

Article

DVIT—A Decentralized Virtual Items Trading Forum with Reputation System [†]

Zuobin Ying ^{1,*}, Wusong Lan ¹, Chen Deng ², Lu Liu ³ and Ximeng Liu ⁴ ¹ Faculty of Data Science, City University of Macau, Macau, China² National Institute of Education (NIE), Nanyang Technological University, Singapore 637616, Singapore³ Faculty of Finance, City University of Macau, Macau, China⁴ College of Computer and Data Science, Fuzhou University, Fuzhou 350025, China

* Correspondence: zbying@cityu.mo

[†] An earlier version of this paper was presented at the Conference on CCNIS2022. Its number is ccnis2022-0053. This article is one of the results of MOST-FDCT Projects (0058/2019/AMJ, 2019YFE0110300) (Research and Application of Cooperative Multi-Agent Platform for Zhuhai-Macao Manufacturing Service).

Abstract: The metaverse provides us with an attractive virtual space in which the value of the virtual property has been increasingly recognized. However, the lack of effective cross-metaverse trading tools and the reputation guarantee makes it difficult to trade items among different metaverses. To this end, a decentralized reputation system for virtual items trading forum named DVIT is devised. To the best of our knowledge, DVIT is the first decentralized cross-metaverse item trading prototype inspired by the online-game trading system. We designed the corresponding transaction function and realized the autonomous governance of the community by introducing the reputation mechanism. An improved election mechanism is proposed to improve efficiency based on Delegated Proof-of-Stake (DPoS). Through token rewards associated with activity levels, users' motivation can be stimulated. The experiments indicate that our proposed scheme could dynamically measure the trustworthiness degree of the users through the dynamic reputation value and thereby exclude malicious users from the blockchain within 20 epochs.

Keywords: metaverse; blockchain; DPoS; video games; virtual economy; virtual worlds**MSC:** 68M14

Citation: Ying, Z.; Lan, W.; Deng, C.; Liu, L.; Liu, X. DVIT—A Decentralized Virtual Items Trading Forum with Reputation System. *Mathematics* **2023**, *11*, 429. <https://doi.org/10.3390/math11020429>

Academic Editor: Antanas Cenys

Received: 25 November 2022

Revised: 27 December 2022

Accepted: 6 January 2023

Published: 13 January 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Metaverse, a digital world parallel to reality, also reckoned as the post-reality universe, integrates a perpetual and persistent multiuser environment with physical reality through digital virtuality, in which each person can have a virtual avatar [1]. In many film and television productions, such as *Ready Player One* (A film Directed by Steven Spielberg in 2018), people have shown a passionate imagination for living in a virtual space called the *Oasis* with advanced devices [2]. Now, our imaginations about the metaverse are no longer illusory. In 2021, Facebook changed its name to Meta, which completely ignited the fever of the metaverse. The company would invest many billions of dollars in the metaverse [3]. According to the survey by Statista, 67.65% of the companies interviewed believe that the metaverse market is going to boom in the next five years [4].

However, to achieve reliability, the metaverse still faces a series of problems. For example, different companies are competing to launch their metaverses. For technical and commercial reasons, these metaverses are not interconnected and will continue to be isolated from each other for the foreseeable future [5]. What if the person from different metaverses wants to exchange stuff or commodities with each other? Take two virtual characters, Alice and Bob, who live in two different metaverses as an example. If Alice has a virtual closet in metaverse α , and now she wants to exchange it with Bob in metaverse β

for a virtual coat. Unless there is already sufficient trust between her and Bob, a trusted third party is needed to go through this transaction. However, introducing a trusted third party would result in a high trading fee and high delay. Moreover, it will also become the bottleneck when cross-metaverse trading increases explosively. To our knowledge, there exists no sufficient solution for trading virtual assets across the metaverses, and in the foreseeable future, due to technical and commercial considerations, metaverses will continue to be independent of each other [6]. Although many metaverse developers have tried to formulate a unified set of guidelines for all metaverses, such as the Web3.0 Open Metaverse Alliance (OMA3) and The Metaverse Standards Forum (MSF), they are still some distance away from being put into use [7,8]. Solving this problem will be beneficial both for the current metaverse market and for the future development of a more complete economy in the metaverse.

Given the fact that we have not entered the metaverse yet, we need to simulate virtual transactions between metaverse by other means. Video games, for example, are a considerable option. First, there is ample precedent for using video games for real-world simulation. In 2005, a virtual plague broke out in *World of Warcraft* (A multiplayer online role-playing game released in 2004 by Blizzard Entertainment). Due to game developers' mistakes, a disease (i.e., Corrupted Blood) could make players lose life continuously and spread among players in the game world. Because of its many similarities to real-world outbreaks of infectious diseases, some infectious disease propagation models were proposed through the inspiration of Role-Playing Games [9]. Secondly, we found that the trading pattern among different metaverses has the most in common with the m in some old video games. Forums are a common form of community on the Internet for enthusiasts to communicate with each other. There is a category of forums where players can trade in-game items with other players. Because it has a wide user base and a mature trading system, we decide to use forums to simulate virtual item trading in the metaverse [10].

In this paper, we introduce DVIT—a decentralized reputation system for virtual item trading forums. The main contributions of this paper are summarized as follows.

- To the authors' knowledge, we are the first to construct a decentralized in-game item-trading forum system. Not only do we design a series of functions to realize the selling and renting of the virtual stuff, but we also put forward a dispute adjudication system for players to resolve the controversy.
- An improved election mechanism is devised to improve efficiency on the basis of Delegated Proof-of-Stake. Through token rewards associated with activity levels, the motivation of users can be increased.
- The simulation experiments indicate that our proposed scheme could dynamically measure the trustworthiness degree of the users through the dynamic reputation value. Therefore, malicious users would be excluded from the blockchain within 20 epochs.

The rest of this paper is organized as follows: Section 2 introduces the preliminaries. Section 3 presents the proposed model. Section 4 presents the model designed in this paper. Section 5 presents simulations. Section 6 presents the performance analysis. Section 7 is the related work, and Section 8 is the conclusion and future work.

2. Preliminaries

In this section, we introduce the building blocks used in our solution, including blockchain consensus algorithms, the reputation value system, and the background knowledge of in-game item-trading platforms.

2.1. Blockchain Consensus Algorithms

The prevailing in-game item-trading forums model has the disadvantage of being too centralized. Therefore, we need to establish trust and consensus among strangers while reducing centralization. Blockchain is a chain of blocks that store all committed transactions using a public ledger [11]. Blockchain has some key characteristics, such as decentralization, transparency, immutability, and audibility [12]. According to different

consensus algorithms, blockchains can be classified as Proof-of-Work (PoW), Proof-of-Stake (PoS), and Delegated Proof-of-Stake (DPoS) [13]. DPoS is developed from PoS and is a currently popular consensus algorithm. In DPoS, users will vote and elect delegates (or witnesses) to validate the next block [14]. DPoS is considered by its supporters to be more democratic than PoS. DPoS allows more qualified users to participate in the election process [15]. Further, the speed of block confirmation in DPoS is faster than in PoS [16]. Moreover, DPoS is considered by some scholars to require less energy than PoW [17]. There will be much less tendency to create forks on DPoS [18].

2.2. Reputation Value System

Blockchains may face many security vulnerabilities, such as 51% attack and Double-spending attack [19]. If there is no way to distinguish the evil users who have carried out attacks from normal users, it will pose a risk to the security of the blockchain. In order to improve the security of the blockchain, we introduce a reputation value system. When the node behaves well, it will receive the corresponding reputation value as a reward, and the reputation value will be reduced as punishment when the node misbehaves [20]. DPoS blockchain faces the problem of increasing centralization due to the decreasing motivation of users to participate [21]. Therefore, we combine traditional DPoS with a reputation-based voting mechanism to increase the participation of nodes [16]. On the other hand, to motivate nodes to behave well, we also introduce an incentive system [22].

2.3. Merkle Tree

The Merkle tree is a fundamental part of blockchain technology that realizes data availability and traceability [23]. It is a type of tree where the lower base elements are called leaves while the top element is called the Merkle root. The bottommost leaf node contains the stored data or its hash value, and non-leaf nodes (including intermediate and root nodes) are hashes of the contents of its two child nodes [24]. Merkle trees are formed by repeating pairs of hash nodes until only one hash, the Merkle root remains. The structure is shown in the diagram.

In Figure 1, we show the basic structure of the Merkle tree. First, let $H(\cdot)$ be the hash function. The leaf nodes $Hash_i$ can be calculated by the input data $DATA_i$, such as $Hash_a = H(DATA_a)$. The next layer is denoted by leaf nodes $Hash_i$, and the intermediate nodes can be computed by $Hash_{ab} = H(Hash_a, Hash_b)$. Then we repeat the above operation. Finally, we get the root node result by $Hash_{abcd} = H(Hash_{ab}, Hash_{cd})$ [25].

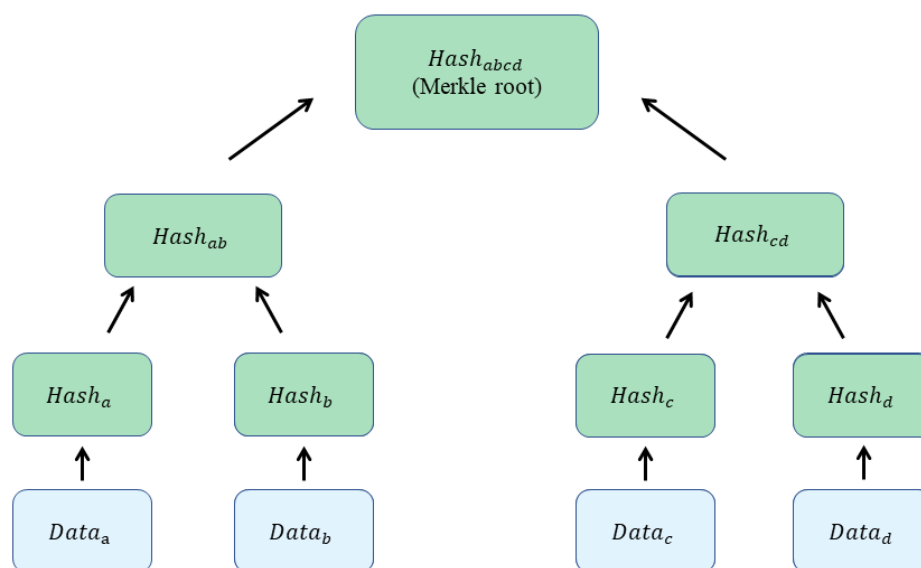


Figure 1. The Merkle Tree.

Merkle trees allow secure, efficient, and consistent validation of large volumes of data. Any changes to the underlying data will be passed to its parent node, layer by layer, to the root node. If attackers tampered with any transactions, the Merkle tree root hash value would be incorrect [26]. Merkle tree can help in improving the efficiency of blockchain verification. It would be cumbersome for nodes to store the full blockchain ledger to verify transactions, but with the Simplified Payment Verification (SPV) technique, verifying the inclusion of transactions would be easy. For each block, a Merkle tree is constructed using the transactions in the block as leaf nodes. Light nodes stored the Merkle root [27]. Merkle tree can also be combined with DPoS. The selected block generators need to prove their identity before generating blocks. They can create a delegated proof with the Merkle root and a Merkle verification path from the Merkle tree. The Merkle root can be used to verify that the block signer used the correct set of delegates and by providing a valid Merkle verification path from their uids to the Merkle root, which means they can prove their identity [28].

2.4. In-Game Item-Trading Platform

Diablo II is a classic action role-playing video game developed by Blizzard North which has developed a mature and complete in-game item-trading ecology. Due to the limitations of Diablo II, players usually choose to use the forum for online item trading. We introduce some of the mainstream trading platforms and their features as follows.

Blizzard has an official forum (<https://eu.forums.blizzard.com/en/d2r/c/trade/9>, accessed on 10 August 2022) for Diablo II which supports trading between players. Except for the official forums, there are a number of third-party trading sites. *Kaienzhijiao* (<https://bbs.d.163.com/>, accessed on 10 August 2022) is a forum where you can trade with other players. *Traderie* (<https://traderie.com/diablo2resurrected>, accessed on 10 August 2022) is a website where you can exchange your in-game items with other players. On those websites or forums, real-money trading is not allowed. Players need to swap in-game items with items. When players are desperate for in-game items, they have other options. *Anheihe* (<http://d3.17173.com/content/2022-07-18/20220718202629902.shtml>, accessed on 10 August 2022) is a mini program based on Wechat where players can trade in-game items of Diablo II. Players can conduct real-money trades in disguise through a kind of token it offers. There is a forum called *d2jsp* (<https://www.d2jsp.org/>, accessed on 10 August 2022) where users can perform real-money trading by tokens. Due to Diablo II's large player base, it is profitable to engage in in-game item trading. Therefore, naturally, some businessmen set their eyes on this place. *DD373* (<https://www.dd373.com/s-1psrbm.html>, accessed on 10 August 2022) is a professional in-game item-trading platform on which in-game items are sold at the price of CNY.

Most of these platforms are centralized. They are under the control of a small number of administrators, while normal users are not involved in the governance of the community. In some trading platforms, such as *Traderie*, *Anheihe*, and *DD373*, past trading records are not directly disclosed, which has created a barrier for players to understand the correct price. The next part of our work is improving the existing trading platform mechanism.

3. Proposed Model

In this section, we formalize the system model and the threat model. The system definitions and goals of the proposed system will be introduced in this section.

3.1. System Model

Figure 2 depicts the DVIT system architecture. The system has five entities, and the introduction of these entities is as follows:

- Normal Users (NUs) are active game players on the forum. They have their nodes on the blockchain. They are honest and want to make transactions with other players.
- The Forum (TF) provides a space for users to communicate. Transactions take place between members on TF.

- Administrators (**ADM**) on **TF** are responsible for supervising transactions and intervening when players can not resolve problems.
- The blockchain (**BC**) records transactions of **NUs**. Trading between users will be performed on the **BC** by tokens. In addition, the **BC** supports some extended functionality such as in-game item-trading of Non-Fungible Token (NFT).
- Evil Users (**EVs**) are users who would pose a threat to the order of transactions. Some **EVs** try to steal in-game items while trading. Some **EVs** are sent by competing platforms to disrupt the normal functioning of this forum.

3.2. Threaten Model

In our model, **TF** and **BC** need to work together to keep the system running properly. It is assumed that **TF** and **BC** are fully trusted, which means they will follow all protocols and will not collude with **EVs**. **NUs** are assumed to be honest and rational. They will tend to follow the rules. **EVs** are evil. They will break the rules to profit or interfere with the normal order of the system. **EVs** can pose a threat to the system at various points. When trading, **EVs** will induce other players to trade at too high or too low prices. In the block-minting process of DPoS, **EVs** may disrupt the operation of **BC** by deliberately not generating blocks after they are elected.

3.3. System Definitions

1. *Setup*: The *Setup* algorithm is executed by **TF**. The master key MK and public key PK are generated by the **ADM** with a security parameter SP and attributes of the **ADM** AM . SP should be kept confidential. MK and PK will be used to generate their keys for the registered users. The *Setup* process is described as: $(AM, SP) \rightarrow (MK, PK)$.
2. *Keygen* $\{(MK, PK, I) \rightarrow k_i, k_{pi}\}$: When **NUs** generate nodes on **BC**, they can request the administrators of **TF** to generate keys that belong to them. After administrators receive a request from user i , they will generate a personal secret key k_i and a public key k_{pi} for user i using the user's personal information I , MK , and PK . When users are elected as witnesses, they can use secret keys to sign the blocks generated by them.
3. *Encryption*: When a **NU** i is elected as a witness, i is required to sign the transaction with the personal secret key k_i on the block that i generates. The details of the election process will be described below. It takes i 's personal secret key k_i and the details or trading **TD** as input and sig_i , the signature of witness i as output like: $(k_i, TD) \rightarrow (sig_i)$.
4. *Decryption*: When users challenge whether a transaction is recorded by user i , they can verify the sig_i with i 's public key k_{pi} . If the transaction was recorded by the correct user, the **TD** that matches the transaction record will be decrypted from sig_i . If the block was produced by an impostor, then the decryption of sig_i will fail. It takes sig_i and k_{pi} as input and **TD** as output, such as $(k_{pi}, sig_i) \rightarrow (TD)$.

3.4. Goals of the Proposed System

The proposed system defines the following design goals:

3.4.1. Security

Given security is the first thing that needs to be ensured in the trading process, we add the **BC** to the original forum mechanism. Tokens for transactions will be transferred on the **BC**, making the process secure. Furthermore, we have added a dispute adjudication mechanism for transactions ensuring controversial transactions will be resolved in time.

3.4.2. Transparency

It is necessary to show the record of transactions in the forum to **NUs** because it will save them from being cheated by **EVs**. Accordingly, we record all transactions and make them available to all players by **BC**.

3.4.3. Decentralization

A BC is introduced to avoid the possible tampering and deletion of transaction records in the traditional forum mechanism. Moreover, we set incentives based on reputation value so that NUs will spontaneously record transactions and resolve disputes in transactions. Witnesses for generating blocks will be elected by NUs themselves.

As Table 1 shows, our DVIT has quite a few improvements over the existing common in-game item-trading platforms. ● in the table indicates that the characteristic is met while ✗ indicates that the characteristic is not met. DVIT provides a decentralized, democratic and transparent trading system. In the next section, we will introduce more details about the construction we proposed.

Table 1. Features of Trading Platforms.

Names of Trading Platforms	Forum	Real-Money Trade	Decentralized	Users Participation in Management	Open Transaction Records
the Official Forum	●	✗	✗	✗	●
Kaienzhijiao	●	✗	✗	✗	●
Traderie	✗	✗	✗	✗	✗
Anheihe	✗	●	✗	✗	✗
d2jsp	●	●	✗	✗	●
DD373	✗	●	✗	✗	✗
DVIT	●	●	●	●	●

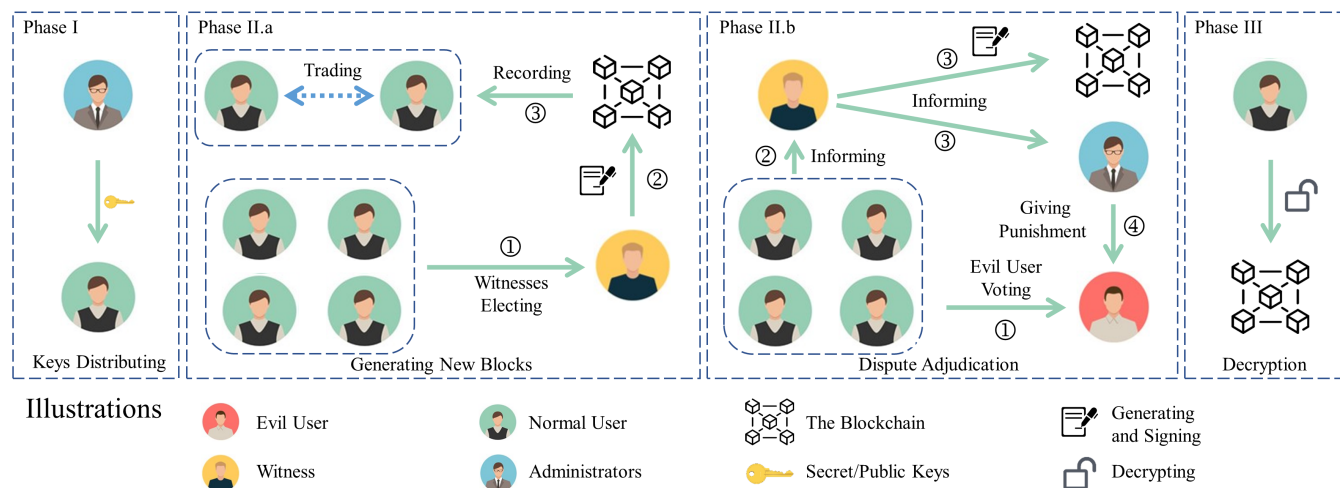


Figure 2. The System Model of DVIT.

4. Detailed DVIT

In this section, we give the concrete construction of the proposed trading system. We present the detail of the reputation value system, the witnesses' election system, and the dispute adjudication system. We also introduce the details of the in-game item-trading forum, such as Trading, Renting, and in-game item-trading NFT.

Our trading system is based on Diablo II, a classic game with a relatively well-developed forum trading mechanism. We will give a brief introduction to how to use the system in the following part. First of all, new users need to register an account. To make themselves trustworthy, they need to pledge some tokens on the chain, which can be exchanged for cryptocurrencies such as Eths.

4.1. Calculation of Reputation Value

After users successfully register on the BC, the reputation value of their nodes will be calculated by the following steps.

Step 1: i_{rep0} , which is the fixed reputation value of user i , is calculated based on the number of tokens pledged by i on BC as the initial reputation value. The upper limit of i_{rep0} is 60, and i_{rep0} does not change over time. The reputation value for new participants will generally be designed to be half of the maximum reputation value, and we set the i_{rep0} to fluctuate with the number of pledged tokens to encourage users to pledge more tokens [29].

Step 2: To avoid the disadvantage of not actively voting by nodes in the traditional DPoS consensus, when NUs cast a vote in the election of witnesses or dispute adjudication, NUs will receive three points of reputation value as a reward [30]. This part of reputation value is called dynamic reputation value, which changes over time. First, calculating i_{repa} , the reputation value user i got in the last 0–10 epochs.

Step 3: Calculating i_{repb} , the reputation value user i got in the last 10–20 epochs.

Step 4: The actual reputation value of user i , i_{rep} , consists of a fixed reputation value and dynamic reputation value. The formula to calculate i_{rep} is as in (1). Weight w in this paper is $1/3$. We set the weight to avoid the unlimited accumulation of the reputation value. Their newly acquired reputation value will have a greater weight than the previously acquired one because recent positive behavior will bring more influence [31].

$$i_{rep} = i_{rep0} + i_{repa} + w * i_{repb} \quad (1)$$

4.2. Assessment of Reputation State

According to i_{rep} , we classify users into several reputation states. The notation of the reputation state of user i is i_{rst} . There are four states of i_{rst} : G , W , N , and B , which represent the i 's reputation states as "Great", "Well", "Normal", and "Bad". How to calculate i_{rst} is represented in Algorithm 1.

Algorithm 1 Evaluation of i_{rst} .

Input: Reputation value of user i : i_{rep} .

Output: Reputation state of user i : i_{rst} .

```

if  $i_{rep} > 70$  then
     $i_{rst} = G$                                 ▷ User  $i$ 's reputation state is "Great"
else if  $i_{rep} > 50$  then
     $i_{rst} = W$                                 ▷ User  $i$ 's reputation state is "Well"
else if  $i_{rep} > 40$  then
     $i_{rst} = N$                                 ▷ User  $i$ 's reputation state is "Normal"
else
     $i_{rst} = B$                                 ▷ User  $i$ 's reputation state is "Bad"
end if

```

In DPoS, transactions will be recorded by witnesses, and any users registered on TF can be nominated as a candidate or participate in a vote if they meet the conditions. To keep the system safe, users must reach the reputation target to participate in the election. When $i_{rst} = N, W$, and G , user i can vote for others; when $i_{rst} = W, G$, user i can be nominated as a candidate. Users can vote for others whether they were nominated as a candidate or not. The specific voting process in an election phase is shown in Algorithm 2. In the following part, we introduce the various features of the forum.

4.3. Witnesses Election

The election of Witnesses will take place by the following steps and will be open to any registered nodes that meet the criteria:

Step 1: The system generates a list of candidates $Candidate[]$. Users whose $i_{rst} = W, G$ will be added to $Candidate[]$.

Step 2: Users whose $i_{rst} = N, W$, and G can vote for users in $Candidate[]$.

Step 3: At the end of the voting phase, users in $Candidate[]$ will be ranked in descending order according to the votes they receive. The top X users in $Candidate[]$ will become witnesses and be included in $Witness[]$. Blocks will be generated by the users in $Witness[]$.

Algorithm 2 Election process.

Input: Reputation value of user i : i_{rst} , Other users' ballots.

Output: Dynamic reputation value of user i : i_{repa} , newly generated blocks, token rewards, witnesses voting process

```

if  $i_{rst} = N$  then                                ▷ Determining user  $i$ 's reputation state
    user  $i$  can vote to others
    if  $i_{rst} = W$  then                                ▷ Determining user  $i$ 's reputation state
        user  $i$  can be nominated as a candidate
        if user  $i$  being elected as a witness then        ▷ Determining the identity of user  $i$ 
            generate a block
            receive handling fee reward by reputation value
        end if
    end if
end if
if user  $i$  voted in this epoch then
     $i_{repa} + 3$                                        ▷ Reward for user  $i$ 's participation in voting
end if

```

4.4. Forum Functions

- **Trading in-game items.** To begin with, seller U_{se} displays the in-game items, I_{it} , to be sold, its price I_{pri} , and seller i 's id n_i in a posting (I_{it}, I_{pri}, n_i) on **TF**. Then buyer U_{bu} can initiate trade requests to sellers on **TF**. After U_{bu} and U_{se} confirm the details of the transaction, they can start the transaction on the **BC** through smart contracts.

Step 1: U_{se} and U_{bu} make the final confirmation about the I_{it} and I_{pri} in the posting on **TF**. After that, the post will be locked.

Step 2: U_{bu} locks the tokens on the **BC**.

Step 3: U_{bu} and U_{se} hand over the It in the game.

Step 4: U_{bu} and U_{se} confirm the transaction on the **BC** by voting; they can choose *yes* or *no* in voting. If the result is $< yes, yes >$, the transaction will complete, and the tokens will be sent to the U_{se} 's account. If either party selects *no* in the confirmation vote, the tokens will be locked on the **BC** and enter the dispute adjudication phase.

The blockchain has already been introduced into the supply chain to record food safety-related messages [32]. Inspired by this, we will record all transactions on the **BC**. Those recorded messages will be defined as:

$$M_{sellx} = [sig_o || timestamp || n_{Bu} || n_{Se} || TD] \quad (2)$$

where sig_o , the signature of witness o , is the signature on **TD** using the signing key k_o . The details of sig_o is $hash(timestamp || n_{Bu} || n_{Se} || TD)$. n_{Se} is the U_{se} 's node id, n_{Bu} is the U_{bu} 's node id, and **TD** is the details about this trade. This information is non-falsifiable and publicly available.

- **Renting in-game items.** The process of renting is similar to buying and selling in-game items. First, lessees U_{le} initiate lease requests by posting on **TF** and lock the deposit Dep and rents Ren on **BC**. The posting (I_{it}, Dep, Ren) is about the I_{it} that U_{le} wants and Dep and Ren that U_{lo} would give. Then, lessors U_{lo} should send It to U_{le} . When the lease period is over, the U_{le} needs to return the I_{it} in time. If any dispute occurs

during the transaction, it could be resolved by the dispute adjudication mechanism. The details are as follows:

Step 1: U_{le} locks tokens as Dep and Ren on the **BC** and posts lease requests. After communication, U_{le} and U_{lo} make the final confirmation about the I_{it} , Dep , and Ren in the posting on **TF**. Afterward, the post will be locked.

Step 2: U_{le} and U_{lo} hand over the I_{it} in the game, U_{le} should return It in time.

Step 3: When the lease expires, U_{lo} and U_{le} confirm the transaction on **BC** by voting. They can choose *yes* or *no* in voting. If the result is $\langle yes, yes \rangle$, the transaction completes, and Ren will be transferred to U_{lo} 's account while Dep will be returned to U_{le} 's account. If either party selects *no* in the confirmation vote, the token will be locked on **BC** and enters the dispute adjudication phase. If the U_{le} defaults on the contract, Dep may be given to the U_{lo} as compensation.

Messages of the lease process will be recorded on the chain like:

$$M_{rentx} = [sig_o || timestamp || n_{Lo} || n_{Le} || TD] \quad (3)$$

where sig_o is the signature of witness o , its detail is $hash(timestamp || n_{Lo} || n_{Le} || TD)$. n_{Lo} is U_{lo} 's node id, n_{Le} is the U_{le} 's node, and **TD** means the details about this trading of in-game item information and rental date.

- **In-game item-trading NFT.** For players to buy in-game items in bulk, we introduce the in-game item-trading NFT **iNFT**. Players who $i_{rst} = G$ can submit a request for minting **iNFT** to the forum administrators. After verifying that the players have a sufficient number of in-game items, administrators will mint an **iNFT** for players, and the following information will be recorded in the **iNFT**:

$$Mnft_x = [sig_a || timestamp || in || n_i] \quad (4)$$

where sig_a is the signature of administrator a , and the detail of sig_a is $hash(timestamp || n_i || n_a || in)$. in is the information about the in-game items, such as names and amounts, and n_i is the id of U_{is} , the player who submits the mint request. n_a is the id of the administrator a . An **iNFT** can be traded on the **BC** as the equivalent of a specified number of in-game items. The user who holds the **iNFT** can send a redemption request to U_{is} . The redemption process is as follows:

1. The holder initiates a redemption transaction with U_{is} .
2. U_{is} delivers in-game items to the holder according to n_i .
3. U_{is} and the holder confirm the transaction, and if either party does not confirm, the transaction proceeds to the dispute adjudication stage. If both parties confirm that the transaction is correct, a request is sent to the administrator to burn the **iNFT**.
4. Administrator burns the **iNFT** after confirming the request.

The trading processes and the delivery processes of **iNFTs** will be recorded on the **BC** too. Users can also use in-game items from other games to mint an **iNFT** for trading.

- **Handling fees system.** After recording tradings, witnesses will receive a pro-rate handling fee. To ensure the security of transactions and to increase the motivation of users to maintain a high reputation value, the distribution of transactions between witnesses is by the reputation value. All witnesses will be ranked in order of reputation value from highest to lowest. The witness with the highest reputation value will be responsible for recording transactions with the highest value, and so on. There is often a big price gap between different in-game items. In Table 2, we show the difference in item prices in Diablo II on a trading forum by fg (The token used in the forums). The in-game items on the game forums usually consist of a large number of low-value in-game items and a small number of high-value in-game items, which means the handling fees will have a big difference between transactions.

- *Dispute adjudication system.* When a dispute arises during users' trading on the forum, it goes to the dispute adjudication stage. First, the accounts and tokens held by both parties will be locked. Then the system will randomly select 11 users that $Rst_i \neq B$ to form the jury. The two users in the dispute, users A and B , will be required to present various pieces of evidence to the jury, such as records of chats, screenshots of games, etc. The jury will need to vote to decide after viewing the evidence, and the vote will be given a weight λ based on the voters' reputation rating. The better the reputation rating is, the higher the λ of the voting is. Algorithm 3 shows how user i 's votes are counted.

l_i is the final result of user i 's vote, and L is the final decision in dispute adjudication, which is calculated by $\sum_{k=1}^{11} l_k = L$. The rule for judging the adjudication process is shown below. If user i abstains or does not vote within the time limit, $l_{i0} = 0$. When $L = 0$, the system will randomly select a user whose $i_{rst} = G$ to join the jury to vote until $L \neq 0$. Users who are found guilty must compensate the victim, and all their pledged tokens will be confiscated while their accounts will be banned.

$$\begin{cases} L > 0, & \text{user } B \text{ is guilty} \\ L < 0, & \text{user } A \text{ is guilty} \end{cases} \quad (5)$$

Algorithm 3 Dispute adjudication.

Input: Initial voting result of user i : l_{i0} .

Output: Final result of user i 's vote: l_i .

if user i supports user A **then**

$l_{i0} = 1$

▷ The Original Voting Result of user i

else if user i supports user B **then**

$l_{i0} = -1$

▷ The Original Voting Result of user i

end if

if $i_{rst} = N$ **then**

$\lambda = 0.7$

▷ Calculate the voting weight of user i based on reputation state

else if $i_{rst} = W$ **then** ▷ The weight of user i 's voting will be higher when user's reputation state is higher

$\lambda = 1$

else if $i_{rst} = G$ **then**

$\lambda = 1.41$

end if

$l_i = \lambda * l_{i0}$

▷ The Final Voting Result of user i

Table 2. Item Prices in Diablo II Measured in Forum Token.

Name of Item	Price in fg
Unid eth demonlime tyrant club	5
Unid eth blackhand key	5
Unid shadowkiller	5
Firelizards Talon	5
Rising sun	5
Unid vampire gaze	10
Angelic ring	5
Nats mask	5
Aldurs full set	20
Ber	750
Jah	650

5. Simulation and Discussion

We present the simulation of the reputation value mechanism and handling fee mechanism in this section. For experimental performance, simulations were implemented under various conditions and compared with the traditional reputation value mechanism.

5.1. Simulation of the New Reputation Value Mechanism

Our experimental simulation (except data decryption) was simulated on a PC with Windows 11, 11th Gen Intel(R) Core(TM) i7-11800H @2.30 GHz, and 16 GB RAM. Simulation experiments were conducted for the designed forum reputation value system to prove the effectiveness of the design. Usually, the user's reputation value does not change over time. Therefore, after users have acquired enough reputation value, their motivation to participate decreases rapidly; an aging mechanism can be introduced to the system, which will make reputation values decrease over time [33]. In the first part of the simulation, we will simulate the process of users participating in the election voting and receiving reputation value rewards, as Figure 3 shows. There are five nodes in the experiment: Alice, Bob, Charlie, Dave, and Eve. The probability of their participation in voting is 90%, 60%, 60%, 30%, and 90%. Their fixed reputation values are A_{rep0} : 50, B_{rep0} : 60, C_{rep0} : 50, D_{rep0} : 60, and E_{rep0} : 60. At the beginning of the experiment, their dynamic reputation values are 0. It is worth mentioning that Eve is a malicious user who will intentionally not generate a block after being selected as a witness. Figure 4 shows the change in their reputation value over 30 epochs under our system design. In the graph, the horizontal coordinates represent the time. An epoch represents an election process. The vertical coordinate indicates nodes' actual reputation values A_{rep} , B_{rep} , C_{rep} , D_{rep} , and E_{rep} . The lower limit of the vertical coordinate is 50. When $i_{rep} = 50$, $i_{rst} = N$, user i cannot be nominated as a candidate.

At the beginning of the experiment, we can see that Bob and Dave take the lead by relying on their high starting reputation value. However, A_{rep} is the highest in *epoch* 30 because of Alice's highest participation rate. The change in C_{rep} is noteworthy. In the beginning, Charlie quickly accumulated reputation value by frequently voting, making a sharp rise in C_{rep} . However, after *epoch* 19 C_{rep} started to drop significantly. It was due to Charlie's non-voting over a while, and the reputation value accumulated earlier started to expire. Dave has the lowest voting intention, so D_{rep} remains in the lower range even though D_{rep0} is 60. Eve will intentionally not generate blocks when Eve becomes a witness. Eve will try to keep voting to earn reputation value. However, due to the penalty mechanism, after *epoch* 17, Eve was disqualified from being nominated as a witness. In *epoch* 30, the users with the highest reputation values are Alice and Bob, the former has the highest willingness to vote, and the latter has a huge number of tokens

pledged. It represents that our system can select two types of users that we believe are more trustworthy: those with a high willingness to vote and those who have pledged ample tokens.

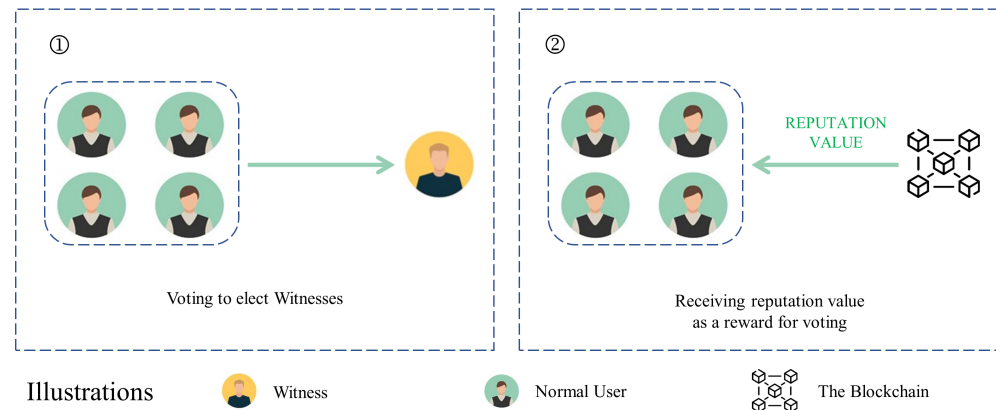


Figure 3. The simulation of the new reputation value mechanism.

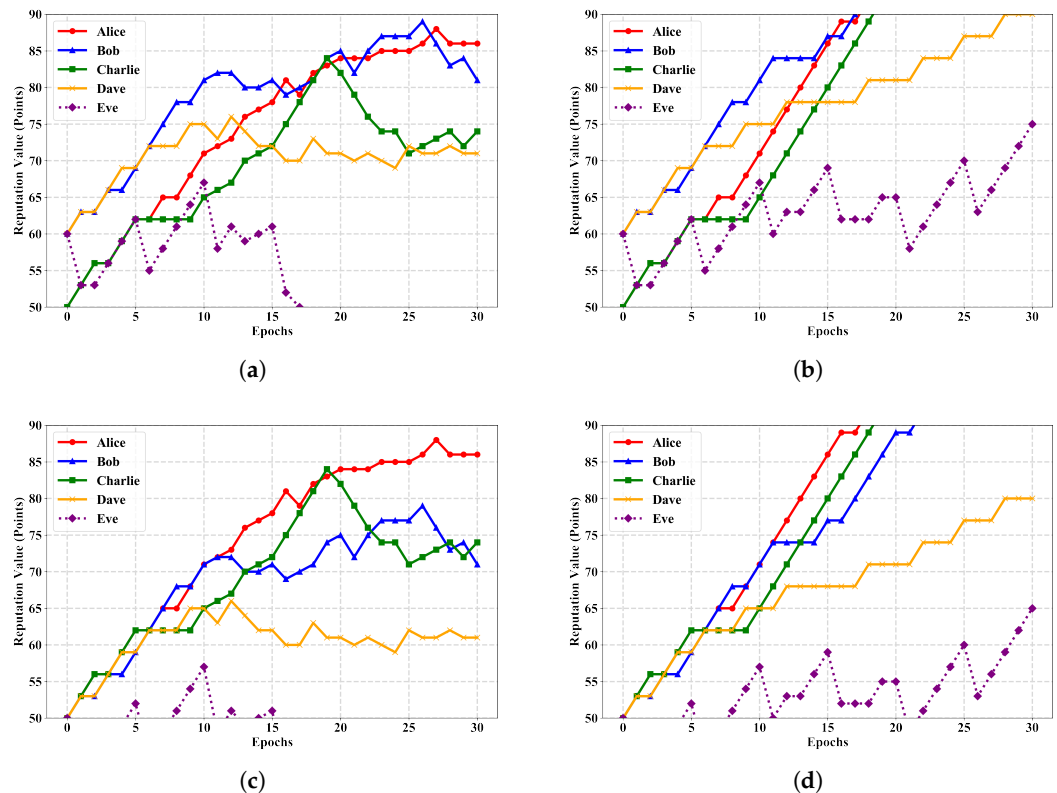


Figure 4. The Simulation of the Reputation Value. (a) The reputation value changes in DVIT with the different fixed reputation values. (b) The reputation value changes in the traditional DPoS mechanism with the different fixed reputation values. (c) The reputation value changes in DVIT with the same fixed reputation values. (d) The reputation value changes in the traditional DPoS mechanism with the same fixed reputation values.

Figure 4b shows the result of the same behavior of the same group of users in the traditional reputation value system. Not including a dynamic reputation mechanism poses two main problems. The first one is the reputation value will unlimitedly increase, which will make it hard for new users to catch up with old users. We can see A_{rep} , B_{rep} , and C_{rep} reached 90 before *epoch* 20. Even if an upper limit is designed for the reputation value, users may not participate in voting at all after accumulating enough reputation

values. The vitality of the forum will be weakened. The second one is evil users can keep their nomination by constant voting. In *epoch 21*, E_{rep} was deducted for not generating blocks. However, in *epoch 25*, E_{rep} is 70, which is higher than in *epoch 21*. Eve can keep replenishing the reputation value deducted for doing evil. It greatly increases the destructiveness of the forum system by evil users. What is more, we compare the changes in reputation values for Alice and Eve under both the old and new mechanisms in Figure 5a.

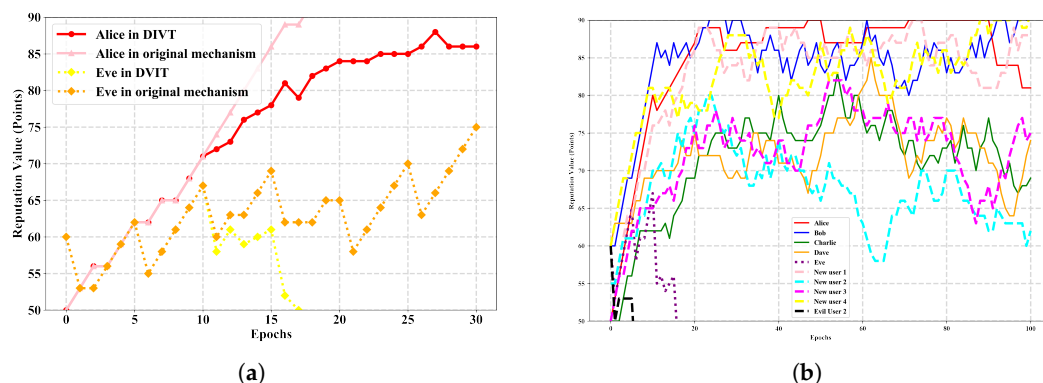


Figure 5. The comparisons of simulation. (a) The changes in reputation values for Alice and Eve under both the old and new mechanisms. (b) The changes in reputation values with 10 nodes in 100 epochs.

When users have the same fixed reputation value, more active participation can bring more rewards. Figure 4c shows the result of the simulation when users have the same reputation value in the beginning. With the highest voting intention, A_{rep} is the highest after 30 epochs compared to other users. Because of the similar willingness to vote, B_{rep} and C_{rep} are close in the last epochs. As a lazy voter, Dave's reputation value is the lowest after 30 epochs compared to the first three. D_{rep} is lower than 61 in *epoch 30*. Since the reputation value was deducted at the beginning due to rule violations, Eve could not meet the conditions to participate in the witness election for some time afterward.

Figure 4d shows the result of the simulation when users have the same reputation value in the beginning but without a dynamic reputation mechanism. D_{rep} is significantly lower than other users in terms of reputation value due to low voting frequency. After 30 epochs, Alice, Bob, and Charlie have all accumulated a significant reputation value. These cases are similar to Figure 4b. It shows the necessity of a dynamic reputation mechanism.

In Figure 5b, we extended the test period to 100 epochs and added 5 new nodes to show the performance of the DVIT reputation system under longer periods and more users. The fixed reputation value of New user 1 is 55, and the probability of New user 1 participating in voting is 80%; The fixed reputation value of New user 2 is 55, and the probability of New user 2 participating in voting is 30%; The fixed reputation value of New user 3 is 50, and the probability of New user 3 participating in voting is 50%; The fixed reputation value of New user 4 is 60, and the probability of New user 4 participating in voting is 50%; What is more, we add Evil User 2 whose fixed reputation value is 60 and is 30% likely to participate in voting. As the result shows, the new simulation result shows similar outcomes to the original one. Users with a high willingness to vote or have pledged ample tokens gain more reputation value, and we believe those users are more trustworthy. Malicious users are also all quickly removed by the system without administrator intervention. This suggests that our system can also serve to encourage nodes to behave well and select better-quality witnesses over a longer period.

5.2. Simulation of the New Handling Fee Mechanism

In the second part of the experiment, we tested the impact of different reward allocation mechanisms on users with high reputation value. As shown in Figure 6, in the original mechanism, the witness will be randomly assigned to record some transactions and receive a corresponding fee. However, with the new mechanism, the witness with the highest reputation value will obtain the highest value transactions. In the experiment, we simulated the handling fee revenue of two nodes within 30 epochs. Alice has an average reputation value, while Bob has the highest reputation value in the forum. In the simulation environment, it is assumed that the items traded in the forum consist of 90% low-priced items and 90% high-priced items.

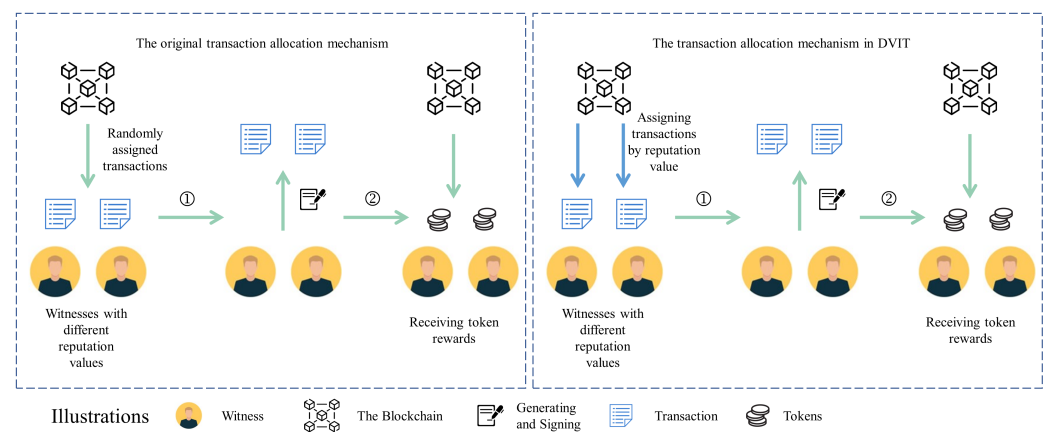


Figure 6. The simulation of the new handling fee mechanism.

The simulation under the traditional DPoS mechanism is shown in Figure 7a; all nodes will be assigned a lot of low-value transactions and a few high-value transactions. In the graph, we use bar charts to compare the handling fees received by Alice and Bob. We set every five epochs as an E_{period} . We define Alice's handling income in $E_{period} k$ as A_{hk} and Bob's handling income in $E_{period} k$ as B_{hk} . The percentage of income in $E_{period} k$ Θ_k is calculated as:

$$\Theta_k = \frac{A_{hk}}{A_{hk} + B_{hk}} \quad (6)$$

As shown in Figure 7a, Bob earns more in $E_{period} 1$, $E_{period} 3$ and $E_{period} 5$, while Alice earns more in $E_{period} 2$, $E_{period} 4$ and $E_{period} 6$. Θ_1 , Θ_3 and Θ_5 are lower than 0.4 while Θ_2 , Θ_4 and Θ_6 are higher than 0.6. It shows how random the traditional allocation mechanism is. A higher reputation value does not provide more benefit to the user at this point, which makes users have less incentive to maintain it.

With the new transaction mechanism, since the value of the assigned transaction is proportional to the reputation value of the node, the node with the highest reputation value can record transactions with the highest value all the time. In Figure 7b, Bob's handling fee income is significantly higher than Alice's in every E_{period} . Θ_1 to Θ_6 all stay lower than 0.2. In the simulation of 6 E_{period} , we increased the revenue of users with the highest reputation value, which shows nodes with high reputation value are rewarded. Nodes in the system will work harder to improve their reputation value to compete with other nodes. The problem of low willingness to participate in DPoS can be solved. The forum will also become more dynamic.

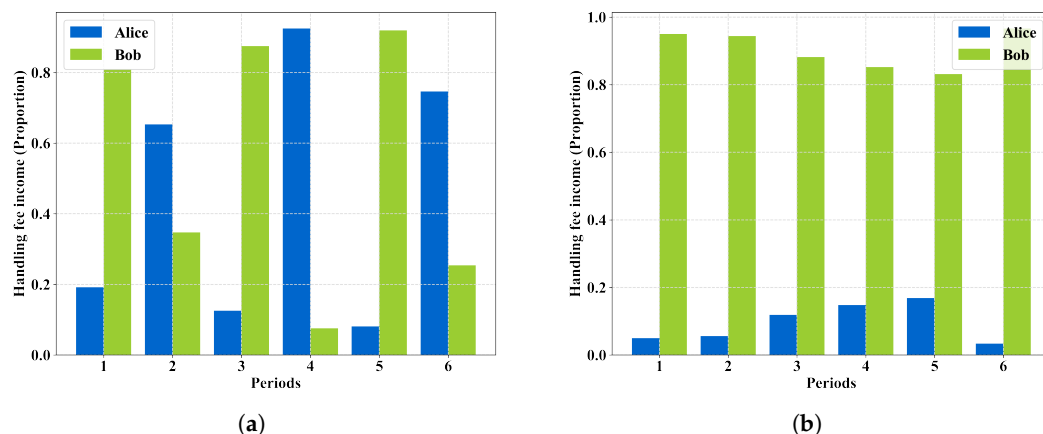


Figure 7. The simulation of handling fees. (a) The handling fee incomes in the traditional DPoS mechanism. (b) The handling fee incomes in DVIT.

6. Performance Analysis

We present the security, efficiency, and scalability analysis regarding the theoretical analysis in this section.

6.1. Security

The proposed system in this paper has good resistance against data tampering. Using the blockchain, the recorded transactions will not be tampered with. Impersonation attacks are where someone poses as another entity, which has various forms [33]. The identity of the block generator can be verified through the digital signature *sig* in the recorded message *M*. Because of the introduction of *timestamp*, Replay Attacks launched by attackers can also be resisted [34]. Transactions via tokens on the blockchain can reduce the risk of transfers.

6.2. Effectiveness

Our DPoS blockchain-based forum trading system for in-game items has several advantages over the currently available forum systems. It enables decentralized and more transparent trading without making huge changes to the original forum trading system. Compared to the original DPoS algorithm, the DPoS algorithm we use increases the willingness of users to participate in voting by adding a reputation system.

6.3. Scalability

Our system does not need to limit the number of participants. The number of witnesses and the size of the production blocks can be changed by the administrator in TF, which brings greater flexibility to our system. Our in-game item-trading NFT has no small prospect as well. With the consent of the administrator, players can use items from other games, or even virtual items from the metaverse, to mint an iNFT. Our system can be used to trade virtual items between metaverse in the future.

7. Related Work

In this section, we introduce some relative work about this article, including the state of blockchain technology and a vision of the future of the metaverse.

7.1. Blockchain Technology

7.1.1. Applications of Blockchain Technology

There are many applications of blockchains now. For example, blockchains can contribute to the circular economy (CE). It helps record the consumption of resources so that the general public can audit the environmental friendliness of the production process. People can better manage the destination of various recyclable resources on a waste recycling

platform built on blockchain and smart contract technology [35]. Blockchain technology is considered a significant driver for smart initiation along with the Internet of Things (IoT) and fog computing technologies under the background of smart cities. A more trusted and decentralized database can be built using blockchain technology [36]. Metaverse, as the latest buzzword, has attracted great attention from both industry and academia. The flow of data will be beyond the previous scale in the metaverse. The security protection of this data is a very urgent need. The security and decentralized nature of the blockchain makes it a perfect fit for people. It has led to the belief that it is the key to the next round of industrial transformation [37].

7.1.2. Blockchain for Online Trading

In this section, we will introduce some uses of blockchain for online trading. Atomic swaps, which means the quick and automatic exchange of cryptocurrencies between parties or groups, can be performed on-chain or off-chain. It can realize peer-to-peer transfer, which safeguards the privacy of users' transactions and reduces transaction costs by bypassing the exchanges. It is an area with a lot of research potential [38]. Data have become an extremely important asset worth trading. However, traders may encounter problems of a single point of failure (SPOF), opaque transactions, uncontrollability, untraceability, and issues of data privacy. Blockchain and smart contracts can be used in automated transactions of data. Data matching, price negotiation, and reward assigning in data trading will be completed by smart contracts [39]. In addition to the research findings mentioned above, there have also been some attempts at using the blockchain to trade offline physical objects. Peer-to-Peer (P2P) energy trading, which means energy consumers/producers directly trade with each other. In the past, energy trading was rarely performed on a P2P basis because it was hard to have a system that could support such large and complex settlements. Nevertheless, with the help of blockchain, a highly automated, secure, and real-time settlement trading platform can be implemented [40].

Attempts to reduce centralization through blockchain are being made all the time. It has brought innovations in various business domains and spawned a new form of organization—the decentralized autonomous organization (DAO). Steemit is recognized as one of the earliest blockchain-based online communities and a typical example of a DAO. It has more than 1 million registered users. The forum model proposed in this paper can also be considered a DAO after further development [41]. DMarket is a cross-game trading platform based on blockchain and smart contracts. DMT is the only token that users need to use while trading via smart contracts. However, the platform is a bit centralized and only supports games that can offer a trading interface.

7.1.3. Security and Efficiency in Blockchain

Blockchain is widely used in security due to its public and tamper-evident nature. Nevertheless, it also faces multiple security threats. One of the most classic ones is 51% Vulnerability. The 51% attack may occur in PoW-based blockchains if a single miner's hashing power accounts for more than 50% of the total hashing power of the entire blockchain. Double Spending attacks, which means an attacker uses the same cryptocurrency multiple times for transactions, and Criminal Smart Contracts, also pose threats to the blockchain [42]. In the practical application of blockchains, there are still many issues to be solved as how to integrate the new blockchain-based application with the existing legacy system and the data loss and breach risk when a blockchain-based application [43].

Correspondingly, several studies have shown that the proper use of blockchain can maintain user privacy and security. For example, to remap the virtual address to the individual's identity while hiding the user's reality information, blockchain-based meta-native communications need to be introduced to meet the need [44]. Entities can find each other on the blockchain by generating encrypted addresses, which means users from the whole metaverse can acquire the connection information in a decentralized manner. A hierarchical blockchain architecture with the main chain and multiple subchains can be introduced

to perform decentralized, secure, and privacy-preserving data training on both physical and virtual spaces. It can help users to build a user-defined privacy-preserving framework with decentralized, federated learning for industrial metaverses [45]. The efficiency of blockchain has also been a topic that has captured the attention of researchers. The issue of efficiency is also a challenge that we cannot avoid if we want to put a blockchain system into practical use. Bitcoin, for example, was split into two separate blockchains—original Bitcoin (BTC) and Bitcoin Cash (BCH) in 2017 due to the overcrowding caused by the over-expansion of users [46]. While the introduction of blockchain can bring a variety of benefits, such as availability, no single point of failure, confidentiality, and privacy, it also increases the chances of escalating overall network costs with high energy and resource consumption [47]. Blockchains with different consensus protocols have performance differences in terms of resource consumption. According to research, Hyperledger Fabric generally surpasses Ethereum against the four performance metrics, including success rate, average latency, throughput, and resource consumption, while executing 100 transactions [48].

7.1.4. Improvements on DPoS

There are many more possibilities for improvements to the DPoS system. Some scholars have improved the election mechanism of DPoS by adding weights to the votes based on reputation value [49]. Some scholars have improved the consensus algorithm by adding a dynamic trust mechanism [50]. Some scholars combine DPoS with other fields and develop a three-stage Stackelberg game to jointly minimize the users' cost and maximize the utilities of the master node and the validation nodes [51]. The improved DPoS has good practicality. For example, it can be against chargeback fraud in e-commerce [52]. These ideas may be helpful to us in future work.

7.2. Metaverse and The Future

Personal computers, the Internet, and mobile devices have been three major technological innovation waves that changed modern society, and the metaverse may be the fourth. The metaverse is a post-reality universe, a perpetual and persistent multiuser environment merging physical reality with digital virtuality [1]. In the past, such technology would have been unthinkable. No matter how high the degree of simulation of the virtual world is, it will always leave people with a sense of alienation due to the limitations of technical means. However, with technologies that enable multisensory interactions with virtual environments, such as virtual reality (VR) and augmented reality (AR), the expressive and infectious power of the meta-universe is unparalleled by the techniques of the past. Some scholars have used immersive virtual reality (iVR) and head-mounted display (HMD) systems to help rehabilitate injured patients [53]. The concept of digital twins, which is related to the metaverse, has also had a profound impact on areas outside the Internet, such as industry [54].

The metaverse has shown strong potential in several areas now. The metaverse can be combined with artificial intelligence to enhance the effectiveness of online education. Some scholars have envisioned a metaverse in which intelligent NPCs (non-player characters) are simulated by artificial intelligence techniques to help students learn. NPCs can become peers and friends that study with the students. When students have problems with lessons, they can turn to NPC students or teachers for help [55]. The metaverse is also promising in the medical field. Due to the impact of COVID-19, the existing offline healthcare system has been affected, and the need for online healthcare has become urgent. The metaverse has brought a lot of innovation to the current healthcare system. Combined with blockchain and Non-Fungible Tokens (NFTs), the metaverse can be applied to telehealth, supply chain, payments, secure data sharing, and remote monitoring. Metaverse has a wide range of applications in clinical care. It allows online immersion in a live simulation of the operating room environment, assisting surgeons complete procedures remotely. Combined with artificial intelligence, it can provide more personalized health assistance to patients. In medical education and training, metaverse technology can give medical

students a better practice environment [56]. COVID-19 has also taken a considerable toll on the hospitality and tourism industry, and metaverse technology also can be used to save tourism. Improvements in technology and sophistication in the quality of virtual reality (VR) headsets have made travel in the metaverse as good as offline travel. For example, Japan-based First Airlines has begun offering virtual flights from Tokyo [57].

Among all these applications, the combination of the metaverse and video games is the most striking. Metaverse is learning from the experience of the gaming industry. At present, many metaverses are developed with game engines such as Unreal and Unity [58]. The combination of the metaverse and video games is showing unprecedented appeal. ROBLOX, a sandbox game platform, was the first metaverse concept game stock to be listed on the New York Stock Exchange. Its USD 40 billion valuation proved that the value of the metaverse is recognized [59]. The virtual rewards in the metaverse can even exert an influence on people's real lives. Some researchers suggest that tokenized incentivization in the metaverse can be used to architect people's choices and lead people to live healthy lifestyles. The prospect of the game market is immense in the metaverse [60].

Players' willingness to pay for in-game items has been cultivated over the years. In MMORPGs (Massively Multiplayer Online Role-playing Games), such as World of Warcraft (WoW), a mature inter-player economic system has been established [61]. There are even studios that earn their living by producing in-game items. Players can pay real money to those studios for in-game items they want. A similar situation will occur in the metaverse. Since the interaction between players and the game is more realistic in the metaverse, players are more willing to acknowledge the value of various in-game items. Now in-game items in some metaverse games are much more useful than before. For example, in ZEPETO, a metaverse game launched in 2018 by Snow and owned by the company Naver, users can use in-game currencies, such as coins and gems, to decorate their avatars and maps for space [62]. Concepts such as metaverse and Gamefi, which is a combination of the words Game and Finance, meaning a blockchain game that provides financial incentives for players to earn while they play, are now very prevalent. Many people have already managed to make a profit from them. CryptoKitties is the first game in which game assets and collectible items exist as Non-Fungible Tokens (NFTs) on the blockchain and can be traded for cryptocurrency. It is a relatively successful experiment in the gamification of blockchain [63]. Due to the nature of the metaverse, the scale of buying and selling virtual items in the metaverse is already large and subversive enough. For example, virtual land in the metaverse can be bought and sold just like in reality. There are 90,601 lands in the Decentraland metaverse and 166,464 virtual lands in the Sandbox metaverse [64]. The in-game items trading system designed in this paper can be used in a metaverse context. The growing demand for buying and selling virtual goods in the metaverse must be a bright future for our system.

As Table 3 shows, we introduce a chart containing a comparative study of some representative papers we cited and our work. It can be seen that our work combines the two domains of metaverse and DPoS while incorporating the virtual economy. In our future work, we will continue to draw inspiration from related fields to achieve further results in the exploration of metaverse trading.

Table 3. A comparative study of related papers.

Citation Number	DPoS	Reputation System	Metaverse	Virtual Economy	Incentive Mechanism
[13]	●	●	✗	✗	●
[16]	●	✗	✗	✗	✗
[21]	●	✗	✗	✗	●
[33]	✗	●	✗	✗	●
[44]	✗	✗	●	✗	✗
[45]	✗	✗	●	✗	●
[50]	●	●	✗	✗	✗
[51]	●	●	✗	✗	●
DVIT	●	●	●	●	●

8. Conclusions and Future Work

In this work, we studied the problem of virtual item exchange in the metaverse. We proposed a blockchain-based in-game items trading forum system, combined a DPoS blockchain with an in-game items trading system, and increased the decentralization and security of the system. We added many new features to the system, such as in-game item trading Non-Fungible Token (NFT) and in-game item renting. We designed a user incentive system based on reputation value to guide users to trade correctly in the system. We believe that our solution can substantially improve the existing in-game items trading forum system and can be used in the metaverse for virtual item exchange. In future work, the fairness and rationality of reputation calculation will be reserved for further consideration, and more variables, such as coinday and the number of historical transactions, will be taken into account. Moreover, the economic game theory will also be modularized to facilitate the completeness of the DVIT. To achieve more decentralization, after completing experiments with forum-based virtual item trading, we will try to propose a framework where users can trade directly between consortium-blockchain-based metaverses. We will try to extend our work from in-game item trading to simulations in an environment that is closer to the metaverse.

Author Contributions: Conceptualization, Z.Y. and W.L.; methodology, W.L.; formal analysis, C.D.; investigation, L.L.; data curation, W.L.; writing—original draft preparation, W.L.; writing—review and editing, Z.Y. and W.L.; project administration, X.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research is partially supported by FDCT under its General R&D Subsidy Program Fund (Grant No. 0038/2022/A), Macau, and partially supported by MOST-FDCT Projects (0058/2019/AMJ,2019YFE0110300) (Research and Application of Cooperative Multi-Agent Platform for Zhuhai-Macao Manufacturing Service).

Data Availability Statement: The simulations of this paper can be accessed at <https://github.com/LanWusong/DVIT-simulations> (accessed on 8 January 2023).

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

MK	master key
PK	public key
SP	security parameter
AM	attributes of the ADM
k_i	secret key of user i
k_{pi}	public key of user i
i	identification of the User
i_{rep}	actual reputation value of user i
i_{rep0}	fixed reputation value of user i
i_{repa}	reputation value user i got in the last 0–10 epochs
i_{repb}	reputation value user i got in the last 10–20 epochs
w	expired weight
l_{i0}	initial voting result of user i in dispute adjudication
l_i	final result of user i 's vote in dispute adjudication
λ	user's vote weight in dispute adjudication
L	the final decision in dispute adjudication
E_{period}	each 5 epochs is a <i>Period</i>
Θ_k	the percentage of income in <i>Period</i> k
M_{sell}	record of item selling on the blockchain
M_{srent}	record of item renting on the blockchain
sig_k	signature of user k
$Candidate[]$	list of candidates in election process
$Witness[]$	list of witnesses
X	number of witnesses
n	users' node id on the blockchain
in	the information about the in-game items
U_{se}	seller
U_{bu}	buyer
U_{le}	lessee
U_{lo}	lessor
Dep	deposit
Ren	rent
$timestamp$	timestamp of the blocks
U_{is}	issuer of iNFT
I_{pri}	in-game item price
I_{it}	in-game item

References

1. Mystakidis, S. Metaverse. *Encyclopedia* **2022**, *2*, 486–497. [CrossRef]
2. Matthews, J. Ready Player One (Movie Review). 2018. Available online: https://digitalcollections.dordt.edu/faculty_work/886/ (accessed on 1 October 2022).
3. Salvador, R. Facebook Changes Company Name to Meta. Available online: <https://www.cnbc.com/2021/10/28/facebook-changes-company-name-to-meta.html/> (accessed on 10 August 2022).
4. Clement, J. When Do You Think the Metaverse Will Start Booming? Available online: <https://www.statista.com/statistics/1302240/metaverse-business-boom/> (accessed on 10 August 2022).
5. Ronit, G.; Nisha, S.; Sophia, B.; Kaiwan, M.; Ronak, S.S.; Puneet, S. Metaverse and Money. Available online: <https://www.citivelocity.com/citigps/metaverse-and-money/> (accessed on 1 October 2022).
6. Jansen, S. How Cross-Chain Games Are Giving Users the First Look at a Metaverse. Available online: <https://cointelegraph.com/news/how-cross-chain-games-are-giving-users-the-first-look-at-a-metaverse> (accessed on 25 December 2022).
7. Radahn, C. All About the Open Metaverse Alliance (OMA3). Available online: <https://www.altcoinbuzz.io/metaverse/all-about-the-open-metaverse-alliance-oma3/> (accessed on 25 December 2022).
8. Ravenscraft, E. What, Exactly, Is the Metaverse Standards Forum Creating? Available online: <https://www.wired.com/story/metaverse-standards-forum-explained/> (accessed on 25 December 2022).
9. Balicer, R.D. Modeling infectious diseases dissemination through online role-playing games. *Epidemiology* **2007**, *18*, 260–261. [CrossRef]

10. Salter, A.W.; Stein, S. Endogenous currency formation in an online environment: The case of Diablo II. *Rev. Austrian Econ.* **2016**, *29*, 53–66. [\[CrossRef\]](#)
11. De Filippi, P.; Mannan, M.; Reijers, W. Blockchain as a confidence machine: The problem of trust & challenges of governance. *Technol. Soc.* **2020**, *62*, 101284.
12. Monrat, A.A.; Schelén, O.; Andersson, K. A Survey of Blockchain From the Perspectives of Applications, Challenges, and Opportunities. *IEEE Access* **2019**, *7*, 117134–117151. [\[CrossRef\]](#)
13. Wei, Y.; Liang, L.; Zhou, B.; Feng, X. A Modified Blockchain DPoS Consensus Algorithm Based on Anomaly Detection and Reward-Punishment. In Proceedings of the 2021 13th International Conference on Communication Software and Networks (ICCSN), Chongqing, China, 4–7 June 2021; pp. 283–288.
14. Saad, S.M.S.; Radzi, R.Z.R.M.; Othman, S.H. Analysis of the Blockchain Consensus Algorithm Between Proof of Stake and DelegatComparativeed Proof of Stake. In Proceedings of the 2021 International Conference on Data Science and Its Applications (ICoDSA), Virtual, 6–7 October 2021; pp. 175–180.
15. Staff, C. What Are Proof of Stake and Delegated Proof of Stake? Available online: <https://www.gemini.com/cryptopedia/proof-of-stake-delegated-pos-dpos> (accessed on 13 August 2022).
16. Chen, S.; Xie, M.; Liu, J.; Zhang, Y. Improvement of the DPoS Consensus Mechanism in Blockchain Based on PLTS. In Proceedings of the 7th IEEE International Conference on Big Data Security on Cloud, IEEE International Conference on High Performance and Smart Computing, and IEEE International Conference on Intelligent Data and Security, BigDataSecurity/HPSC/IDS 2021, New York, NY, USA, 15–17 May 2021; pp. 32–37.
17. Nguyen, B.M.; Nguyen, T.; Nguyen, T.; Do, B. MPoC—A Metaheuristic Proof of Criteria Consensus Protocol for Blockchain Network. In Proceedings of the IEEE International Conference on Blockchain and Cryptocurrency, ICBC 2021, Sydney, Australia, 3–6 May 2021; pp. 1–8.
18. Dhillon, V.; Metcalf, D.; Hooper, M. Recent developments in blockchain. In *Blockchain Enabled Applications*; Apress: Berkeley, CA, USA, 2017; pp. 151–181.
19. Shin, D.D. Blockchain: The emerging technology of digital trust. *Telemat. Inform.* **2019**, *45*, 101278. [\[CrossRef\]](#)
20. Sun, Y.; Xue, R.; Zhang, R.; Su, Q.; Gao, S. RTChain: A Reputation System with Transaction and Consensus Incentives for E-commerce Blockchain. *ACM Trans. Internet Technol.* **2021**, *21*, 15:1–15:24. [\[CrossRef\]](#)
21. Wang, L.; Xu, P.; Su, W.; Li, Y.; Chen, X. Research on Improvement of Blockchain DPOS Consensus Mechanism Based on HK Clustering. In Proceedings of the 2021 China Automation Congress (CAC), Beijing, China, 22–24 October 2021; pp. 1167–1172.
22. Hu, Q.; Yan, B.; Han, Y.; Yu, J. An improved delegated proof of stake consensus algorithm. *Procedia Comput. Sci.* **2021**, *187*, 341–346. [\[CrossRef\]](#)
23. Johari, R.; Kumar, V.; Gupta, K.; Vidyarthi, D.P. BLOSUM: BLOckchain technology for Security of Medical records. *ICT Express* **2022**, *8*, 56–60. [\[CrossRef\]](#)
24. Merrad, Y.; Habaebi, M.H.; Elsheikh, E.A.A.; Suliman, F.E.M.; Islam, M.R.; Gunawan, T.S.; Mesri, M. Blockchain: Consensus Algorithm Key Performance Indicators, Trade-Offs, Current Trends, Common Drawbacks, and Novel Solution Proposals. *Mathematics* **2022**, *10*, 2754. [\[CrossRef\]](#)
25. Zhu, H.; Guo, Y.; Zhang, L. An improved convolution Merkle tree-based blockchain electronic medical record secure storage scheme. *J. Inf. Secur. Appl.* **2021**, *61*, 102952. [\[CrossRef\]](#)
26. Cho, S.; Park, S.Y.; Lee, S.R. Blockchain consensus rule based dynamic blind voting for non-dependency transaction. *Int. J. Grid Distrib. Comput.* **2017**, *10*, 93–106. [\[CrossRef\]](#)
27. Mitra, D.; Tautz, L.; Dolecek, L. Concentrated stopping set design for coded Merkle tree: Improving security against data availability attacks in blockchain systems. In Proceedings of the 2020 IEEE Information Theory Workshop (ITW), Riva del Garda, Italy, 11–15 April 2021; pp. 1–5.
28. Hellenbrand, A. Asynchronous and Decentral Group Management in Messengers with Delegated Proof of Stake. In *SKILL 2020-Studierendenkonferenz Informatik*; Gesellschaft für Informatik e.V.: Bonn, Germany, 2020.
29. Wang, T.; Guo, J.; Ai, S.; Cao, J. RBT: A distributed reputation system for blockchain-based peer-to-peer energy trading with fairness consideration. *Appl. Energy* **2021**, *295*, 117056. [\[CrossRef\]](#)
30. Chen, Y.; Liu, F. Research on improvement of DPoS consensus mechanism in collaborative governance of network public opinion. *Peer-to-Peer Netw. Appl.* **2022**, *15*, 1849–1861. [\[CrossRef\]](#) [\[PubMed\]](#)
31. Wang, Z.; Xiong, R.; Jin, J.; Liang, C. AirBC: A Lightweight Reputation-based Blockchain Scheme for Resource-constrained UANET. In Proceedings of the 25th IEEE International Conference on Computer Supported Cooperative Work in Design, CSCWD 2022, Hangzhou, China, 4–6 May 2022; pp. 1378–1383.
32. Putra, G.D.; Kang, C.; Kanhere, S.S.; Hong, J.W. DeTRM: Decentralised Trust and Reputation Management for Blockchain-based Supply Chains. In Proceedings of the IEEE International Conference on Blockchain and Cryptocurrency, ICBC 2022, Shanghai, China, 2–5 May 2022; pp. 1–5.
33. Battah, A.; Iraqi, Y.; Damiani, E. A Trust and Reputation System for IoT Service Interactions. *IEEE Trans. Netw. Serv. Manag.* **2022**, *19*, 2987–3005. [\[CrossRef\]](#)
34. Wang, P.; Pan, B.; Tao, Q.; Yang, C.; Luo, S. Distributed Storage and Traceability System for Aviation Equipment Biographies Based on Consortium Blockchain. In Proceedings of the 2022 4th International Conference on Advances in Computer Technology, Information Science and Communications (CTISC), Suzhou, China, 22–24 April 2022; pp. 1–5.

35. Böhmecke-Schwafert, M.; Wehinger, M.; Teigland, R. Blockchain for the circular economy: Theorizing blockchain's role in the transition to a circular economy through an empirical investigation. *Bus. Strategy Environ.* **2022**, *31*, 3786–3801. [\[CrossRef\]](#)
36. Kamruzzaman, M.; Yan, B.; Sarker, M.N.I.; Alruwaili, O.; Wu, M.; Alrashdi, I. Blockchain and Fog Computing in IoT-Driven Healthcare Services for Smart Cities. *J. Healthc. Eng.* **2022**, *2022*, 9957888. [\[CrossRef\]](#) [\[PubMed\]](#)
37. Yang, Q.; Zhao, Y.; Huang, H.; Xiong, Z.; Kang, J.; Zheng, Z. Fusing Blockchain and AI with Metaverse: A Survey. *IEEE Open J. Comput. Soc.* **2022**, *3*, 122–136. [\[CrossRef\]](#)
38. Mohanty, D.; Anand, D.; Aljahdali, H.M.; Villar, S.G. Blockchain Interoperability: Towards a Sustainable Payment System. *Sustainability* **2022**, *14*, 913. [\[CrossRef\]](#)
39. Hu, D.; Li, Y.; Pan, L.; Li, M.; Zheng, S. A blockchain-based trading system for big data. *Comput. Netw.* **2021**, *191*, 107994. [\[CrossRef\]](#)
40. Esmat, A.; de Vos, M.; Ghiassi-Farrokhfal, Y.; Palensky, P.; Epema, D. A novel decentralized platform for peer-to-peer energy trading market with blockchain technology. *Appl. Energy* **2021**, *282*, 116123. [\[CrossRef\]](#)
41. Liu, Z.; Li, Y.; Min, Q.; Chang, M. User incentive mechanism in blockchain-based online community: An empirical study of steemit. *Inf. Manag.* **2022**, *59*, 103596. [\[CrossRef\]](#)
42. Li, X.; Jiang, P.; Chen, T.; Luo, X.; Wen, Q. A survey on the security of blockchain systems. *Future Gener. Comput. Syst.* **2020**, *107*, 841–853. [\[CrossRef\]](#)
43. Islam, M.R.; Rahman, M.M.; Mahmud, M.; Rahman, M.A.; Mohamad, M.H.S. A Review on Blockchain Security Issues and Challenges. In Proceedings of the 2021 IEEE 12th Control and System Graduate Research Colloquium (ICSGRC), Shah Alam, Malaysia, 7 August 2021; pp. 227–232.
44. Xu, H.; Li, Z.; Li, Z.; Zhang, X.; Sun, Y.; Zhang, L. Metaverse Native Communication: A Blockchain and Spectrum Prospective. In Proceedings of the 2022 IEEE International Conference on Communications Workshops, ICC Workshops 2022, Seoul, Republic of Korea, 16–20 May 2022; pp. 7–12.
45. Kang, J.; Ye, D.; Nie, J.; Xiao, J.; Deng, X.; Wang, S.; Xiong, Z.; Yu, R.; Niyato, D. Blockchain-based Federated Learning for Industrial Metaverses: Incentive Scheme with Optimal AoI. In Proceedings of the IEEE International Conference on Blockchain, Blockchain 2022, Espoo, Finland, 22–25 August 2022; pp. 71–78.
46. Jiang, S.; Li, Y.; Wang, S.; Zhao, L. Blockchain competition: The tradeoff between platform stability and efficiency. *Eur. J. Oper. Res.* **2022**, *296*, 1084–1097. [\[CrossRef\]](#)
47. Shahzad, I.; Maqbool, A.; Rana, T.; Mirza, A.; Khan, W.Z.; Kim, S.W.; Zikria, Y.B.; Din, S. Blockchain-based green big data visualization: BGbV. *Complex Intell. Syst.* **2022**, *8*, 3707–3718. [\[CrossRef\]](#)
48. Dabbagh, M.; Kakavand, M.; Tahir, M.; Amphawan, A. Performance Analysis of Blockchain Platforms: Empirical Evaluation of Hyperledger Fabric and Ethereum. In Proceedings of the 2020 IEEE 2nd International Conference on Artificial Intelligence in Engineering and Technology (IICAIET), Kota Kinabalu, Malaysia, 26–27 September 2020; pp. 1–6. [\[CrossRef\]](#)
49. You, L.; Wang, Z.; Hu, G.; Cao, C. An Improved Model on the Vague Sets-Based DPoS's Voting Phase in Blockchain. *IACR Cryptol. ePrint Arch.* **2022**, 391.
50. Sun, Y.; Yan, B.; Yao, Y.; Yu, J. DT-DPoS: A delegated proof of stake consensus algorithm with dynamic trust. *Procedia Comput. Sci.* **2021**, *187*, 371–376. [\[CrossRef\]](#)
51. Wang, D.; Jia, Y.; Liang, L.; Dong, M.; Ota, K. A Game for Task Offloading in Reputation-Based Consortium Blockchain Networks. *IEEE Wirel. Commun. Lett.* **2022**, *11*, 1508–1512. [\[CrossRef\]](#)
52. Liu, D.; Lee, J.H. CFLedger: Preventing chargeback fraud with blockchain. *ICT Express* **2021**, *8*, 352–356. [\[CrossRef\]](#)
53. Elor, A.; Powell, M.; Mahmoodi, E.; Teodorescu, M.; Kurniawan, S. Gaming Beyond the Novelty Effect of Immersive Virtual Reality for Physical Rehabilitation. *IEEE Trans. Games* **2022**, *14*, 107–115. [\[CrossRef\]](#)
54. Jiang, Y.; Yin, S.; Li, K.; Luo, H.; Kaynak, O. Industrial applications of digital twins. *Philos. Trans. R. Soc. A* **2021**, *379*, 20200360. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Hwang, G.J.; Chien, S.Y. Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective. *Comput. Educ. Artif. Intell.* **2022**, *3*, 100082. [\[CrossRef\]](#)
56. Thomason, J. MetaHealth-How will the Metaverse Change Health Care? *J. Metaverse* **2021**, *1*, 13–16.
57. Gursoy, D.; Malodia, S.; Dhir, A. The metaverse in the hospitality and tourism industry: An overview of current trends and future research directions. *J. Hosp. Mark. Manag.* **2022**, *31*, 527–534. [\[CrossRef\]](#)
58. Chia, A. The metaverse, but not the way you think: Game engines and automation beyond game development. *Crit. Stud. Media Commun.* **2022**, *39*, 191–200. [\[CrossRef\]](#)
59. Huang, J.; Sun, P.; Zhang, W. Analysis of the Future Prospects for the Metaverse. In Proceedings of the 2022 7th International Conference on Financial Innovation and Economic Development (ICFIED 2022), Zhuhai, China, 21–23 January 2022; pp. 1899–1904.
60. Thomason, J. Metaverse, Token Economies, and Chronic Diseases. *Glob. Health J.* **2022**, *1*, 13–16.
61. Linnainmaa, H. Virtual economy design in MMORPGs. Bachelor's Thesis, Aalto University, Espoo, Finland, 2021.
62. Han, J.; Heo, J.; You, E. Analysis of metaverse platform as a new play culture: Focusing on roblox and zepeto. In Proceedings of the 2nd International Conference on Human-Centered Artificial Intelligence (Computing4Human 2021), CEUR Workshop Proceedings, Da Nang, Vietnam, 28–29 October 2021.

63. Serada, A. Vintage CryptoKitties and the Quest for Authenticity. In Proceedings of the 2021 IEEE Conference on Games (CoG), Copenhagen, Denmark, 17–20 August 2021; pp. 1–10.
64. Sonmezer, S.; Çelik, G.G. How returns of metaverse tokens are interrelated? *Int. J. Soc. Sci.* **2022**, *8*, 213–223. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.