpful in selecting the appropriate CPMMS development tool.

In [20], DT-aided RIS-based Network Design (DT-RIS-ND) may increase network latency and reliability for 6G metaverse implementation. After reviewing the newest RIS and DT technologies, the prospective use cases and services of DT-aided RIS-based network architecture are discussed. This architecture's communication latency improvements are confirmed using a relevant simulation environment: final problems and future study on the suggested DT's position in RIS-enabled smart wireless spaces.

A dynamic hierarchical structure is proposed as an agile approach in [21]. In this paradigm, VSPs at the top calculate appropriate synchronization intensities, while IoT devices at the bottom are driven to detect physical item status collectively. In addition to a sensitivity analysis for system parameters, we experimentally and theoretically show that the lower-level game equilibrium exists, is unique, and is stable. The findings show that the dynamic hierarchical game outperforms the control group.

With the recent maturation of digital technology in the fields of augmented reality (AR), virtual reality (VR), and networks, the application of Metaverse in several areas has been accelerated [22]. It would be a mistake to ignore the Metaverse as a relevant actor in the future of digital architecture, engineering, and building. Stakeholders in the AEC sector would do well to begin early development to keep up with the rapid growth, expansion, and worldwide trend of the Metaverse, which encompasses the AEC industry. A better grasp of the Metaverse is essential.

The survey article [23] analyzes cutting-edge metaverse technologies and ecosystems and proposes a digital "big bang" in the first full framework. First, technology allows the Metaverse to supplant the Internet. Thus, we examine eight enabling technologies: VR, AI, Blockchain, CV, IoT, Robotics, Edge and Cloud Computing, and Future Mobile Networks.

The Metaverse has enabled the integration of diverse technologies to construct virtual duplicates of tangible assets [24] implemented the Metaverse requires 3D character animation or avatars. Costly motion capture technologies are used to create lifelike avatars.

A data-driven 3D animation system using motion primitives yields qualitative and quantitative outcomes [26]. These customizable and modular methodologies and technology make them suitable for building digital twins in many business scenarios.

Selvarajan Shitharth et al. [27] suggested Federated learning optimization for the computational blockchain process with offloading analysis to enhance security. The suggested method's main contribution is incorporating an offloading mechanism for data processing, executed using the blockchain methodology, guaranteeing total security for each data. We combine a load balancing mechanism with data weights to assess the consistency of each monitored data set using IoT in real time because a problem methodology is built concerning clusters. Five-scenario research found that offloading analysis via blockchain is safer, leading to an 89% improvement in data processing accuracy for all IoT applications.

Haifa Alqahtani [28] proposed the Green IoT for the sustainable smart environment using WSN. Due to the IoTs, physical objects can be integrated and linked to the internet with little human interaction and no need for human-to-human or human-to-PC communication. It discusses the pattern that's coming and the next big change in the IT industry. Through the use of administration or organization, everything and everything may be connected to everybody and anything at any time. Green Internet of Things (G-IoT) is another area of emphasis, which is how the Internet of Things (IoT) may help make the world a better, cleaner place. Learn the basics of the Internet of Things and G-IoT in this article. Additionally, it discusses the potential benefits and drawbacks of G-IoT regarding energy efficiency. Features, security issues, and trends in technology adoption are all defined in this article, which helps place the Internet of Things (IoT) into context.

Rita de fátima muniz and sheila maria muniz [29] recommended the Investigation of IoT-Integrated Smart Homes. Using an Internet of Things (IoT) architecture as a starting point, this article delves into the challenges encountered by smart home systems that are IoT-enabled and offers suggestions for overcoming them. A smart house streamlines the home automation process and provides consumers more convenience. After the success of the Industrial Wireless Sensor Network (WSN) with the Internet of Things (IoT), it is only natural to see IoT used in smart homes. The essay delves into several facets of smart homes that rely on the IoT and stresses the need for solid management and security measures. The research concludes by looking at smart house IoT integration, illuminating the problems and solutions linked to smart home IoT system development.

The goal is to develop a plan for creating and overseeing smart homes that use the IoT to improve people's daily lives. Javad Pourqasem et al. [30] presented the IoT and Industry 4.0 for enhanced environmental safety. Since water is essential to human survival, setting up systems to monitor water quality periodically is reasonable. Contaminated water on Earth causes around 45% of all deaths. Consequently, it is critical to ensure that people in cities and towns have access to clean water via filtration. Using IoT technology, Water Quality Monitoring provides a realistic and efficient framework for screening drinking water quality. The suggested system in this research uses several sensors to measure various parameters, such as water pH and turbidity, tank level, temperature, and relative humidity. A Personal Computer (PC) communicates with these sensors to gather more data using a Microcontroller Unit (MCU). Using an IoT program called Think Speak to monitor the water's characteristics, the collected data is sent from the cloud.

Seyed Ahmad Edalatpanah et al. [31] introduced the Smart Home Integrated with IoT. Problems have arisen due to the rapid development of both technology and design. These include but are not limited to, the need to protect servers and smart homes and the management and regulation of the whole system. Presented below is the architecture of the Internet of Things. "Smart" refers to a home that can be watched and controlled remotely via various home equipment and gadgets. Whenever different smart home gadgets connect to the internet via suitable network design and standard protocols, the whole setup is called an "IoT-based smart house" or a "smart home in an IoT environment." "Smart homes" simplify home automation needs. This article goes over some of the problems with the Internet of Things (IoT) and smart home systems that use it, but it also provides some answers.

Javad Pourqasem [32] examined the transforming user experience in the metaverse through edge technology. The network's periphery may host the Metaverse, a novel distributed computing paradigm for computationally heavy activities. This article provides a high-level overview of the metaverse's design and the technologies that will propel it forward. It then stresses the importance of edge computing as a critical component of the metaverse's digital backbone. Next, the author presents a Metaverse that uses edge computing, emphasizing how well it renders, allocates resources, communicates, and handles latency. To provide a thorough comprehension of the issue, the author finally gets into the obstacles of using edge approaches.

Çi ˘gdem Sıcakyüz1 et al. [33] suggested Data mining applications in risk research. All aspects of society, the environment, and businesses are vulnerable to global threats. Business risk has mostly attracted academic attention in the banking, market, and construction industries, while environmental risk encompasses hazards associated with natural disasters. Among the social dangers are transportation, traffic safety, and education. Researchers in genetics and molecular biology often use clinical data, while those in the public health sector often use data from various radiomic databases. Adverse medication effects are the primary target of DM in pharmacological research. The results of this analysis indicate that computer science and medicine have been the primary focus of research efforts. Intending to improve knowledge growth about implementing data mining methods in risk-related investigations, the study also addresses limits and offers a roadmap to direct future research.

Hossein Komasi et al. [34] proposed the Artificial Intelligence-baed Best Practice Performance of COVID-19 in the American continent. Using ANFIS and metaheuristic methods, researchers may assess countries. The countries' performance will be used to identify and build clusters. Out of thirteen criteria, only two were considered for the study. There are seven separate categories, one for each of the 35 countries. According to studies, COVID-19 has the worst performance in the US. Furthermore, in reaction to the COVID-19 pandemic, these three countries went above and above. There are two main ways to examine the work's contribution: the methodology and the context of the literature review. There has to be a focus on the whole continent since research gaps show that regional attention is necessary, not only on a country or part of a country.

Bui Hai Phong [35] recommended deep neural networks for classifying plant leaf diseases. Applying several Deep Neural Networks (such as Densenet-121) to the problem of disease classification in plant leaves is the main focus of this research. The colour attributes have made a big difference in how accurate the categorization is. For this reason, we examined and contrasted the classification accuracy using two publicly available datasets (Plant village leaf datasets) that include both colour and grayscale photos. Comparing colour and grayscale pictures, the approach achieved a classification accuracy of 98.08% and 92%, respectively. The findings that were gathered demonstrated that the strategy was successful. The research analyzes the influence of colour characteristics on the classification accuracy of several Deep Neural Networks based on the collected findings. The research compares how well different optimization techniques trained deep neural networks to identify certain leaf diseases.

Sushil Kumar Sahoo [36] presented the Role of Robotics in Maritime Technology. Through a critical analysis of these obstacles and a discussion of possible solutions, the study highlights the significance of cooperation among scholars, policymakers, and industry stakeholders. It describes new ideas like swarm robotics, human-robot cooperation, and AI decision-making. This study emphasizes the possible advantages of these innovations, which may lead to better efficiency, lower costs, and higher levels of safety.

Michael Nosonovsky et al. [37] introduced machine learning methods for frictional instabilities. This is important for unstable motion, where deterministic models are hard to construct. Among the many friction-induced instabilities, one may find those resulting from the velocity dependence of dry friction, those resulting from the coupling of friction with another process (such as wear or heat production), and there are still more. Similar to the beginning of sliding, the process is unsteady. The frictional instabilities may also be addressed using ML/AI methodologies, such as Topological Data Analysis and several ML algorithms, which have been used for data analysis on friction in general.

3 Proposed Scheme

An AI system that is conceptual and technical, digital twins with several potential uses across many domains, including but not limited to product creation, producing goods, health evaluation, aviation, and many more. The area of engineering building is now being used the most extensively, while intelligent manufacturing has garnered the most interest from researchers. Figure 1 shows the application regions' categorization diagram.

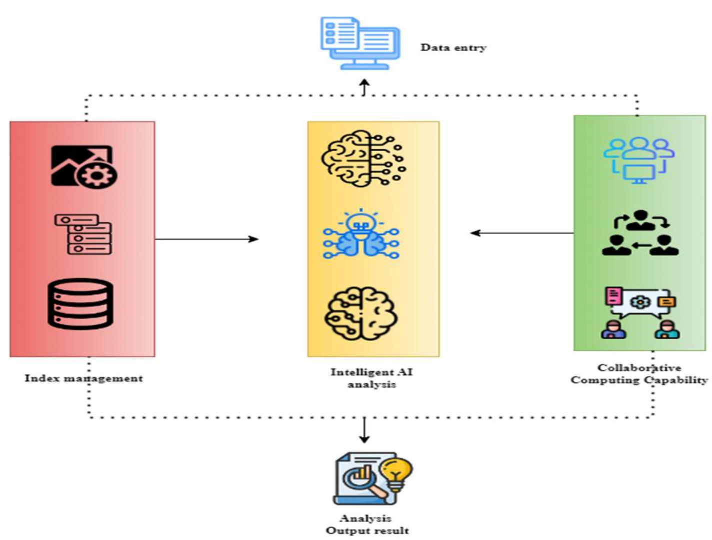

Figure 1. AI-based Digital Twin application.

DTs facilitate the creating of cutting-edge services that aid in administering, planning, and operating power grids and associated assets. Physical and digital twins may work together in a DT-based system by constantly sharing data via interconnected devices. A digital twin (DT) should mimic the physical system's actions in a digital setting and provide insights or predictive analytics about the real system. Computational technology allows for representing cyber-physical systems with behaviours indistinguishable from actual systems. Various domains may be used to construct and calculate the required functionality and the complicated decision-making process. When integrated into a system, DTs may create detailed digital representations of actual objects, complete with bidirectional communication capabilities, allowing for real-time interactions between the digital and physical worlds. One way in which the DT keeps tabs on and analyzes the most recent state of its physical entity is by using data measured on the physical twin to update it simultaneously. However, modern data analysis technologies allow for the manipulation or guidance of real systems by sending back the DT's evaluated findings to the physical system.

A digital twin is an electronic representation of a real system. Its characteristics and actions may take on some or all of those of its physical analogue as it ages. Maintaining consistency between a product's virtual and physical versions requires an adaptive approach. A wide variety of models may serve as virtual twins, including but not limited to rule models, 3D models, data-driven models, probabilistic models, and model-based simulations. With their characteristics, these models may represent various traits and perform multiple functions in a DT setup. One workable option is using co-simulation technologies, which unite domain-specific models into a single framework, to construct such an artificial twin in more than one area. Distributed modelling and simulation of large-scale digital twins, where many sub-models and sub-modules of a system are located at separate geographical locales, is another viable option. Each app defines its services, which are useful for digital and physical things. Depending on the service kind, physical twins may directly or indirectly rely on their virtual counterparts for assistance. One defining feature of DT-based systems is the abundance of internal and external data. One internal data source includes information transmitted between components, historical databases, real and virtual twins, and other sources. As an alternative, external data includes human operations, predicting results, and historical data logs. Data pre-processing is the first stage in effectively managing data from and to its destinations, which is necessary due to the variety of data sources. For the advantage of both the digital and physical twins, data mining and big data technologies examine all pertinent data. Additionally, data storage is essential for storing crucial information in a proper logic that allows for their future usage. Between physical-physical, virtual-virtual, physical-virtual, and past-present-future, data communication infrastructure connects all information inside DT-based systems.

The various hardware components can work together on tasks thanks to physical-physical connectivity. Knowledge transfer and data fusion are made possible via virtual-virtual interactions, allowing for the extension of functions. By establishing physical-virtual connections, a physical twin's measurements can inform a virtual twin and vice versa. Communications are also a key part of the physical twin lifecycle, which optimizes operations both now and in the future by drawing on prior data. Strategically addressing issues like process inefficiencies and dependency on human involvement, digital twin ecosystems may benefit from AI integration to enable autonomous decision-making. This method establishes a smooth connection between digital and physical assets by letting systems evaluate data in real time, make predictions, and improve operations without human intervention. One use of AI is smart manufacturing, where digital twins can automatically change production settings to save downtime and maximize resource usage. Both operational efficiency and the need for intelligent systems that can adapt to complicated settings in real time are being met by this capacity.

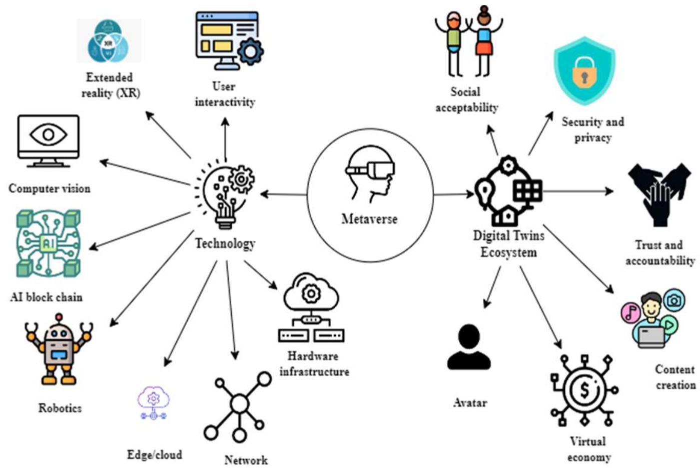

Figure 2. Metaverse technology with DT Ecosystem.

Technologies and ecosystems that enable the Metaverse:

Technology allows the Metaverse to work as a wide application, as indicated in Figure 2, which are the emphasis zones of the two kinds. Under the technological side of the eight pillars, there are extended reality (XR) and user interaction approaches. These allow people to access the Metaverse and manipulate virtual items. Several goals in the domains of machine vision (CV), distributed ledger, artificial intelligence (AI), automation, the Internet of Things (IoT), and the Metaverse may be achieved via XR user interaction. Systems with substantial bandwidth needs and a sensitivity to latency may benefit from computing on the edge. Data preparation gets processed using edge computers from the current data set. The scalability of processing and storage capacity is a hallmark of cloud computing. Improved application performance and user experiences are two potential synergies emerging from integrating cloud and edge-based services. An ecosystem is a realistically scaled virtual environment that functions independently. Virtual reality (VR) and user interaction (UI) technologies allow real-life users to direct their avatars in collaborative tasks like content production. A virtual economy has emerged as a direct result of these Metaverse activities. Social acceptability, privacy and security, and trust and responsibility are the three primary issues we address. For instance, virtual goods should remain in the hands of their rightful owners, and avatars should be aware of the consequences of using them. People who use the Metaverse want to behave freely without worrying about someone prying on their personal information. The proposed approach uses advanced AI algorithms and distributed computing methods to handle the complexity of large-scale implementations' inherent dynamic interactions, linked systems, and massive datasets. For example, to deal with rising computing needs, one may use cloud-based architectures and parallel processing, and to scale efficiently across many applications, one can use modular AI models. The technique has methods for real-time optimization and allocating resources to ensure the system keeps working well even as the environment becomes bigger and more complicated.

Cloud-Based AI for the Metaverse:

With the help of AI, we should soon be able to understand how the brain learns. The present state of artificial intelligence (AI) research in visual analysis, making decisions, and natural language processing (NLP) is mostly based on neural networks (ML), deep neural networks (DL), and reinforcement modelling. Recent advances in AI have piqued people's interest in exploring the possibility of materializing the Metaverse using AI. With the use of Metaverse AI-based activities, it is possible to deduce which displays a visitor has visited in a Metaverse museum by looking at their second life mobility record. To accurately and swiftly implement recommendation systems in metaverse museums, they must first identify which exhibits the user sees by analyzing the avatar's state. It details techniques for reliably evaluating and identifying avatar faces. Inspired by the one used in the video game Unreal Tournament, a casual engine powers the prototype. To deliver different results for the competitors' activities, this engine gets around the native physics engine. Conventional evaluation methods make it hard to understand things like the typical mental framework gamers use while playing a game. Narratives based on players' subjective experiences are common in games.

The Metaverse, the digital ledger:

A lot of people think that blockchain is one of the main infrastructures of the Metaverse. To facilitate the establishment of trustworthy, open, efficient, and transparent laws in the Metaverse, blockchain technology is anticipated to unite separate tiny enterprises into a unified economic framework. Hash algorithms and timestamp technologies, among others, provide users with metaverse data traceability and confidentiality. There are five levels in the conventional Blockchain design: network, data, consensus, applications, and contracts. The links between those levels and the Metaverse are as follows: Data verification and transmission techniques provide network assistance for diverse data transfer and verification of the metaverse economic system. One advantage of incorporating digital avatars, the decentralized ledger, and AI into the Metaverse is eliminating the credit problem associated with purchases. Another advantage is the enhanced safety of virtual assets and user identities provided by blockchain-shared storage. Lastly, smart contracting ensures an appropriate atmosphere for every member of the Metaverse. Transparency in executing system rules described in contract codes is ensured, and Metaverse value exchange is implemented. Once implemented, the codes of smart contracts cannot be modified. Strict adherence to the conditions outlined in such smart agreements is required. Decentralized exchanges are essential for metaverse economic systems that use NFTs or cross-chain circulation tokens. All system expenses for Smart Construction Lifetime Maintenance with Intelligent Digital Twins, comprising licensing and executing expenses, are based on the overall number of transactions, not the number of operations done by a single participant. The financial loop is created by users' digital participation in the production and selling of bitcoins. Avatar, the community, banking systems, and advanced utilization of resources are all shown in the graphic as collaborating on several blockchains.

Features of Metaverse Transactions:

Real estate transactions, product rents, service purchases, and almost all other monetary transactions are available in the Metaverse. This means that token transfers and transactions inside the Metaverse are not the only possible uses for Metaverse transactions. Transactions on most blockchains are initiated by sending them to miners, who then store them in their respective local transaction pools. Using hash-based consensus, the miner selects transactions to agree upon. The primary crusher is responsible for locating a print of the problem that satisfies the defined difficulty level. After that, it will notify each additional miner and add the data block to the mining network. These blockchain nodes are expected to process a high volume of transactions since the Metaverse constantly leads digital commerce via various intraoral inter-metaverse applications. As is typical, complete blockchain nodes in the Metaverse are under great strain from having to store all transactions that have ever taken place locally. Keeping confirmation latency to a low is another challenge with metaverse transactions. Internet applications that facilitate human activity often have an end-to-end latency measurement in milliseconds. In addition, a ten-millisecond lag is required for vertigo-free 3D display and interaction metaverse applications. For these low-latency applications, Metaverse transactions must have a short confirmation latency. The architecture's first essential component uses artificial intelligence algorithms, namely deep learning models and reinforcement learning agents, to assess and forecast system behaviours in real-time. These algorithms learn from data created by the digital twin. These AI models are constantly adjusting to new circumstances to provide dynamic optimization. Based on the predictions generated by the AI models, particular logistical and resource allocation issues like production scheduling or energy distribution are solved utilizing OR approaches, such as optimization algorithms and linear programming. Integrating the two systems works like a feedback loop: the digital twin system uses the optimal solutions from the OR to make real-time decisions, and AI-driven insights inform the OR models. Due to their combined efforts, the digital twin ecosystem will be quick to respond and highly efficient in its operations.

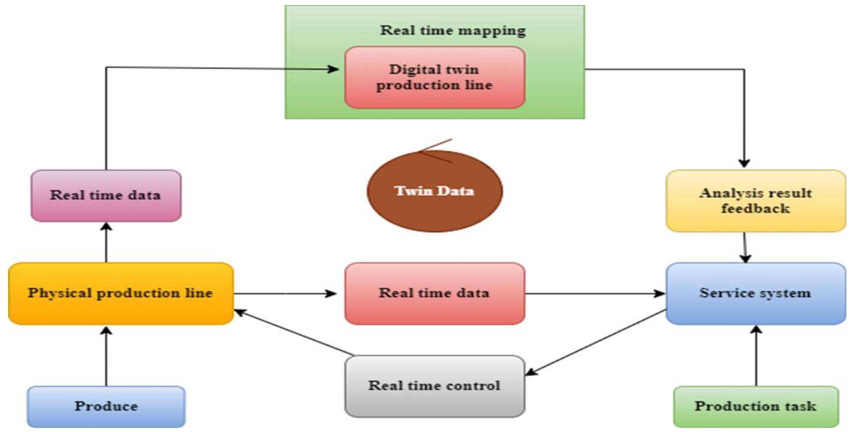

Figure 3. Operations research in Digital Twins for real-time optimization.

The advent of Internet innovations, such as cloud computing, has accelerated the growth of the intelligent sector and contributed to the fast expansion of the firm. More and more, physical components in manufacturing are integrating and interacting with digital networks. Digital twin technology enables the integration of real-world methods, processes, and service data into an information body, capturing multifunctional and multi-informational simulation data. Making a perfect copy of the object using the data virtual space is possible. Monitor and analyze product research and development and creation, manufacture solutions, and other aspects via data interaction to reduce production expenses and boost product competitiveness. Although the theory and design of the simulation examination of an adaptable, economical shop are laid out by the digital twin technology, there are still occasional safety risks in the workshop. Digital twin innovation establishes the continually changing routing model of the virtually adaptable production workshop, accesses the main oversight, supplementary oversight, safety, and other device-detecting indications, and collects various types of condition data in real-time. Supporting the workshop's efforts regarding "continuous machinery examination," gaining a good grasp of how things function there, spotting unusual behaviour in the machinery rapidly, and keeping it running longer can all be accomplished without the transporting examination team coming to the flexible industrial operation workshop.

The current workshop operation and the theory of operation for the digital twin line are shown (Figure 3). The service system oversees the workshop's equipment and instructs the physical production line to carry out the tasks specified in the production plan. Concurrently, the twin manufacturing facility uses the entity's real-time operations data to generate a real-time map of the production processes. Once the service system has this map, it may utilize it to notify users, improve control, and forecast production outcomes. The adaptable model of industrial operations is constructed following digital twin technology. The visualization that links industrial machinery's digital and physical realms consists of three parts: machinery, surroundings, and system. In real-time, the manufacturing devices update the processing method at each station on a manufacturing line by tracking the motions, positions, and functioning statuses of robots, AGVs, machine tools, and other accessories. Several metrics must be computed during the resource allocation procedure, including the cost of data transmission, channel utilization, and services provided by IoT devices. The following is the definition of the cost D_x^k related to the data collection by IoT device x in Equation (1),

$$D_x^k = \sum_{c=1}^{j_x} l_{xc} \propto_{xc} \tag{1}$$

In this case, k stands for the data collection phase of the IoT device, D_x^k is the computed cost of the IoT device x gathering real-world data about the outdoors and j_x is the count of those sensors. where $\propto_{xc}$ is the unit cost of obtaining real-world ecological data from sensor c of IoT device x and l_{xc} is the amount of data obtained by sensor c of IoT device x. Size reduction occurs when Internet of Things devices train on raw data collection; the following is a definition of post-training data size in Equation (2),

$$s_x^t = \eta_x \sum_{c=1}^{j_x} l_{xc} \tag{2}$$

Where t stands for the simulated data phase, s_x^t is the data size acquired after IoT device x has trained the raw data and η_x is the data compression rate of IoT device x during training. Information gathered during training is what the Internet of Things device sends to the Virtual Service Provider (VSP). Objects in the raw data may have their size, relative location, speed, weather condition, and other semantic data extracted by the IoT device using the algorithm for training. This leads us to the following definition in Equation (3) of the communication cost for data transfer from IoT device x to VSP via base station y,

$$D_{xy}^g = s_x^t \beta_{xy} \tag{3}$$

g is the communication cost of IoT devices x that send data to the VSP using base station y, and D_{xy}^g is the cost of communication for all IoT devices? The following Equation (4) is how the Internet of Things devices ask for the number of channels based on the data size after training,

$$Dh_{xy} = s_x^t / v_y \tag{4}$$

Equation (4) states that the number of networks received by a connected device x from base station y and the number of channels possible of base station y are equal to Dh_{xy} divided by v_y. Consequently, the following is the definition of the cost of base station-seeking channels,

$$D^{nn} = \sum_{y=1}^{|I|} \sum_{x=1}^{|J|} c_y i_{xy} Dh_{xy} \tag{5}$$

Each IoT base station has a unique channel allocation cost based on distance from the centre, as shown in Equation (5). So, c_y is the cost per unit of channel allocation for wireless service providers to BSs. When the value of i_{xy} is 1, it means that base station y is allocating resources to IoT device x; otherwise, it is 0. When the VSP makes allocation choices, the data value is crucial as it shows how much value an IoT device can provide via the data it is ready to send. Here is how the data value δ_x is defined as equation (6),

$$\delta_x = r(s_x^t) \tag{6}$$

When s_x^t the data acquired by the IoT device has been processed to assess the data's worth, and the VSP transmits the model parameter r to the IoT device over the BS. Using edge computing and distributed processing, the technique ensures that data is processed closer to the source to decrease transmission delays, thereby addressing latency in data synchronization between the physical and digital twins. Digital twin models simultaneously handle real-time data streams from Internet of Things (IoT) sensors and physical assets to reduce the lag time between physical and digital updates. In addition, communication protocols and specialized data pipelines like Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP) are used to guarantee efficient and rapid data sharing.

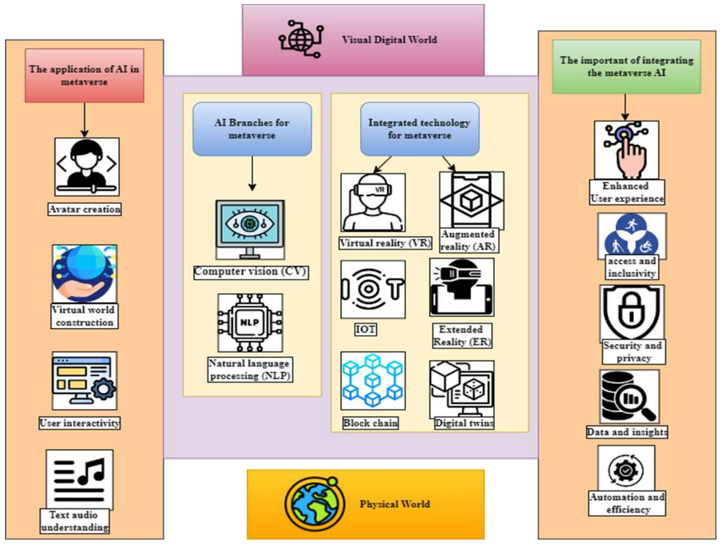

Figure 4. AI for DT and metaverse technology.

Figure 4 shows the Metaverse worlds, and the immersive experiences they provide are made possible by a wide variety of technologies, many of which rely on artificial intelligence. Monitored, autonomous, and positive reinforcement are the three main categories into which computer vision approaches fall. Algorithms in controlled training learn the link between samples and their labels utilizing the characteristics of the samples after being tagged with the labels of their classes. By constructing a classifier, computers may learn to distinguish between them and identify a fresh sample's label. Through a sequence of behaviours that culminate in an external reward, a person engages in feedback learning to gain knowledge about their surroundings. This data determines the value of its activities and adapts it to its environment. It is also possible to classify artificial intelligence models as creative or prejudiced based on their goals. Learning the relationship between inputs and their output labels is the main goal of discriminative models. This allows them to categorize fresh samples. Conversely, generative models may learn to produce new data similar to an existing one by studying the dataset's generation process via a probabilistic lens.

The system efficiently manages real-time data flows and updates using high-performance computing resources and optimized data pipelines, guaranteeing seamless connection between digital and physical assets. Modern algorithms swiftly analyze incoming data streams, enabling optimization and modifications in ever-changing contexts. However, problems may develop in cases with very large data sets or complicated simulations, especially when real-time updates require much processing power. Distributed computing and edge processing alleviates this problem by reducing the load on centralized servers and ensuring low-latency performance. Metaverse users may use AI's many features to improve their experience and engage with virtual worlds. Using AI algorithms to build more lifelike and engaging AR and VR experiences may be a game-changer. Users may construct individualized virtual representations of themselves with the help of AI-assisted avatar generation and modification. Additionally, AI may improve 3D modelling and rendering, leading to more efficient and quicker rendering times. More natural user interactions in virtual worlds are possible with computer vision and natural language processing, and voice recognition makes it easier for users to communicate. New opportunities for social engagement and cooperation in virtual places may be created by making the Metaverse more immersive, engaging, and accessible via various AI applications. The importance of AI-integrated technologies in defining our interactions with virtual environments is anticipated to grow significantly as the Metaverse progresses and changes. Personalized content suggestions, adaptable interfaces, and more natural and intuitive interactions are just a few ways artificial intelligence (AI) might improve the immersive and engaging experiences made possible by innovations combining elements of augmented and virtual realities in the Metaverse. Connecting real and virtual worlds via the IoT also allows for smoother transitions between the two and gives AI algorithms additional data to work with. Conversely, blockchain technology may establish trustworthy and decentralized virtual marketplaces in the Metaverse, allowing users to purchase, sell, and exchange digital products and services.

The combination of AI with developing technologies for use in the Metaverse is shown in Figure 4. Optimal resource allocation, scheduling, and operational efficiency in digital twin settings may be defined by optimization methods, including linear programming, integer programming, and simulation-based optimization. Research shows that by integrating restrictions and goals representing real-world limits, decision-making processes may be improved using a combination of OR techniques and AI algorithms. Improvements in operating costs, downtime, and resource utilization are some of the observable outcomes of this integration's effects on system optimization. In a digital twin for manufacturing, for instance, OR can optimize production plans while AI responds instantly to new factors, guaranteeing that the system works at its best with minimal human input. By facilitating more realistic and intuitive experiences, combining AI with VR may revolutionize our interaction with the Metaverse. Developers can tailor VR experiences to each user by analyzing and learning from their habits and preferences in the virtual world. One usage of AI in virtual reality is gaze and gesture tracking, which allows for more organic and intuitive interactions with simulated items and settings. Additionally, AI has the potential to enhance the realism and immersion of virtual reality (VR) environments by simulating the effects of user-controlled lighting and audio. Metaverse applications that combine AI and VR have the potential to improve user interfaces, increase efficiency, and strengthen security, among many other benefits for both consumers and enterprises. In virtual reality (VR), users can fully immerse themselves in a computer-generated, three-dimensional model of the physical world. Virtual reality has four main components: a digital environment, user interaction, sensory input, and immersion. The fundamental building blocks of a virtual world are a three-dimensional environment, avatars, and virtual items. A virtual museum or university campus can be an example of a real-life location that it mimics. 3D virtual things can imitate real ones. According to its substance, it ought to look and feel the same. More natural and effortless interactions with the integration of AI with the IoT open the door to the possibility of a metaverse. Artificial intelligence algorithms can now access and learn from massive amounts of data in real-time due to the Internet of Things (IoT) gadgets that bridge the gap between the real and virtual worlds. This allows for the creation of Metaverse apps that are more customized and adaptable. Internet of Things (IoT) devices may monitor user actions and preferences in virtual worlds, which can then be fed into artificial intelligence (AI) algorithms to provide tailored recommendations for content and services. Metaverse settings that mimic the user's actual surroundings in terms of temperature and lighting may be created with the help of IoT devices, making them more realistic and immersive. By combining AI with IoT, developers can create Metaverse apps that are more intelligent and responsive.

This offers many benefits for consumers and businesses, such as enhanced security, greater efficiency, and better user experiences. Within a metaverse smart city simulation, data from digital twins of automobiles, traffic signals, and road infrastructure may be used to manage traffic flow in real-time using AI methods like reinforcement learning. To maintain traffic flowing smoothly and efficiently, the AI system always adjusts the timing of the lights to account for changing trends. Deep neural networks can also be employed to anticipate possible system failures, like equipment malfunctions in digital twin models of power grids, and make proactive adjustments to operations to prevent disruptions. This is especially useful in the metaverse, where thousands of interconnected elements constantly interact. Through the interplay between the online and offline worlds made possible by the rise of the Internet of Things (IoT), a digital twin a precise digital replica of a physical object is created. Suppose the Metaverse is serious about making a digital twin that works. In that case, it will go to great lengths to ensure that the reflection accurately represents the physical state. Because of this unique quality, digital twins become an essential tool in the Metaverse. Using the Tactile Internet and Haptic Codecs, one may develop digital twins to enhance a group gathering professionally. Users may communicate with one another while interacting with or showing the application or equipment sample. Engineers learn to control complicated 3D renderings of networks using digital twins in educational sessions. The digital twins provide a virtual setting linked to a physical one, allowing for remote maintenance.

4 Result and Discussion

Engineers may use the right MBSE technology to create events-driven or agent-based simulations to investigate the digital twin's activities and interactions accordingly. Incorporating 3D data, simulations, and characterizations utilizing approaches like response surface models into the digital twin is possible. A vast amount of information about user activities and interactions will be stored in the Metaverse. Data and traces collected over time threaten privacy in the long run. When using any website with a 2D user interface, users will be overwhelmed by the number of permission forms already in place. People who use 3D virtual environments cannot afford to fill out many permission papers daily. Digital twins may be used to model plants, products, or services at an appropriate degree of abstraction, allowing one to measure consumer experience and the effect of innovation on that experience. Digital twins would also be eligible for the policy's advantages.

The computational needs of the proposed system include high-performance graphics processing units (GPUs), such as the NVIDIA A100 or H100, which have 40 GB of memory and can provide 624 TFLOPS FP16 performance for artificial intelligence (AI) training and inference. Data processing in real-time and large-scale simulations may need up to 1 TB of RAM, while storage for high-resolution 3D models and dynamic interaction data can necessitate at least 10 TB of SSD. The smooth synchronization of physical and digital systems requires a network bandwidth of 10 Gbps or more, and continuous operation is projected to use 5-10 kW of electricity. Advanced cloud services, such as AWS EC2 P4 instances or Google Cloud AI Platform, can meet these needs, which align with what existing metaverse technologies can do.

Dataset description: The Metaverse has gained appeal and inspired us since it connects the actual and virtual worlds. Metaverses allow the development of digital twins in industrial settings and other situations, generating huge volumes of data for model training. It provides MetaGraspNet, a vast benchmarking dataset for physics-based metaverse synthesis of vision-driven robotic grasping. The proposed dataset contains 100,000 photographs with 25 item types in five challenges to test object recognition and segmentation algorithms in compelling settings. Together with the dataset [25], one can propose a layout-weighted performance measure for robotic grab applications better for item detection and segmentation than existing general-purpose measures.

4.1. Verification cost for data transmission and test duration

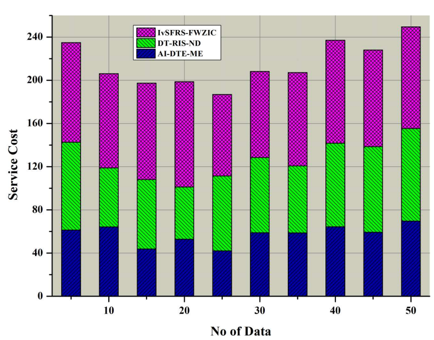

Figure 5a. Service cost for data transmission.

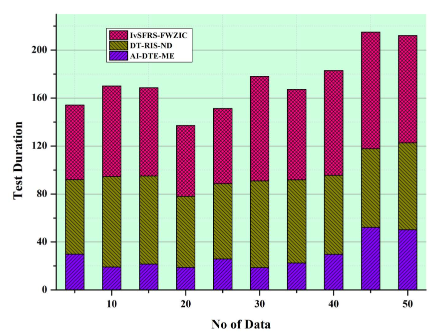

Figure 5b. Test Duration.

Figure 5a and Figure 5b show integrating digital twins into metaverse engineering and systems procedures is never a done deal without cost considerations. Cost estimates for digital twin implementation need a well-defined scope and purpose. The initial investment in a digital twin is higher, according to Equation (1). Still, there will be a substantial return on investment (ROI) later in the system life cycle due to including one or more of these models. The time, energy, and complexity needed to create a virtual model of a system determines the final price tag. Nevertheless, nowadays, most firms are actively working towards developing virtual system models due to their ability to decrease verification and test times and expenses using Equation (2). Following this development, the digital twin makes perfect sense. The complexity of the algorithms used to accomplish certain functions, the number of system components, the number of interfaces and dependencies among those components, and the amount of knowledge and expertise needed to develop the digital twin all contribute to its cost. A key aspect of digital twin architecture is the ability to cut costs even further by designing for reuse.

The cost of sending massive volumes of sensor data from traffic lights, cars, and environmental sensors may accumulate rapidly in a smart city digital twin system. To get around this, the system uses edge computing to process data locally at sensor nodes, lowering connection costs and eliminating the need to transmit data to centralized servers constantly. Further, data compression methods reduce the bandwidth needed for real-time updates. This research validates the practical application of the technique by performing simulations based on real-world data, such as traffic patterns and sensor outputs. These cost-saving measures efficiently preserve system performance while decreasing operating expenditures. Figure 5a shows the correlation between data transmission volume and related service costs, which may increase dramatically as the system expands. Important components of the total cost include bandwidth consumption, data update frequency, and data transit distance. The impact of various approaches on these expenses, including data compression, edge computing, and efficient communication protocols, deserves more investigation. For example, transmission costs may be substantially decreased with edge computing as the transmission of information to central servers is not continuously needed. This is probably the time needed to run simulations, analyze data, or do real-time optimizations in the system, as shown in Figure 5b, which displays the length of the tests performed. The elements that impact the time it takes to complete a test, including the algorithms' complexity, the amount of data being processed, and the available computing resources, need a more in-depth analysis. Evaluating the system's performance as the size of the digital twin ecosystem or metaverse environment rises requires comparing test durations across various situations, especially regarding scalability. If they are considered, the system's efficiency and any bottlenecks may be better understood.

4.2. Impact and user's interaction with metaverse technology

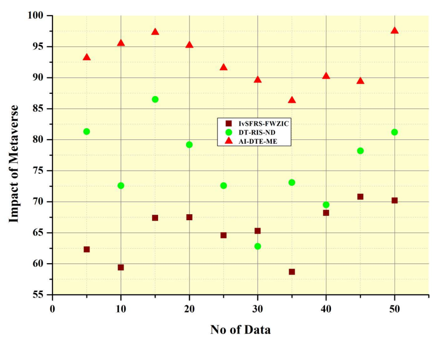

Figure 6a. Impact of metaverse.

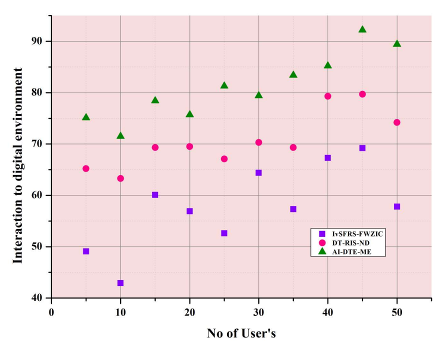

Figure 6b. user's Interaction in a digital environment.

Figures 6a and Figure 6b show one description of the Metaverse as a new digital environment that blends VR, AI, cloud computing, and blockchain. An interactive, immersive shared AR is planned. The Metaverse emerged as a network connectivity crisis solution during the epidemic. The Metaverse's realistic virtual environment and blockchain connection may be used for socializing, shopping, and work. Learning, medicine, entertainment, performing arts, community life, and the rest of society are projected to gain from XR's rapid expansion and the creation of more immersive 3D online worlds. Any new digital technology raises concerns about health, safety, privacy, and the economy. Users may use the Metaverse's high-tech, multi-modal interaction services online and offline using Equations (3 and 4). Problems with immediate information flow and cross-metaverse interaction among players pose the greatest threat to full immersion. Smart devices allow the Metaverse's powerful perceptual and interactive capabilities, even with increasingly complex rendering computations. Synchronization, large-scale reconstruction and rendering, and real-time engagement are multi-player interaction issues.

The second need for employing several Metaverse services is the ability to synchronize and switch between digital and physical realities in various zones. Figure 6a shows factors like real-time engagement, increasing data complexity, and connection between the physical and digital spheres that might be used to describe the effect. A more in-depth analysis would show how the metaverse's immersive and linked character necessitates more complex algorithms, data synchronization methods, and techniques for managing resources in a digital twin environment. For the framework to function at its best, it has to handle the potential problems that the metaverse brings, such as massive volumes of real-time data and the need to provide seamless interaction between virtual and physical assets. Figure 6b emphasizes user interaction in a digital setting, which may be the metaverse or a digital twin platform. Avatars, sensors, or AI-driven interfaces are examples of how they might portray many forms of user participation. How different kinds of interactions impact the functioning of digital twins in real-time (e.g., visual, haptic, or voice-based) should be covered in more detail.

4.3. Decision Enhancement and scheduling resource allocation

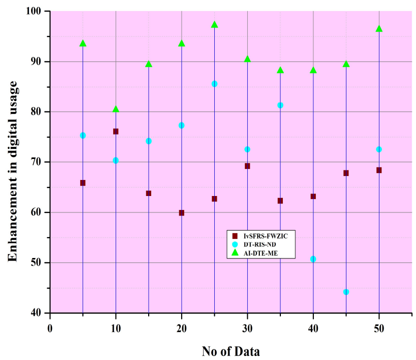

Figure 7a. Enhancement in digital usage.

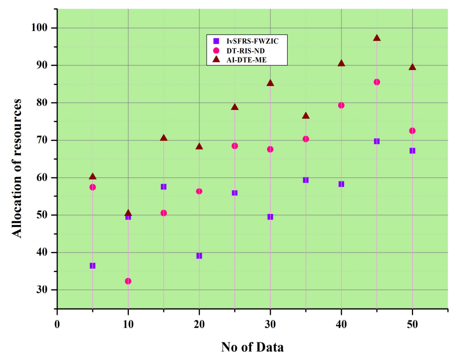

Figure 7b. Resource allocation.

Figures 7a and Figure 7b show that businesses may get valuable insight into customer systems and product use habits via the integration of digital twins with the Internet of Things (IoT) calculated using Equations (5) and (6). With this data, customers can better plan for product failures, optimize resource use and maintenance schedules, and reduce system downtime. The digital twin may eventually enhance system maintenance using the system's past operations and maintenance records. Incorporating more digital twins into the Internet of Things (IoT) may make monitoring scheduling and maintenance cycles from a central location much easier. In the second case, data ownership could become more complicated, especially when renting equipment. Despite the potential benefit of access to execution data, most manufacturers do not possess the necessary data to optimize their equipment. Conversely, suppliers often have an abundance of interconnected gadgets and machinery that yield useful data. The vendors' emphasis on customers' readiness to share data with them is significant. If this is correct, then optimization may be done promptly.

The suggested solution facilitates data interchange and communication across digital twin platforms using open standards like RESTful APIs and OPC UA. It allows for incorporating sophisticated analytics and machine learning models via its compatibility with other AI frameworks like TensorFlow and PyTorch. To control devices and collect data in real-time from sensors, the system integrates with Internet of Things (IoT) technologies using protocols such as MQTT and CoAP. Integrating blockchain systems with smart contracts to handle transactions and guarantee confidence in decentralized processes further improves data security and transparency. Because of its adaptability, the system may be used in various industrial and metaverse applications since it is compatible with numerous technologies. Artificial intelligence (AI) training on incomplete or inaccurate data raises ethical concerns about the possibility of bias in AI algorithms, which might result in discriminating or unjust conclusions when used in digital twin systems. Additionally, those who work in jobs where digital twins and AI can do better may find themselves out of a job as digital twins and AI become more popular in digital twin-using businesses. Another concern is the potential for privacy breaches caused by AI systems that, without proper protections, might handle sensitive information about people or physical assets. It will be difficult to determine who is responsible for important results if AI is used to make decisions, which might reduce human accountability.

5 Conclusion

The proliferation of big data, the IoT, the commercial Internet, and smart control techniques has led to the widespread use of digital twins as a novel technology in several domains. The idea of digital twins has been gaining popularity as a way to efficiently deploy technological solutions that allow both the virtual and real worlds in manufacturing to communicate and collaborate and as a practical way to eliminate the divide separating the two realms. A digital twin may help create an actual thing digitally by modelling its life cycle in software and then simulating, validating, forecasting, and managing it using real-time data, historical data, and algorithm models. When designing models, gathering data, analyzing it, making predictions, and running simulations, digital twins may be crucial for boosting digital industrialization and industrial digitalization and integrating the digital and real economy's growth. They are also an essential instrument for enhancing productivity. Combined with other technologies such as the Internet of Things (IoT), the distributed ledger, augmented perception (AR), flipped reality (MR), and simulated reality (XR), AI will play an increasingly important role as the Metaverse expands and VR experiences improve. The article has discussed the past, present, and future of AI in the Metaverse, along with the advantages and disadvantages of integrating it. Digital twins use the Internet of Things (IoT) and other innovations to build digital models. They use information processing and digitization to turn knowledge and data from actual objects into terms of data alongside other innovations to build a digital copy of an actual item. Many industries stand to gain from this because of applications such as digital twin explanations, clinical pre-adjustment/prediction, and automated decision-making made possible by cloud computing, artificial intelligence, and big data. Artificial intelligence is a key component of the digital twin ecosystem. Mechanism automatic optimization and internal information handling highlight its significance as the digital twin ecosystem's central nervous system. Because of this, every part of the ecosystem may work together like a well-organized cloud. Research now depends on a combination of the two, and research to come will apply intelligent transformations to various industries to varying degrees. In the next several years, we will see a dramatic uptick in the development of digital twins. Manufacturers increasingly turn to digital twin technologies to improve operations, make real-time database choices, and find new ways to enhance imaginative items, services, and corporate practices. The experimental results demonstrate that the proposed model achieves a high user interaction ratio of 90.2%, less service cost of 20%, allocation of resource ratio of 94.5%, and digital resource usage ratio of 97.3% compared to other existing models. Future studies will explore the full usage of digital twin technologies, which may need ecosystem-wide data and system integration. Although it is still necessary to incorporate outside materials into the corporate virtual ecosystem, it is possible to construct a comprehensive digital model of the client's life cycle or supply network that involves primary vendors and suppliers and presents a smart macro-operational vision.

Limitations of the study

One important issue to overcome is the system's scalability, particularly in vast and complicated digital twin ecosystems. Performance may suffer as the amount of real-time data increases and the system's complexity grows. A further issue is data quality. Artificial intelligence models rely heavily on accurate and representative training data, which might cause bias or less-than-ideal judgments if the data isn't up to snuff. One potential constraint is the computing power and memory needed to run the framework, which might be a problem in large-scale deployments. While there are many advantages to integrating AI and OR models, there may be certain problems with synchronization and seamlessness that cause decision-making to be delayed or inefficient. Finally, it's important to remember that ethical concerns like AI prejudice and the effects of automation on employment might impact the model's broad acceptability and adoption.

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Conflicts of interest

The authors declare no conflict of interest.

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