Wireless Personal Communications (2023) 131:2193–2216
https://doi.org/10.1007/s11277-023-10538-6

# Integrating Digital Twins with IoT-Based Blockchain: Concept, Architecture, Challenges, and Future Scope

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Accepted: 21 May 2023 / Published online: 8 June 2023


## Abstract

In recent years, there have been concentrations on the Digital Twin from researchers and companies due to its advancement in IT, communication systems, Cloud Computing, Internet-of-Things (IoT), and Blockchain. The main concept of the DT is to provide a comprehensive tangible, and operational explanation of any element, asset, or system. However, it is an extremely dynamic taxonomy developing in complication during the life cycle that produces an enormous quantity of the engendered data and information from them. Likewise, with the development of the Blockchain, the digital twins have the potential to redefine and could be a key strategy to support the IoT-based digital twin's applications for transferring data and value onto the Internet with full transparency besides promising accessibility, trusted traceability, and immutability of transactions. Therefore, the integration of digital twins with the IoT and blockchain technologies has the potential to revolutionize various industries by providing enhanced security, transparency, and data integrity. Thus, this work presents a survey on the innovative theme of digital twins with the integration of Blockchain for various applications. Also, provides challenges and future research directions on this subject. In addition, in this paper, we propose a concept and architecture for integrating digital twins with IoT-based blockchain archives, which allows for real-time monitoring and control of physical assets and processes in a secure and decentralized manner. We also discuss the challenges and limitations of this integration, including issues related to data privacy, scalability, and interoperability. Finally, we provide insights into the future scope of this technology and discuss potential research directions for further improving the integration of digital twins with IoT-based blockchain archives. Overall, this paper provides a comprehensive overview of the potential benefits and challenges of integrating digital twins with IoT-based blockchain and lays the foundation for future research in this area.

**Keywords** Digital twins · Internet-of-Things · Artificial intelligence · Control system · And Blockchain

Extended author information available on the last page of the article

## 1 Introduction

Recently, the evolution in information technologies such as the Internet of Things (IoT), Cloud Computing (CC), and Cyber-Physical System (CPS) besides development in communication technologies, are revolutionizing the system approach to transmitting information between various sources. Undoubtedly, the revolution in all aspects of life nowadays is due to digitalization. Because of this advance and rebellion in Information-communication technology (ICT), the Digital Twins (DT) has emerged as one of the talented ideas [1–8]. The DT is a digital representation of a real system from the perspective of (CPS). Therefore, a virtual complement of a convinced system mimics its actual performance. During full lifecycle development, the digital data from the virtual system, coupled with a real system, characterizes the information from the physical system. Consequently, combining digital and its real counterparts creates an effective way to handle, control, and improve coordination when the system is operating [4]. Furthermore, the DT records all data collected from physical sensors as well as the execution system response. As a result, the critical role of DT is to predict and diagnose the behavior of the physical system in order to foresee any malfunction or fault and feed data to the system in order to provide the best possible maintenance [6].

The virtual representation of the system is the major goal of DT to enhance productivity, increase the operation's flexibility, and decrease maintenance prices and efforts. On the Other Hand, DT could be run depending on the requirement, either on a cloud-hosted system or at the edge layer, to address the issues of Industry 4.0, which arise from the production of linked components. DT, on the other hand, supports both a clarification of the behavior of the actual system and the best possible solutions for the physical model. To improve the control action, foresee the system performance, and endorse decision-making, DT uses a fundamental modeling system, simulation procedures, and transparent simulation [9–12].

The digital twins' concept was first introduced by Grieves in 2002 [13], and then NASA was the first to apply it to constructing virtual space machine models. Existing DT works and implementations are still in their early stages, according to the literature, and require a lot of effort. However, It is well-integrated into a wide range of applications, such as biomedical systems, manufacturing, aerospace, agriculture, Smart Cities, and weather forecasting [1, 2]. In addition, many distinct specialist engineers and computer scientists are needed in this essential subject to design an efficient Digital twin system for any physical system. Their responsibilities will include building and designing the essential product prototype as well as creating a detailed explanation of the virtual system.

With the advance of modern technologies currently, the digital twin is integrating with other technologies like cloud computing, Artificial Intelligence (AI), Big data, blockchain, and IoT, and sensor data fusion to develop a dataset that will be reorganized and modified when its actual counterparts alter [7, 10, 14–16]. In recent years, IoT integration with DT has allowed for greater visibility of physical Twins and their current status. It also simplifies the system function's connection and documentation so that the physical devices' performance may be understood and clarified. Furthermore, Artificial Intelligence is continually improving DT's abilities by processing data from its physical counterpart and surroundings. Data assessment and prediction results in the detection of patterns, classification of data, and identification of the model. Additionally, it provides the essential features necessary for producing the necessary action from the vast amounts of data and information generated by the DT, such as classification, regression, clustering, and pattern recognition. The introduction of modern technologies, such as Blockchain, has recently made it easier to use Digital Twins in practical applications [14, 15]. Also, the deployment of digital twins and the developing AI technologies like deep learning with cyber-physical systems (CPS) is aimed at improving manufacturing output and productivity [15]. It proposes a concept for smart manufacturing and Industry 4.0 through the use of conceptual schema and modern technology. In [23], they presented a novel scheme for fault detection and prognosis based on Deep learning and Digital Twins. The deep learning system may simply identify the malfunction in the system by observing the weakening of the actual part and making a comparison with its normal behavior. Digital Twins are used to creating a defect diagnosis for an electrical machine, which is proposed in [20]. A modified DT with the Industrial IOT system is introduced in [24] to improve the vision for smart production. It is believed that adopting DT is critical to developing the Industrial IoT, as it would enhance customer connection with the supply chain.

Digital twins are digital representations of physical objects or systems, which can be used to monitor and control their behavior in real-time. The Internet of Things (IoT) is a network of connected devices that can share data and communicate with each other. Together, digital twins and IoT can be used to create smart systems that can optimize performance and predict potential issues. Artificial intelligence (AI) can be used to analyze data collected from digital twins and IoT devices, to identify patterns and make predictions. AI algorithms can be used to develop control systems that can optimize the behavior of complex systems, such as manufacturing processes or transportation networks. Blockchain technology can provide a secure and transparent way to store and share data between different parties. This can be especially useful for digital twins and IoT devices, which can generate large amounts of data that need to be shared and verified in real-time. Blockchain can also be used to develop decentralized control systems, which can operate autonomously and provide a high level of security and resilience. In summary, digital twins, IoT, AI, control systems, and blockchain are all technologies that can work together to create smart and secure systems. By combining these technologies, it is possible to develop systems that can optimize performance, predict and prevent issues, and operate autonomously with a high level of security and transparency.

In this work, we will highlight the use of blockchain with the digital twins to benefit from their characteristics such as full transparency, promising availability, trusted traceability, and immutableness of the transactions. In conclusion, the primary contributions of this work can condense as follows:

- Providing an outline of Digital Twins characteristics and applications and explore the digital Twins process.
- Presenting perceptions, concerns, and application of Blockchain technology.
- Highlighting the recent studies of the integration of blockchain with digital twins for various applications.
- Providing a framework for blockchain-based digital twins for IoT systems.
- Presenting opportunities and future research directions for this cutting-edge research subject.

Thus, the major contributions of this paper are:

- *Conceptual Framework* The paper provides a conceptual framework that integrates digital twins with blockchain technology for the Internet of Things (IoT). This framework is designed to improve the efficiency, security, and transparency of IoT systems by enabling the creation of secure, decentralized, and immutable digital replicas of physical assets.

- *Architecture* The paper proposes an architecture for integrating digital twins with blockchain technology that includes four layers: the device layer, the data layer, the blockchain layer, and the application layer. This architecture enables IoT devices to communicate with each other and share data securely and transparently, while also enabling the creation of smart contracts and other blockchain-based applications.
- *Challenges* The paper discusses the challenges of integrating digital twins with blockchain technology, including issues related to data privacy, security, scalability, interoperability, and governance. The paper proposes several solutions to these challenges, including the use of encryption, decentralized identity, and consensus algorithms.
- *Future scope* The paper highlights the potential future applications of integrating digital twins with blockchain technology, including in areas such as supply chain management, energy management, healthcare, and smart cities. The paper also identifies several areas for future research, including the development of new consensus algorithms, the integration of artificial intelligence and machine learning, and the exploration of new blockchain-based business models.

This paper is organized as follows. The concepts, characteristics, and applications of a digital twin are presented in Sect. 2, while the integration of digital twins with blockchain is provided in Sect. 3. The challenges and Future directions in research are introduced in Sect. 4. Finally, the conclusion of the paper is presented in Sect. 5.

## 2 Digital Twins

### 2.1 Taxonomy of Digital Twins

In the 1970s, the first Digital Twins technique is developed during NASA's Apollo mission. In this technique, two identical spacecraft were released, one on Earth for flight training and the other to replicate the behaviour. In 2002, Grieves was the first to establish the essential digital twin paradigm for product life cycle management (PLM) [17]. The fundamental concepts are to develop the digital simulated model for a physical system where the simulation model's information is twinned with the data from the real system throughout its entire life. Thus, the DT is incessantly analyzing the system's behaviour and performance in order to determine the location and the time of the fault is likely to occur and provide the best solution. As a result, digital Twin is known as an active paradigm capable of handling the variances in real-world systems. Appropriately, product lifecycle management is being digitalized (PLM) to increase the physical product's efficiency and ensure consistent and quick operation.

The three key elements of the DT are shown in Fig. 1 as the following: (1). The actual product, (2). The virtual model, and (3). The relationship between the digital model and the actual product transmits the data from the actual product to the virtual model and vice versa. A block diagram and a mathematical model are required to create such a digital twins system for a physical element. Later, a simulation is developed that is as close to the real thing as possible. Using a variety of communication and visualization approaches, the digital replica is recognized as sensor information for the real-time system. Then, to increase performance and depict how the thing would behave in a real

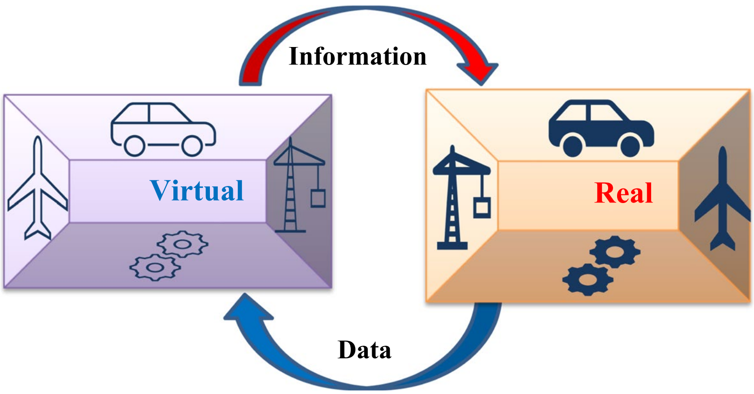



**Fig. 1** Model of digital twins

model, this mimic model generates information and digital data that is fed back to its actual part. Consequently, a DT is believed to be an advanced system that can replicate, monitor, examine, regulate, control, and improve the response and function of the system.

Digital Twin is a relatively recent idea in control systems. Control system aims to regulate other system based on the required performance and actual output and it plays a crucial role in both automation and industry. So DT with a control system work in managing the product and making an optimal decision on the performance of the whole system like a Model Predictive Control (MPC) is implemented in DT from operational and sensor data to provide insights into the state of the equipment and the possibility of various failure types.

The network of physical items, or "things," that are implanted with sensors, software, and other technologies to communicate and exchange data with other devices and systems through the internet is referred to as the Internet of Things (IoT). Moreover, digital twins can IoT data because Iot provides real-time monitoring that can help in analytics to improve the performance of the system and give actual details of the whole process.

Some characteristics are distinctive for DT, which set this technology apart from existing technologies. These characteristics are:

- The DT is a representation of the element's or system's real-time performance with a digital technique that renders it intelligent and fully programmable [7]. As the virtual representation is evolving simultaneously with the actual system through the operating process, predictive analysis and synchronization of fresh data with the physical system improve the operation [18].
- Within Digital Twins, data is homogeneity. Data generated in several areas throughout the physical ecology can interact with one another. Likewise, there is an interaction between dynamic and historical data to give the necessary action. Due to the enormous amount of data, it must be a combination of DT with other techniques such as analysis methods, Big data procedures, and data fusion algorithms to deal with it that gives precise, meaningful data [6].
- A fault diagnosis and fault prognosis use digital traces [20]. Both gathered data and feature extraction are combined to verify the location of the fault and apply this

diagnosis to enhance the system's design so that the same error and trouble will arise less in the future.

- Self-adaptation and self-parametrization abilities [13], this allocates to adjust and enhance a physical model. Because of DT's abilities, the modifications in a component will not disturb any components in the system, and it is simpler to change an unprofitable component with a superior one to enhance the overall behavior.
- Within DT technology, optimization algorithms are utilized to attain the highest productivity by establishing a set of high-value alternative decisions based on a set of goals, criteria, and limitations.

## 2.2 Structure of Digital Twins

As demonstrated in Fig. 2, the DT is regarded as an innovative technology thanks to its substantial effects on closing the gap between real assets, digital simulation, information, and services. Corresponding to Gartner Research [19], DT is likely to be employed by two-thirds of firms using IoT in the coming future. Many organizations propose Digital Twins systems, including Microsoft Azure IoT, GE Predix, IBM, Cisco Systems, Oracle Cloud SAP Leonardo, and other industrial manufacturers. Figure 3 shows an example of SAP Leonardo.

The DT is a merging of various fields like computer science, control systems, and telecommunication scientist. The required DT system is created of key parts containing a digital model, data processing, and datasets [5]. The digital model is a digital reproduction of the real items and their elements, a model of the system's performance and defects, and a telecommunication model. It describes the structure of subsystems, subassemblies, and modules and creates a simulated version of every component with the gained receiving measurements from production, actions, and operation. To improve the product's reliability,

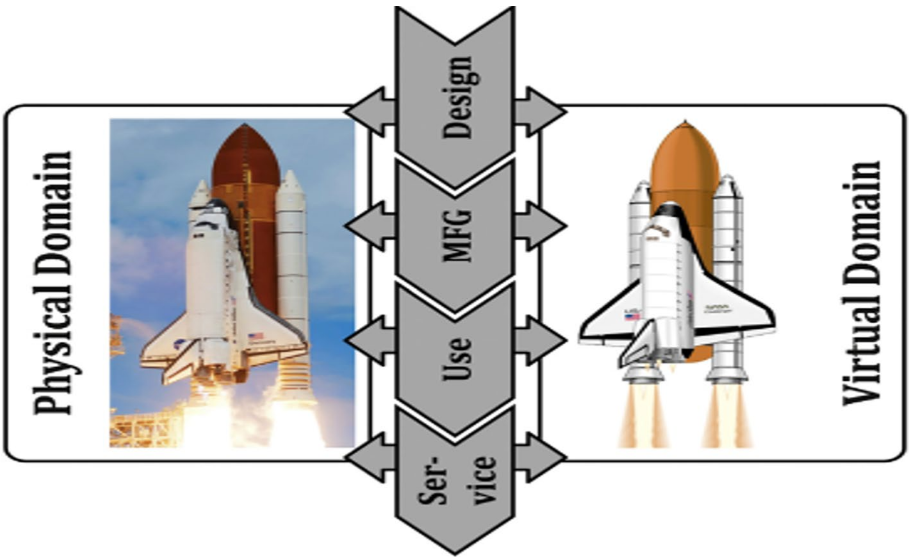



**Fig. 2** Vision of digital twins in PLM

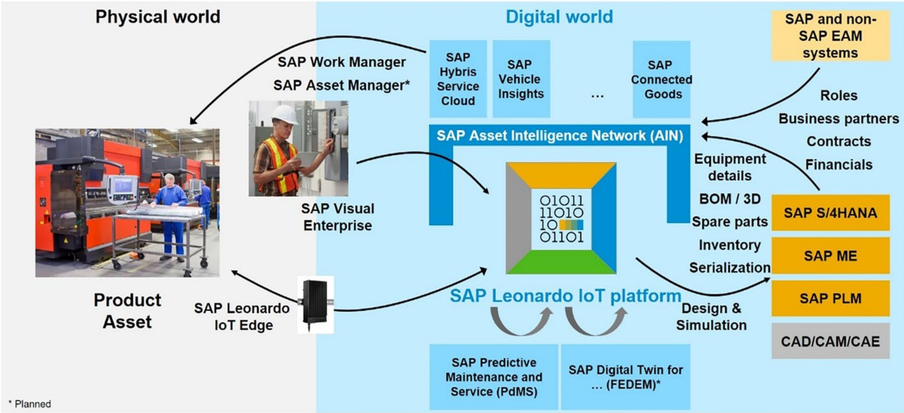



**Fig. 3** Example of DT's vendor [11]

a replica of the sensors can be introduced inside the digital part of the system[20]. Also, the digital simulation could be a mirror image of the physical items by detecting and classifying the key element of actual items. Furthermore, sensor networks, storage systems, and data transmission are critical for digitally modeling the system and analyzing the data in DT. For operation analysis and validation of the virtual model of the process, both numerical models and simulation are needed.

Data fusion is the second key component of DT, and it is used to diagnose, forecast, and prescribe the actual system's behavior by preprocessing and optimizing data. It analyses the physical assets' performance by processing a large amount of data and information. For diagnostic and prognostic, the faults in physical systems, the analyzing data is transferred through knowledge rule-based.

In general, data fusion involves combining data from multiple sources to create a more comprehensive and accurate picture of a system or environment. In the context of digital twins, data fusion algorithms can help to merge data from various sensors and sources to create a unified view of the physical system being modeled. Some specific data fusion techniques that are commonly used in digital twins include:

- *Kalman filtering* A recursive algorithm that estimates the state of a system by combining noisy measurements with a dynamic model of the system.
- *Bayesian networks* A probabilistic model that uses graphical representations to model the relationships between variables and perform probabilistic inference.
- *Dempster–Shafer theory* A mathematical framework for combining evidence from multiple sources that uses belief functions to represent uncertainty.
- *Fuzzy logic* A technique that uses fuzzy sets to represent imprecise or uncertain information and can be used to model complex relationships between variables.
- *Neural networks* A type of machine learning model that can be used to learn patterns in data and make predictions.

These are just a few examples of the many data fusion techniques that can be used in digital twins, and the specific technique chosen will depend on the nature of the system being modeled and the data available.

Connections and operations are the final component of DT for dealing with complex systems. A complex function that any single unit cannot perform can be accomplished by cooperating with the components to transmit critical information between components and continuously refining the digital model. With facility processes such as modelling, operation monitoring, and fault-tolerant, DT can define a real thing and recognize the malfunction data can be identified by DT technology and then suggest a fix that is appropriate for it. Because of the preceding, a crucial question arises.: Why will Digital Twins be the industry's cornerstone in the coming years? The basic concept behind Digital Twins is to use information and data to replicate physical sources. Hence, DT's main merit is to boost efficiency and decrease the expense of the operation. Self-adaptation and self-learning are two of DT's characteristics. This aids in the modification of the system and provides an upcoming idea for the procedure to be done. As a result, while preparing to develop an advanced item, suggest a modification, or offer a new model, the knowledge and the data gathered from the Digital Twins would be employed to reduce problems experienced during the operation or product life cycle.

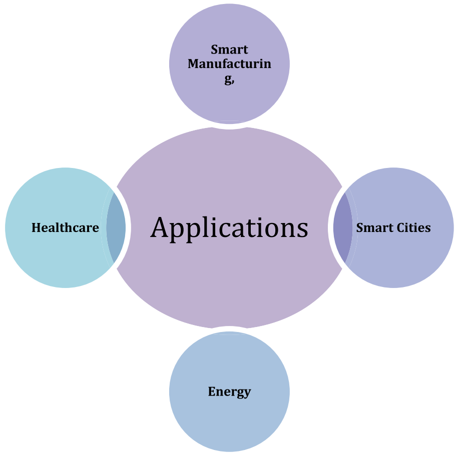
Other pros of utilizing DT are decreasing the fixing time, upgrading the operation procedure, and expecting malfunction. As the data from sensors are collected and analyzed, DTs can diagnose the behavior of the actual model and determine the best course of action. Then the data is classified to diagnose and determine the field's maintenance requirements. Besides, DT can analyze and conclude the object's condition, the duration of the valuable cycle, and the operation's ability. As a result, it will be able to detect and recognize the problem in the future, preventing both foreseen and unpredicted catastrophic operations, and the spare part will be simply estimated. Along with the data from the online measurement, the Digital Twin's simulated part and working history serve as the basis for more powerful service improvement. Stockholders can quickly access the real-time reports and relevant information because DT provides good interaction and records for the operation of the process.

### 2.3 Digital Twins Applications

Nowadays, there are many fields in which Digital Twins are applied, such as manufacturing, biomedical engineering, smart constructions, smart cities, and electrical energy, as shown in Fig. 4 as follows:

- **Smart manufacturing** The primary sector in which Digital Twins are used in industry and manufacturing. DTs are mostly used in the area of product lifecycle systems in manufacturing. So, the DT's strategy in a lifecycle process is to gather and examine the information of a full life cycle operation and use that information to improve the system or results [7, 23]. In [6], The utilization of DT in Big Data and Smart Manufacturing is described in depth. The differences between innovative trends and Digital Twins, as well as their significance, are presented for expanding the industries. In [5], the historical significance of DT in the production process and the life-cycle of the production are discussed. The main contributions of DT are provided for the creation and manufacturing of the assets. The authors in [16] provide a solution to data management difficulties for a DT of a product using blockchain technology. The proposed data managing system is built in a system that connects whole components implicated in the system, and later Blockchain is applied to guarantee that only permitted individuals have access to the database. A new framework in [24] is presented to providea data-driven framework

**Fig. 4** Digital Twin's Applications




for creation of simulation models from smart factory data is proposed. It facilitates the production processes by directing entrepreneurs to build a DT system and utilize the information provided.

The DT is applied to the power plant in [25]. When DT is used to analyze a big power grid, the time necessary for assessment is decreased, and decision-making for operation is enhanced, resulting in a lower time–cost value when evaluated with another technology like as CPSs. Also, Digital Twins is working on the development of power electronics, as presented in [26]. The converter layer is modelled and viewed using FPGA in the DT for fault diagnosis. A comparative analysis with real-time intervention is given to discover irregularity in power electronics. In [27], an Experimental Digital Twins (EDT) is established to achieve a direct integration between actual and digital models and develop a representing domain. EDT is used to implement a controller technique, a smart approach, and a simulation-based procedure. Reference [28] presents the research approach for 3D printing using DT, machine learning, and Big Data. The computationally expensive period for trial and error is cut in this paradigm, and the product's time-to-market is reduced.

- **Smart cities** Digital twin innovations have proven to become smarter in presenting useful smart city features. As the Internet of Things (IoT) and communications have advanced, so has research in this subject, leading to increased interest in the digitalization of our life. The latest technology that can be used for DT in smart cities is presented in [31]. The suggested architecture uses a knowledge-based method with machine learning to provide classification and decision-making processes for managing the transportation and power in a major city [32] describes a framework for developing smart healthcare services for individuals in smart cities through Digital Twins. A practical study demonstrated the proposed method approach's effectiveness by replicating the information collected and examining with retrieving the data.
- **Energy management** in smart cities through the use of Digital Twins. Benchmark based on smart meter data processing is developed in [33] to establish a daily energy-building recommendation. The framework will determine what is the difference between the new expectations from conventional and annual energy assessment meth-

ods, as well as investigate how these processes can help power control close to real [34] gives us a glimpse of emergency management based on DT innovation. The paradigm is constructed by the incorporation of Information and Communication technologies with Digital Twins to produce a robust promise for enhancing the performance of catastrophe administration actions. Using data from high-fidelity boiler simulations, historical process data, and machine learning to manage a complex, multivariate system, a digital twin is developed for the Atikokan Generating Station in [35]. Dynamic predictions with uncertainty, comprising variables measured at the plant and variables required for constraining and optimising the digital twin, are among the outputs from the digital twin.
- **Biomedical** Health care is the most effective industry that has benefited from using Digital Twins principles. Emerging healthcare IoT, fitness bands, and E-health technologies have supported the use of Digital Twins in biomedical areas. DTs technologies are utilized in the health industry to estimate the operation of examination equipment, evaluate and recommend medication, recognize lifestyle changes, enhance hospital activities, provide remote surgery, and assist governments with patient healthcare. A DT virtualization biological approach will assist clinicians in developing in vitro ways for predicting how the real organ will operate in either specified condition [36] investigate the growth of Digital Twins in the biomedical concept affects therapy, diagnostics, and well-being. In patient care, it stresses that the development of individual DT and information derived from it may be utilized in rehabilitation, augmentation, dietary behaviors, and illness prediction. In [11], the use of DT in the biomedical area is presented to aid in the analysis and detection of living things and nonliving objects, hence improving healthcare and welfare.

Saracco et al. investigated the use of DT in the pandemic of Covid-19 in their white paper [35] and specified the concept of Personal Digital Twins (PDT). Various firms are entering this industry because of its tendency and value of pandemic management with its economic implications. Using PDT plays a critical part in the actual observation of biological signals, tracking the actual position of the end user, and identifying the recourses to infect persons. DT has been combined with trend technologies such as Industry 4.0, Virtual reality (VR), and IoT to create a model of telemedicine surgeries [36]. A robotic arm with VR is used in this prototype, and they are attached through a 4G mobile platform to perform remote surgery on patients. The intricacies and pitfalls of integrating Digital Twins with a paradigm are examined and assessed emerging technologies that can help alleviate these challenges. Integration of DT with ICT in view of cloud technology is presented in [37] to create a framework that allows for the observation, examination, and prediction of a patient's state. With the usage of DT and Cloud technology, anticipating the disease and problems of older people can be done using IoT wearable sensors and in-home sensors.

## 3 Blockchain-Based Digital Twins

The advancements in current networking processing and storage technologies have resulted in the establishment of a new idea known as Digital Twins. The term "digital twins" refers to the interpretation of real-world tools, products, or components in our environment. It is used for physical component configuration, monitoring, diagnostics, and prognostics throughout its life cycle. Most current techniques used to create DTs are typically centralized, which has a disadvantage in terms of enabling audits, trustworthy data provenance, and traceability. As a result, the idea of DT may be reformatted under the introduction of Blockchain technology. It could be a critical approach to assisting IoT-based digital twin applications in transmitting information and quantity into the Internet with full clarity while also suggesting secure and trusted traceability, accessibility, and transaction immutability. The paper describes a context for Blockchain-based Digital Twins.

### 3.1 Overview

In recent times, Digital Twin (DT) is can be used for the creation, examination, diagnostics, and expectation of the physical element in its life cycle. The DT is considered as the representation of a real-world physical asset, product, or component around us. The previous study utilized DT's definitions that emphasized two essential features, which are as follows:

1. Every definition highlights the link between the physical model and its simulated form [38].
2. That link is developed by creating real-time data from measurements [39]. The DT model will be compared to other concepts, such as cross-reality environments or co-spaces and replica models, which aim to synchronize with the actual system and its cyber model [40].

The DT of the product involves three modules: (1) the actual product, (2) the simulated model, and (3) The transmission link between the real component and the digital model. The DT for vehicle production is shown in Fig. 5. The interaction between the actual and the digital model component is crucial in maintaining the strength and performance of DT. The information transferred from the simulated model to the actual product could be used to monitor and empower its performance.

With the advent of Blockchain technology in recent years, it may now be utilized to redefine digital twins in a variety of Internet of Things applications. It may be used to securely and transparently transfer data and value across the Internet. To be conservative, a central intermediary capable of analytics and storing data is required to improve a digital twin system. The Blockchain may be used to produce and monitor digital twins safely and irreversibly. Similarly, a safe, trustworthy, robust, and dependable approach is required to track and trace the various steps in the development of DTs. Likewise, connecting digital twins and blockchain would help businesses and brands secure their products against counterfeiting and avoid financial losses.

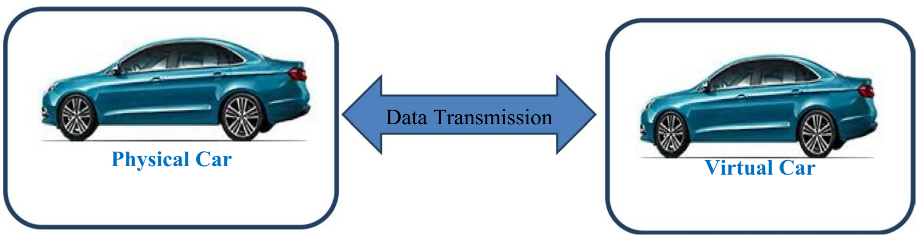



**Fig. 5** A digital twin of car product

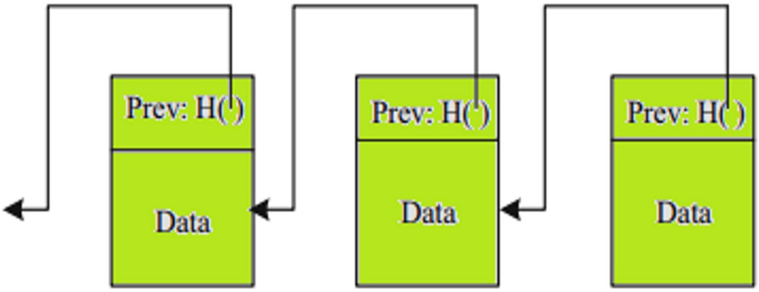



**Fig. 6** Blockchain connected network

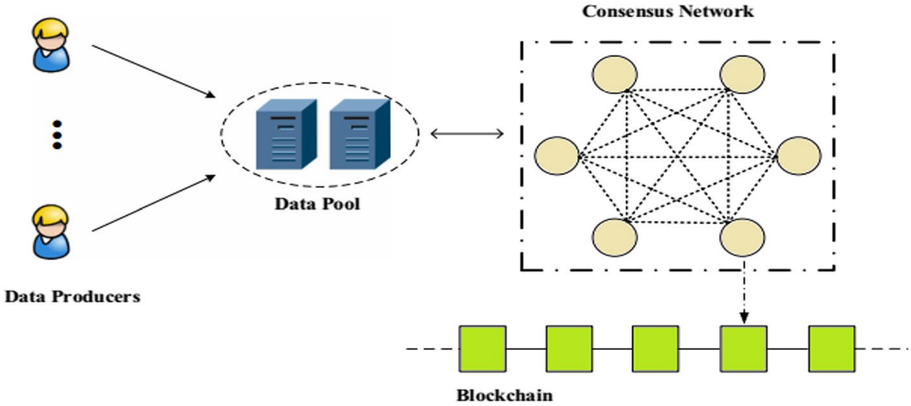



**Fig. 7** The Blockchain network's operation

## 3.2 Blockchain

In 2008, Nakamoto [41] created a blockchain to serve as the public transaction record for the cryptocurrency bitcoin. Blockchain is a growing collection of cryptographically connected blocks. The Blockchain network is structured as an ordered list of blocks; as illustrated in Fig. 6, each block refers to the one before it, resulting in a blockchain. When a block is produced and uploaded to the blockchain, its transactions cannot be altered or reversed [42].

The blockchain core is the consensus mechanism that declares all consensus nodes in the system agree on the overall status of the blockchain. Data producers, consensus nodes, and a data pool comprise a blockchain network. Data producers must first submit their data to the data pool, as indicated in Fig. 7. Consensus nodes in the consensus network will then capture the data from the data pool. After confirming the seized data, the consensus node runs the consensus protocol and chooses the bookkeeping node. The bookkeeping node is responsible for writing data to the Blockchain [43].

The Blockchain system is a decentralized, distributed, and public digital ledger in which no record may be altered retrospectively without affecting all following blocks. Table 1 summarizes the many kinds of Blockchain. Blockchain is now employed in a variety of industries, including transportation, healthcare, electronic voting, logistics, and so on.

**Table 1** Types of blockchain systems

| Type | *Features* | | | | | |
|---|---|---|---|---|---|---|
| | Access to data | Network expansion | Proof of transaction | Identifiability | Transaction speed | Transaction maker |
| Private | Authorized users | Very easy | Central agency | Possible to identify | Fast | Only authorized users |
| Public | Anyone | Difficult | Verification algorithm | Anonymity | Slow | Everybody |
| Consortium | Authorized users | Easy | Previously agreed rule | Possible to identify | Fast | Only authorized users |

There are different algorithms that can be used for features extraction in blockchain systems, depending on the specific use case and the type of data being analyzed. One commonly used algorithm for feature extraction in blockchain systems is the SHA-256 algorithm.

The SHA-256 algorithm is a cryptographic hash function that takes input data and produces a fixed-length output, known as a hash. This hash is unique to the input data, and any changes to the input data will result in a different hash value. In blockchain systems, the SHA-256 algorithm is often used to create a digital fingerprint, or hash, of each transaction in the blockchain. This hash is then stored in the blockchain ledger, providing proof of the transaction and ensuring that the transaction cannot be altered or tampered with.

Other algorithms that may be used for feature extraction in blockchain systems include the Elliptic Curve Digital Signature Algorithm (ECDSA), the Secure Hash Algorithm (SHA-3), and the Advanced Encryption Standard (AES). The specific algorithm used will depend on the requirements of the use case, such as the need for security, speed, or efficiency.

Optimization algorithms are used to find the best solution to a problem by iteratively adjusting the values of parameters until a desired objective function is optimized or minimized. The objective function is a measure of how well the system is performing, and the optimization algorithm seeks to find the values of the parameters that result in the best performance.

There are many types of optimization algorithms, including gradient descent, simulated annealing, genetic algorithms, and particle swarm optimization. Each algorithm works differently and may be better suited for different types of problems. Gradient descent is one of the most commonly used optimization algorithms. It works by calculating the gradient, or rate of change, of the objective function with respect to the parameters. It then adjusts the parameters in the direction of the negative gradient to minimize the objective function.

Simulated annealing is another optimization algorithm that is based on a thermodynamic process. It works by starting with a high energy state and iteratively cooling the system until it reaches a low energy state, which corresponds to the optimal solution. Genetic algorithms are inspired by the process of natural selection. They work by creating a population of potential solutions and iteratively applying selection, crossover, and mutation to the population to generate new solutions. Particle swarm optimization is a population-based optimization algorithm that is based on the behavior of a swarm of particles. It works by iteratively adjusting the velocity and position of the particles in the search space to find the optimal solution.

The parameters of an optimization algorithm depend on the specific algorithm and the problem being solved. Common parameters include the learning rate, which determines the step size of the parameter updates, and the stopping criteria, which determine when the algorithm should terminate. Other parameters may include population size, mutation rate, and crossover rate, depending on the algorithm being used. The values of these parameters can greatly affect the performance of the optimization algorithm, and may need to be carefully tuned to obtain the best results.

### 3.3 Integrating Blockchain and Digital Twins

Blockchain with Digital twins is supposed to be used in tandem to improve security and help businesses prevent fraud and duplication of their components or/and model. Businesses have constantly been faking their items in recent years. Technology is available to everyone and is evolving at a rapid pace. As a result, it is considerably simpler for fraudsters to make duplicates than offer them to naïve buyers. These scammers not only create cash damages to respectable businesses but can also produce long-term reputational damage. The integration of digital twins with blockchain technology has the opportunity to provide a solution for preventing fraud and assisting businesses in maintaining the legitimacy of their products.

The number of IoT devices will exceed 20 billion by 2020. Millions of digital twins will be supported by these gadgets. Digital twins will be one of the essential cornerstones of physical item digitalization. Alternatively, blockchain technology will offer transparency with its decentralized structure, further improving digital data security. The notion of merging digital twins and blockchain may be utilized in a variety of fields, including logistics and biomedical systems. Figure 8 depicts the advantages of utilizing Blockchain for Digital Twins.

Integrating digital twins into a blockchain system involves creating a digital representation of a physical object, asset or system (the "twin") on the blockchain. This twin can then be used to track the object's performance, maintenance, and other data in real-time. This can be especially useful for industries like manufacturing, where the digital twin can be used to optimize production processes and identify potential issues before they occur.

However, there are several challenges associated with integrating digital twins into a blockchain system. These include:

- *Data standardization* In order for digital twins to be integrated into a blockchain system, there must be a standardized format for the data associated with the twin. This can be difficult to achieve, especially in industries with complex systems and multiple data sources.
- *Data security* Digital twins can contain sensitive information about physical objects and systems, making them vulnerable to cyber attacks. Integrating them into a blockchain system requires strong security measures to protect against unauthorized access.
- *Integration with existing systems* Many companies already have established systems for tracking and managing their physical assets. Integrating digital twins into these systems can be a complex and time-consuming process.
- *Scalability* As the number of digital twins in a system grows, the blockchain network must be able to handle the increased volume of data. This can be a challenge for some blockchain systems, which may not be designed to handle large amounts of data.

So, integrating digital twins with IoT involves connecting physical devices to a network and collecting data from sensors and other sources. The data is then used to create digital twins, which are digital representations of the physical objects or systems. These digital twins can be used to monitor and control the behavior of the physical systems in real-time, optimizing performance and predicting potential issues.

Blockchain technology can be used to secure and manage the data collected from IoT devices and digital twins. By using blockchain, it is possible to create a decentralized and transparent system that can store and share data securely between different parties. This can be especially useful for digital twins and IoT devices, which generate large amounts of data that need to be shared and verified in real-time.

In an IoT-based blockchain study, researchers may use a combination of techniques such as data analytics, machine learning, and cryptography to develop a secure and efficient system for managing data from IoT devices and digital twins. They may also develop new algorithms or protocols for optimizing the performance of the system and ensuring its scalability and reliability.

In summary, while integrating digital twins into a blockchain system can offer many benefits, there are several challenges that must be overcome to make it a viable solution for businesses.

### 3.4 Blockchain-Based Digital Twins Framework

In this part, we provide the suggested Blockchain-based Digital Twins system, namely BlockTwins, to the immune DT model, to guarantee the security of every transaction in the twins' system during the communication between the virtual and physical assets; transactions would not need to rely on third-party verifications. Every transaction would instead be timestamped before being added to a chain of hash-based proofs of work. This could stop any unauthorized users and criminals from making harmful changes to the system from the outside (Fig. 9).

Product design, production, maintenance, and other aspects of the product lifetime are created in the industrial control system and manufacturing, and these data are referred to as product lifecycle data. It's a difficult procedure with a lot of little aspects to consider at each stage. Product lifecycle management is necessary to ensure that all activities throughout the product lifecycle are under control. The advent of the DT has provided a means for monitoring all product activities throughout its full lifespan and optimizing process

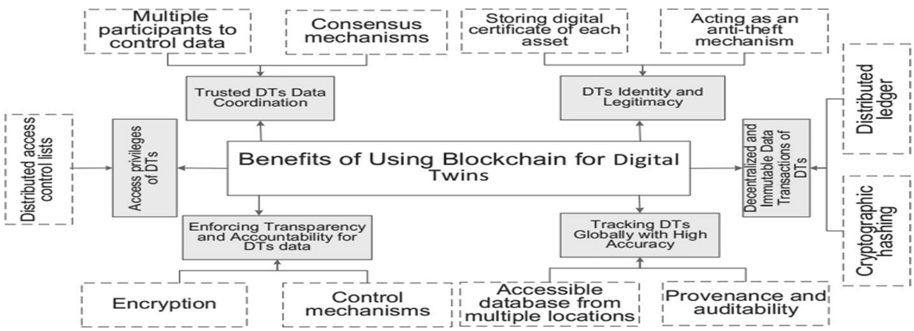



**Fig. 8** Benefits of using Blockchain for Digital Twins [39]

efficiency based on the Digital Twin's simulation outcomes., as shown in Fig. 5. Thus, blockchain can be used to handle the problems in the data management of digital twins within the product lifecycle securely and efficiently. That issues related to data exchange, storage, access, and data validity.

Product lifecycle management (PLM) and process lifecycle management (PLM) are both concepts related to the management of digital twins. A digital twin is a virtual representation of a physical product, system, or process that can be used to monitor, analyze, and optimize its performance over its lifecycle. Product lifecycle management involves managing the entire lifecycle of a product, from concept and design to manufacturing, operation, and disposal. This includes managing product data, engineering changes, and collaboration between different teams and stakeholders.

Process lifecycle management, on the other hand, involves managing the entire lifecycle of a process, from process design to execution and monitoring. This includes managing process data, automation, and optimization. Both PLM and PLM are important for ensuring that digital twins are designed, developed, and operated in the most efficient and effective manner possible. By managing the entire lifecycle of a product or process, organizations can identify areas for improvement, optimize performance, and reduce costs.

Blockchain can be used to balance the load in PLM and PLM by providing a secure and transparent platform for managing data and transactions. Blockchain technology allows for the creation of tamper-proof, distributed ledgers that can be used to track the entire lifecycle of a digital twin, from its initial design to its end-of-life disposal. By using blockchain technology, organizations can ensure that all stakeholders have access to the same information and can trust the data that is being shared. This can help to streamline communication and collaboration between different teams and stakeholders, reducing the risk of errors, delays, and misunderstandings.

Overall, the combination of PLM, PLM, and blockchain can help organizations to create and manage digital twins in a more efficient, effective, and secure manner, improving performance and reducing costs over the entire lifecycle of a product or process.

To model the proposed scheme, it's necessary to develop a Blockchain network to link every participant within the product lifecycle. The transaction records all activities of the DT for the object between competitors. The sensor's readings between the real and virtual

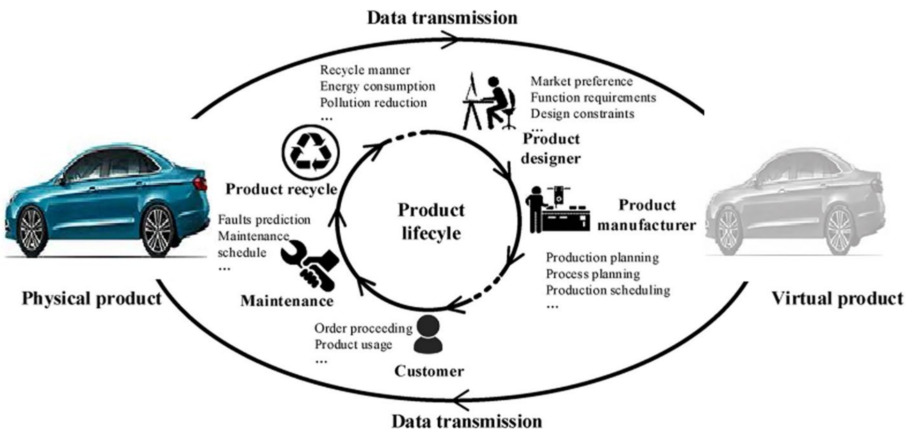



**Fig. 9** Product lifecycle management based on Digital twin

models are also captured as part of the transaction. Using hashing algorithms along with timestamps, these transactions are saved in the blocks connected, require the whole procedure, and are used to track the events. A blockchain-based product management network was created by these blocks interconnecting. Similarly, Blockchain is applied to manage primary stages engaged in the construction procedure of DTs, as shown in Fig. 10. The proposed product lifecycle management-based Blockchain is shown in Fig. 11.

Hashing algorithms are cryptographic functions that can be used to convert a piece of data into a fixed-size, unique digital fingerprint, or hash. In the context of digital twins, hashing algorithms can be used to provide a secure and tamper-proof way to store and verify data. We have provided hashing algorithms in the article for several reasons, including:

- *Data integrity* Hashing algorithms can be used to ensure that data has not been tampered with or modified in any way. By generating a unique hash for each piece of data, any changes made to the data will result in a different hash value. This can help to ensure the integrity of the data stored in digital twins.
- *Data security* Hashing algorithms can also be used to provide data security. By storing hash values instead of the original data, organizations can ensure that sensitive information is not exposed to unauthorized parties.
- *Efficient data comparison* Hashing algorithms can also be used to compare large amounts of data efficiently. Instead of comparing the entire data set, organizations can compare hash values to quickly identify differences and anomalies.
- *Blockchain integration* Hashing algorithms are often used in blockchain technology to create digital signatures, validate transactions, and ensure the integrity of the blockchain ledger.

Overall, hashing algorithms are an important tool for ensuring the security and integrity of data stored in digital twins, and can help organizations to efficiently manage and analyze large amounts of data.

An optimization technique is a mathematical method that helps to find the best solution to a problem within given constraints. Optimization techniques are used in various fields, such as engineering, finance, economics, and science, to find the optimal solution to problems that involve maximizing or minimizing an objective function. Some common optimization techniques are linear programming, quadratic programming, genetic algorithms, simulated annealing, and gradient descent. Blockchain for Digital Twins is a concept that uses blockchain technology to create digital twins, which are virtual replicas of physical objects or systems. The digital twin can store data about the physical object, such as its design, maintenance history, and current status. By using blockchain, the data stored in the digital twin is secure, immutable, and transparent.

Blockchain for Digital Twins is needed because it can provide many benefits, such as:

- *Improved traceability and transparency* By using blockchain technology, the data stored in the digital twin is immutable, meaning that it cannot be altered or deleted. This provides greater transparency and traceability for the physical object, which can be beneficial for various applications, such as supply chain management or asset tracking.
- *Increased efficiency* Digital twins can be used to optimize the performance and maintenance of physical objects. By analyzing data from the digital twin, it is possible to identify potential issues and take preventive actions, which can reduce downtime and maintenance costs.

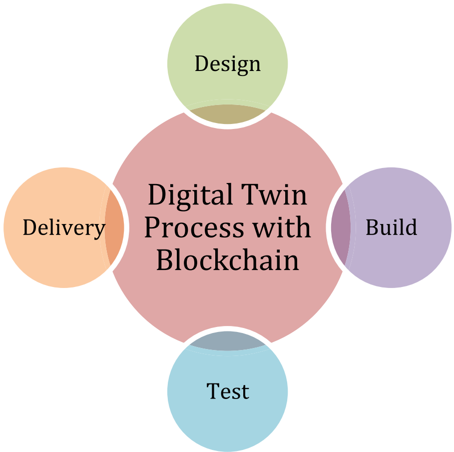



**Fig. 10** Blockchain as controlling entity of DT design procedure

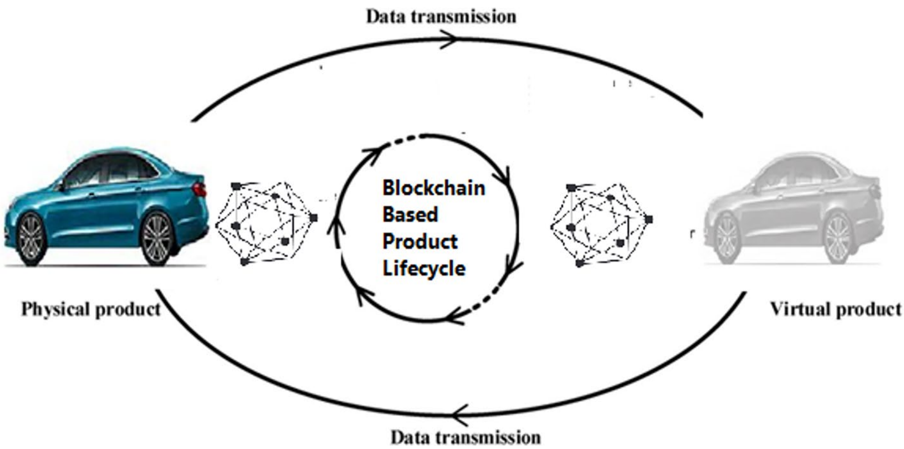



**Fig. 11** Blockchain-based product lifecycle management

- *Enhanced security* Blockchain technology provides enhanced security for the data stored in the digital twin. Because the data is stored on a decentralized network, it is less vulnerable to cyber attacks or data breaches.

Overall, Blockchain for Digital Twins is a promising concept that can bring many benefits to various industries.

## 4 Challenges and Future Research Directions

The research community faces numerous difficulties and challenges in the integration of Digital Twins in several parts of our lives.

- One of the key issues with the application is the high price for large enterprises due to the requirement of multiple software elements in addition to levels of hardware parts to make a DT. As a result, significant work has been carried out in order to construct a low-cost or establish a regular DT framework in the production and health sectors.
- Data privacy and security are two key issues with DT. Data and security privacy are two more key issues with DT. Because the process displays information or data, protecting this data from viruses and hacking is a significant problem in DT since it can destroy essential information in digital contexts. Despite emerging innovations such as Blockchain having been used to provide a solution to the DT security challenge, this field is still in its early stages. Other issues include data collection and storage, as a massive volume of data and information flows between hardware components. Big data, cloud technology, artificial intelligence, and sensor data fusion are strategies utilized for creating a framework for the growth of technologies that would support this challenge.
- Technical issues include real-time communication and data delay. Working in physical environments may expose you to DT. New technologies, such as 5G communication, IoT technology, and data compression, are being used to address this issue. Another issue that occurs while implementing DT is the requirement for ongoing maintenance and modification of virtual conditions. Deep Learning algorithms, for example, could potentially enrich and improve Digital Twins technology in this regard. In Digital Twins, standardization and ethical issues are key concerns. The usage of DT in industry or healthcare is not currently standardized. Also, the ethical problem in studies is especially important in healthcare and science because there is access to high-fidelity data about the patient, and his lifestyle demands the use of ethical standards.

## 5 Conclusions and Future Works

The Digital Twin is a dynamically changing notion that grows in functionality during its life cycle. This study explained the definition and design of DTs and the benefits of using them in numerous applications such as production, smart cities, and biomedical. Because of its major impacts on bridging the difference between the real, digital environment and information, the DT has recently become an emergent technology. Similarly, with the introduction of Blockchain technology, the idea of digital twins may be reinterpreted. This led to powerful technology for empowering IoT-based digital twins to exchange information and benefits through the Internet with features such as visibility, trustworthiness, and tracking. Therefore, this work also presented a framework of Blockchain-based Digital Twins for IoT system. Finally, the challenges and opportunities in this innovative topic are discussed.

The integration of digital twins with IoT-based blockchain is an emerging field with numerous potential future works. Here are some possible avenues for future research:

- *Performance optimization* One area that requires attention is performance optimization. Currently, integrating digital twins with IoT-based blockchain can be computationally intensive, leading to latency and scalability issues. Future research can focus on developing optimized algorithms and architectures that can improve the efficiency and speed of the integration process.
- *Enhancing security* The integration of digital twins with IoT-based blockchain aims to enhance security and privacy. However, there is a need to address security challenges, such as data tampering and unauthorized access. Future research can focus on develop-

ing more robust security protocols and architectures that can improve the security of the system.

- *Interoperability* Another area that requires attention is interoperability. Integrating digital twins with IoT-based blockchain can involve multiple technologies and platforms. Future research can focus on developing interoperability standards that can enable seamless integration of digital twins with IoT-based blockchain across different platforms.
- *Real-time monitoring and control* Digital twins are known for their ability to simulate real-world scenarios. Future research can explore the potential of integrating digital twins with IoT-based blockchain for real-time monitoring and control of physical systems. This can be useful in a wide range of applications, including manufacturing, healthcare, and transportation.
- *Sustainability* Integrating digital twins with IoT-based blockchain can contribute to sustainability efforts by enabling more efficient use of resources and reducing waste. Future research can focus on exploring the potential of this integration to promote sustainable practices across various industries.
- *Data analytics and machine learning* Integrating digital twins with IoT-based blockchain can generate large amounts of data. Future research can focus on developing advanced data analytics and machine learning algorithms that can extract insights and patterns from this data.
- *Application in various industries* Finally, future research can explore the potential of integrating digital twins with IoT-based blockchain in various industries, including manufacturing, healthcare, transportation, and energy. This can help to identify specific use cases and applications where this integration can have the most significant impact.

**Acknowledgements** The authors are very grateful to all the institutions in the affiliation list for successfully performing this research work. The authors would like to thank Prince Sultan University for their support.

**Authors contributions** All authors are equally contributed.

**Funding** The authors did not receive support from any organization for the submitted work.

**Data Availability** All data are available upon request from the corresponding author.

## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.

**Ethics approval and consent to participate** All authors are contributing and accepting to submit the current work.

**Consent for Publication** All authors are accepting to submit and publish the submitted work.

## References

1. Rasheed, A., San, O., & Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. *IEEE Access, 8*, 21980–22012.
2. Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2019). Characterising the Digital Twin: A systematic literature review. *CIRP Journal of Manufacturing Science and Technology, 2019*, 1.
3. Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. *IEEE Access, 1*, 1.

4. Boyes, H., & Watson, T. (2022). Digital twins: An analysis framework and open issues. *Computers in Industry, 143*, 103763.
5. Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital twin in industry: State-of-the-art. *IEEE Transactions on Industrial Informatics, 15*(4), 2405–2415.
6. Yu, W., Patros, P., Young, B., Klinac, E., & Walmsley, T. G. (2022). Energy digital twin technology for industrial energy management: Classification, challenges and future. *Renewable and Sustainable Energy Reviews, 161*, 112407.
7. Singh, M., et al. (2022). Applications of Digital Twin across industries: A review. *Applied Sciences, 12*(11), 5727.
8. Uhlemann, T. H. J., Lehmann, C., & Steinhilper, R. (2017). The digital twin: Realizing the cyber-physical production system for industry 4.0. *Procedia CIRP, 61*, 335–340.
9. El Saddik, A. (2018). Digital twins: The convergence of multimedia technologies. *IEEE Multimedia, 25*(2), 87–92.
10. Alam, K. M., & El Saddik, A. (2017). C2PS: A digital twin architecture reference model for the cloud-based cyber-physical systems. *IEEE Access, 5*, 2050–2062.
11. Schleich, B., Anwer, N., Mathieu, L., & Wartzack, S. (2017). Shaping the digital twin for design and production engineering. *CIRP Ann. - Manuf. Technol., 66*(1), 141–144.
12. Grieves, M., Vickers, J., Kahlen, F. J., Flumerfelt, S., & Alves, A. (2017). Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In F.-J. Kahlen, S. Flumerfelt, & A. Alves (Eds.), *Transdisciplinary perspectives on complex systems: New findings and approaches no. August 2017* (pp. 85–113). Cham: Springer.
13. Grieves, M. (2014). *Digital Twin: Manufacturing Excellence through Virtual Factory Replication*. White Pap., no. March, 2014, (Online). https://www.researchgate.net/publication/275211047_Digital_Twin_Manufacturing_Excellence_through_Virtual_Factory_Replication.
14. Huang, S., Wang, G., Yan, Y., & Fang, X. (2020). Blockchain-based data management for digital twin of product. *Journal of Manufacturing Systems, 54*, 361–371.
15. Lee, J., Azamfar, M., Singh, J., & Siahpour, S. (2020). Integration of digital twin and deep learning in cyber-physical systems: Towards smart manufacturing. *IET Collaborative Intelligent Manufacturing, 2*(1), 34–36.
16. Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *International Journal of Advanced Manufacturing Technology, 94*(9–12), 3563–3576.
17. Grieves, M. W. (2003). *PLM-Beyond lean manufacturing*. Soc Manufacturing Engineers One Sme Drive, Po Box 930, Dearborn, Mi 48121.
18. Alshathri, S., Hemdan, E. E. D., El-Shafai, W., & Sayed, A. (2023). Digital twin-based automated fault diagnosis in industrial IoT applications. *Computers, Materials & Continua, 75*(1), 183–196. https://doi.org/10.32604/cmc.2023.034048
19. Costello, K., & Omale, G. (2019) Gartner survey reveals digital twins are entering mainstream use. https://www.gartner.com/en/newsroom/press-releases/2019-02-20-gartner-survey-reveals-digital-twins-are-entering-mai.
20. Wang, J., Ye, L., Gao, R. X., Li, C., & Zhang, L. (2019). Digital Twin for rotating machinery fault diagnosis in smart manufacturing. *International Journal of Production Research, 57*(12), 3920–3934.
21. Li, L., Lei, B., & Mao, C. (2022). Digital twin in smart manufacturing. *Journal of Industrial Information Integration, 26*, 100289.
22. Friederich, J., Francis, D. P., Lazarova-Molnar, S., & Mohamed, N. (2022). A framework for data-driven digital twins for smart manufacturing. *Computers in Industry, 136*, 103586.
23. Booyse, W., Wilke, D. N., & Heyns, S. (2020). Deep digital twins for detection, diagnostics and prognostics. *Mechanical Systems and Signal Processing, 140*, 106612.
24. Cheng, J., Zhang, H., Tao, F., & Juang, C. F. (2020). DT-II: Digital twin enhanced Industrial Internet reference framework towards smart manufacturing. *Robotics and Computer-Integrated Manufacturing, 62*, 101881.
25. Zhou, M., Yan, J., & Feng, D. (2019). Digital twin and its application to power grid online analysis. *CSEE Journal of Power Energy Systems, 5*(3), 391–398.
26. Milton, M., De La, C. O., Ginn, H. L., & Benigni, A. (2020). Controller-embeddable probabilistic real-time digital twins for power electronic converter diagnostics. *IEEE Transactions on Power Electronics, 35*(9), 9852–9866.
27. Schluse, M., Priggemeyer, M., Atorf, L., & Rossmann, J. (2018). Experimentable digital twins-streamlining simulation-based systems engineering for industry 4.0. *IEEE Transactions on Industrial Informatics, 14*(4), 1722–1731.

28. Mukherjee, T., & DebRoy, T. (2019). A digital twin for rapid qualification of 3D printed metallic components. *Applied Materials Today, 14*, 59–65.
29. Austin, M., Delgoshaei, P., Coelho, M., & Heidarinejad, M. (2020). Architecting smart city digital twins: Combined semantic model and machine learning approach. *Journal of Management in Engineering, 36*(4), 1–14.
30. Laamarti, F., Badawi, H. F., Ding, Y., Arafsha, F., Hafidh, B., & El Saddik, A. (2020). An ISO/IEEE 11073 Standardized Digital Twin Framework for Health and Well-Being in Smart Cities. *IEEE Access, 8*, 105950–105961.
31. Francisco, A., Mohammadi, N., & Taylor, J. E. (2020). Smart city digital twin-enabled energy management: Toward real-time urban building energy benchmarking. *Journal of Management in Engineering, 36*(2), 1.
32. Fan, C., Zhang, C., Yahja, A., & Mostafavi, A. (2019). Disaster city digital twin: A vision for integrating artificial and human intelligence for disaster management. *International Journal of Information Management, 1*, 102049.
33. Spinti, J. P., Smith, P. J., & Smith, S. T. (2022). Atikokan digital twin: Machine learning in a biomass energy system. *Applied Energy, 310*, 118436.
34. Sun, T., He, X., & Li, Z. (2023). Digital twin in healthcare: Recent updates and challenges. *Digital Health, 9*, 20552076221149652.
35. Saracco, R., De Kerckhove, D., & Nisiotis, L. (2020). The role of personal digital twins in control of epidemics. An IEEE Digit. Real. White Pap.
36. Laaki, H., Miche, Y., & Tammi, K. (2019). Prototyping a digital twin for real time remote control over mobile networks: Application of remote surgery. *IEEE Access, 7*, 20235–20336.
37. Liu, Y., et al. (2019). A novel cloud-based framework for the elderly healthcare services using digital twin. *IEEE Access, 7*, 49088–49101.
38. Bacchiega, G. (2018). Creating an embedded digital twin: Monitor, understand and predict device health failure. Inn4mech-Mechatronics Ind. (Vol. 4).
39. Loke, S. W., Smanchat, S., Ling, S., & Indrawan, M. (2008). Formal mirror models: An approach to just-in-time reasoning for device ecologies. *Int. J. Smart Home, 2*(1), 15–32.
40. Loke, S. W., et al. (2015). The La Trobe e-sanctuary: Building a cross-reality wildlife sanctuary. *International Conference on Intelligent Environments, 2015*, 168–171.
41. Nakamoto, S. (2019). Bitcoin: A peer-to-peer electronic cash system. Manubot.
42. Wang, H., & Song, Y. (2018). Secure cloud-based EHR system using attribute-based cryptosystem and blockchain. *Journal of Medical Systems, 42*(8), 1–9.
43. Yaqoob, I., Salah, K., Uddin, M., Jayaraman, R., Omar, M., & Imran, M. (2020). Blockchain for digital twins: Recent advances and future research challenges. *IEEE Network, 34*(5), 290–298.

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