EXPLORING THE IMPACT OF SMART CONTRACTS ON DECENTRALIZED GAMING ECOSYSTEMS

Golshid Jaferian
Darya Ramezani
Michael G. Wagner

This article addresses the crucial significance of smart contracts in blockchain gaming ecosystems, analyzing their influence on the development of decentralized gaming economies. Smart contracts are self-executing programs that contain coded rules and conditions. They have become a powerful tool in the gambling business, providing transparency, security, and efficiency. The study explores how smart contracts allow for trustless interactions, support peer-to-peer transactions, and grant players genuine ownership of in-game assets. The article illustrates how smart contracts enhance the development of blockchain games by promoting player autonomy, interoperability, and the creation of new economic models in the gaming industry through case studies and examples.

Keywords: Smart contracts, Blockchain, games, Blockchain games, Decentralized gaming

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Introduction

The advent of blockchain technology has introduced a new paradigm in various industries (Upadhyay et al., 2021) including the gaming industry, leading to the emergence of decentralized gaming ecosystems (López-Sorribes et al., 2023). Blockchain's decentralized nature has facilitated the creation of entirely new ecosystems where players can engage in gaming experiences that transcend traditional boundaries (Cui et al., 2021) At the heart of these ecosystems are smart contracts, self-executing contracts with the terms of the agreement directly written into lines of code (Balcerzak et al., 2022).

This paper explores the transformative role of smart contracts in decentralized gaming ecosystems. It examines how these contracts are reshaping game development, fostering new economic models, and addressing the challenges associated with decentralized systems. Through case studies and examples, the paper illustrates the impact of smart contracts on the gaming industry and provides insights into their potential to change the future of digital gaming.

Methodology

We conducted a systematic literature review following the methodology outlined by Page et al., (2021), utilizing electronic scientific databases such as Scopus, IEEE, ProQuest, Google Scholar, and ScienceDirect. We used keywords such as "blockchain," "smart contracts," and "blockchain games" along with a combination of them using AND/OR to guide the search. Studies were considered if they were written in English, published between 2014, and 2024, and published in peer-reviewed journals, book chapters, or conference papers.

The search across the specified databases yielded 592 results, and in the second stage, we screened the titles of the shortlisted papers, identifying 331 relevant papers. In the third stage, the abstracts of these papers were reviewed, and filtering criteria based on their contributions were applied. After assessing the quality of 164 preselected papers by analyzing their full texts, 150 papers were ultimately included in the study.

Smart Contracts

Smart contracts refer to portions of code written in a Turing-complete language that can maintain state, including finances, and interact with other smart contracts (Hall-Andersen & Schwartzbach, 2021). Smart contracts (Figure 1), are self-executing computer programs that operate on the blockchain to enable, execute, and enforce an agreement between parties without the need for a trusted intermediary (Khan et al., 2021; Wang et al., 2019). A smart contract possesses three essential components: an account balance, private storage, and executable code (Buterin, 2014; Wang et al., 2018). The contract's status includes both the storage and the balance of the contract (Lin et al., 2022). The state is kept on the blockchain and is modified whenever the contract is called (Alharby & Moorsel, 2017). According to Ciotta et al. (2021) a smart contract facilitates the exchange of a generic file as a transmission between users. More precisely, the smart contract's initial stage involves establishing the format of the registry of transmissions. This registry remains unchangeable and is reset each time a file is transmitted.

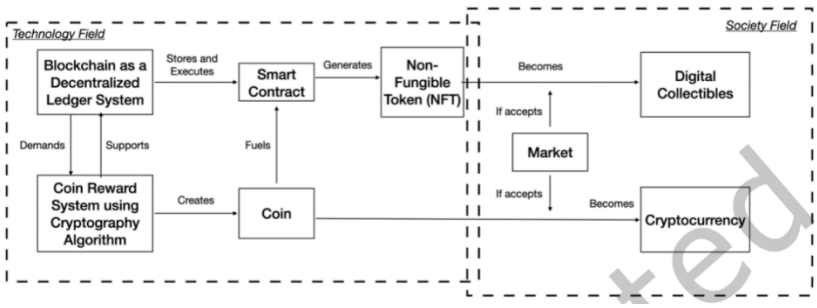

Figure 1. Blockchain and its features (Liu & Holopainen, 2024)

Blockchain technology facilitates the digitization of assets and ensures their secure transfer of value (Pelluru 2021; Javaid et al., 2022). The security of the value transfer is ensured by the inherent nature of the

interaction protocol, eliminating the requirement for trusted transaction middlemen (Pillai et al., 2019). Through the utilization of a blockchain network, it is possible to accomplish this transfer of digital tokenized assets in a straightforward and cryptographically verifiable manner (Christidis & Devetsikiotis, 2016; Li et al., 2019; Sunyaev et al., 2021).

Smart contracts are playing transformative roles across various applications and industries (Zou et al., 2019; Wang et al., 2019). In the financial sector, smart contracts enhance transparency and efficiency in payment systems (Demirel & Zeren, 2021; Almahirah & Salameh, 2021). The supply chain management also benefits from smart contracts facilitating higher levels of trust and coordination among companies (Bottoni et al., 2020; De Giovanni, 2020). Smart contracts are utilized to oversee the conditions of shipments, automate payments, validate recipients, and provide authorizations (Khan et al., 2021). In the automotive industry, smart contracts enhance data security, fraud prevention, and streamlined processes for services like mobility-as-a-service and vehicle tracking (Hornyák & Alkhoury, 2020; Golemi, 2021; Nguyen et al., 2023). Additionally, smart contracts enable the creation of decentralized energy communities in the energy sector, (Chinnici et al., 2022) where prosumers can efficiently manage and trade energy, promoting sustainability and local energy balance (Toderean et al., 2023).

An in-depth evaluation of smart contracts emphasizes their capacity to be programmed and automated (Mik, 2017; Sklaroff, 2017; Borselli, 2020). These qualities are crucial for a wide range of decentralized applications (DApps) (Taherdoost, 2023) which are enabled by smart contracts (Wang et al., 2019).

Smart contracts are utilized to autonomously execute decisions and oversee data (Alladi et al., 2019). DApps are constructed using blockchain technology to include the management of data storage and the execution of on-chain activities (Raval, 2016; Besancon et al., 2022). A decentralized application is one not under the authority of a centralized organization (Vergne, 2020). The rationale behind decentralized apps is that conventional centralized applications are more susceptible to assaults and foster corruption (Zheng et al., 2023). Currently, the Ethereum blockchain hosts several decentralized apps, with many more in the process of being developed (Bracamonte & Okada, 2017; Mukhopadhyay, 2018; Gjorgjev et al., 2024) and Gaming DApps are one of the prominent applications of blockchain technology (Jaferian et al., 2024).

Smart contracts in Games

The video game industry is compatible with the cryptocurrency ecosystem (Besançon et al., 2019) since it enables players to exchange and pass on their virtual character's non-fungible assets for various games (Cai et al., 2018). Unlike the centralized database server used in traditional games, the blockchain provides a more accessible platform for game makers (Manzoor et al., 2020; Stamatakis et al., 2024). The players' data can be retrieved by smart contracts or a collection of application programming interfaces (APIs) (Min et al., 2019; Wang, Shuai, et al., 2019) Smart contracts in the gaming sector, are being employed extensively to assure fairness, security, and transparency (Hu et al., 2020).

Blockchain games are entirely decentralized "on-chain games "or those that utilize smart contracts to perform certain aspects of game processes (Du et al., 2019). By using smart contracts, decentralized gaming platforms can automate complex interactions and transactions (Wang et al., 2019; Carvalho, 2021; Chen et al., 2023). Smart contracts can automate the distribution of rewards in decentralized games (Oliva et al., 2020), ensuring that players are fairly compensated for their achievements and contributions (Chatterjee et al., 2018). As an instance, Sako et al. (2022) provide a decentralized technique for generating pseudo-random numbers using smart contracts. This method aims to demonstrate the efficiency of smart contracts, while also providing incentives to participants and assuring fair distribution of rewards.

Also, Alefs et al. (2022) present a gaming DApp on the Ethereum blockchain using smart contracts to ensure secure, fair gaming with transparent and tamper-proof rules and transactions with securing players' balances and stakes.

Furthermore, according to Min et al., (2019), the server serves as a caching and indexing engine for smart contracts. The blockchain is the primary source of information, but clients rely on the server to search and validate the data returned.

Transparency and trust (Authentication and security)

Smart contracts provide a transparent and secure environment for transactions within the gaming ecosystem, (Carvalho, 2021) ensuring that the rules are immutable and executed as programmed. This eradicates the need for intermediaries, fostering trust among players (Alefs et al., 2022; Pittaras et al. 2021). Participants in blockchain games employ blockchain tokens to allow the buying and selling of in-game objects (Qiao, 2019, Pfeiffer et al., 2020). This is accomplished with smart contracts, which guarantee the authenticity of transferred assets and the verification of game players (Bartoletti & Pompianu, 2017; Oktian et al., 2019). Also, according to Paduraru et al. (2022), since blockchain smart contracts can automate verification, monitoring NFT owners and transactions is more reliable and easier. In contrast, a typical database merely shows the latest element state.

Additionally, they enable the implementation of dynamic strategies on decentralized platforms, resulting in improved level of security and dependability (Shahidehpour et al., 2020; Sharma et al., 2023). Gajrani & Kumar (2024) created a prototype platform to explore the challenges and opportunities involved in developing a blockchain-based gaming environment.

However, to ensure the security of transactions conducted in a decentralized network, it is imperative to include strong security procedures and countermeasures to effectively avoid instances of double spending (Zhang et al., 2019). Based on Liu et al. (2019) findings, key concerns include (1) security threats including selfish mining and DoS attacks, (2) mining management issues like computational power allocation and reward allocation, and (3) blockchain-based applications like energy trading.

Several further papers analyze potential vulnerabilities in the protocol and propose modifications to enhance its security (Koutsoupias et al., 2019). For instance, in their 2017 publication, Zhang et al. presented the Proxy pattern to enhance security. The proxy stores metadata and references to the server, while the actual data is stored on an external server. Also, Paduraru et al. (2022) mentioned that manipulating data in game transactions can result in data breaches throughout the distributed system. It is crucial to ensure that parties reach a mutual agreement on the transaction price and accurately update the balance account.

Ownership of assets

Smart contracts can be implemented for various gaming functionalities, such as processing transactions, handling advertisements, and managing in-game assets (Qiao, 2019; Pittaras et al., 2021; Carvalho, 2021). By leveraging smart contracts, players gain true ownership of in-game assets represented as non-fungible tokens (NFTs) (Popescu, 2021). This ownership is secure and verifiable on the blockchain, enabling a new economy where players can buy, sell, or trade assets without the fear of fraud or repudiation (Raman & Raj, 2021, Putri et al, 2023), therefore, blockchain assets can significantly enhance player retention and engagement (Paajala et al., 2022). For instance, CryptoKitties are popular NFTs governed by a smart contract on the Ethereum blockchain, ensuring its uniqueness and ownership (Evans, 2019; Nadini et al., 2021; Rajendran & Pandey, 2022).

Transfer and use of in-game assets across various ecosystems can be facilitated by smart contracts, known as interoperability between different gaming platforms (Pittaras et al., 2021). This interconnectedness enhances the gaming experience and opens new possibilities for game developers and players (Chen et al., 2023). According to Jiang & Liu, (2021) there are five smart contracts in the game CryptoKitties, that allows players to collect, breed, and trade unique digital cats: SiringAuction contract, the Core contract, Offers contract, SalesAuction contract, and GeneScience contract.

Another prominent example is Gods Unchained a trading card game that leverages smart contracts to ensure the fairness and transparency of card ownership and gameplay (Scholten et al. 2019; Koçer & Tampio, 2022). Players can buy, sell, and trade cards in a decentralized marketplace, with each transaction recorded on the Ethereum blockchain (Jiang & Liu, 2021; Sarathy, 2022; Nguyen et al., 2022).

In educational games, smart contracts can oversee the allocation of prizes, enforce regulations, and guarantee that all participants receive appropriate acknowledgment and remuneration (Ramezani et al., 2024). In addition, in educational games smart contracts can be used to manage credentials and achievements in a secure and tamper-proof manner (Jaferian et al. 2024).

New in-game economic models

Blockchain technology promotes reward-based video game interaction (Predescu et al., 2021) allowing players to earn tokens for playing, reviewing, or sharing games on social media (Trojanowska et al., 2020). According to Pillai et al. (2019) there are three crypto asset categories that players can earn: asset-tokens, crypto-coins, and utility-tokens. Their methodology classifies assets based on their fungibility and tangible nature.

The surge in the popularity of blockchain-based games provided a glimpse into the potential of virtual economies within the framework of Web3, or the third iteration of the internet (Liu et al., 2021; Bambacht & Pouwelse, 2022; Murray et al., 2023). Smart contract-powered decentralized gaming ecosystems facilitate the development of innovative economic frameworks (Xu et al., 2023) which provide players with financial motivations, therefore further blurring the distinction between gaming and earning a living (Sharma et al., 2023) This occurs through the utilization of games that effectively include Web 3.0, web development, and smart contracts to improve the user's experience (Akkaya et al., 2023).

In traditional video games, the prevailing paradigm typically requires players to make payments to obtain benefits such as upgrades, shorter waiting periods, or the acquisition of virtual items (Keogh & Richardson, 2018; Ivanov et al., 2021). GameFi, on the other hand, presents a novel approach to earning money through gaming (Proelss et al., 2023) wherein gamers may create cash by leveraging their skills and the amount of time they dedicate to playing (Cheng, 2024). These games aim to provide players with tangible economic rewards in the real world (Alam, 2022). In addition to earning tokens through gaming, users may obtain in-game rewards such as assets and more by participating in staking, which is a widely used financial activity (Qiao, 2019; Jiang et al., 2022).

Smart contracts can facilitate innovative gaming models such as play-to-earn, (Delfabbro et al., 2022; Zaucha, 2022; Tan, 2024) where players are rewarded with tokens that have real-world value, further driving engagement and monetization opportunities in the gaming ecosystem (Zarifis & Cheng, 2022; Rafaj et al., 2023; Duguleană et al., 2024). NFTs have made it possible for in-game items to only exist in the user's digital wallet and exchanging in-game coins for stable coins or fiat currencies (Lee & Park, 2023). NFTs such as weapons, skins, and monsters may be bought and sold on platforms like OpenSea. Game creators generate a cryptocurrency or play-to-earn token that has value and can be traded by players within the game (Vidal-Tomás, 2022). Many P2E games such as "Big Time" and "Meta Theft Auto," use smart contracts to manage in-game economies, reward systems, and virtual professions (Sahin, 2023). Blockchain-based asset trading within games removes the need for secondary marketplaces because smart contracts secure transactions, thereby minimizing the potential for fraudulent activities (Jaferian et al., 2024)

Duguleană et al. (2024) explains that P2E has gained significant popularity among customers due to other compelling factors in addition to the economic incentives. P2E gamers derive satisfaction from possessing full control and authority over their virtual possessions within the game.

Decentralized autonomous organizations (DAOs) for game governance

The DAO operated as an Ethereum smart contract and was established on 30 April 2016 (Minks, 2017; De Graaf, 2019; Faqir-Rhazoui et al., 2021). DAOs are entities that operate and are controlled by smart contracts, with their business and administrative regulations being stored on blockchains (Santos & Kostakis, 2018; Zichichi et al., 2019; Wang et al., 2019). DAO members can provide choices for decision-making within the organization (Tikhomirov et al., 2018; Jha, 2023). Additionally, they can engage in open discussions and vote on these options using transparent processes. Also, individual behaviors of members cannot be directly ascertained inside the contracts (Zichichi et al. 2019; Zhang & Anand, 2022).

A fundamental goal of web3 games is to establish a DAO where players collectively oversee the development of the game (Direr et al., 2022; Murray, 2023). In their 2020 paper Yao et al., explains that these gaming DAOs are renowned for their expertise and the impactful contributions they make in fostering community growth and advancing program development. As an illustration, a particular DAO successfully executed a task that surpassed the expectations of the game creators, while remaining within the established regulations.

The introduction of the P2E paradigm resulted in the emergence of numerous cryptocurrency gaming guilds (Jirásek, 2022; Kshetri, 2023). A blockchain gaming guild can be defined as an association of gamers who come together to play, advance in, share resources, and make money from blockchain-based games (Bult, 2022; Aguila et al., 2022). These groups, known as DAOs, are constructed in a way that allows them to collaborate in acquiring, managing, using, and monetizing assets from blockchain games (Proelss et al, 2023). These are organizations that collect in-game assets and lend them to players to generate cash through gameplay (Jirásek, 2022).

Furthermore, the development of decentralized autonomous organizations enables collaborative governance, enhancing the democratic management of various applications (Craß et al., 2022). Jaferian et al. (2024) examines the use of DAOs in gaming, where governance tokens allow players to participate in decision-making processes. Smart contracts facilitate the functioning of DAOs by automating governance and financial transaction enhancing community involvement.

Challenges

Security Issues

As mentioned in the paper, one of the main challenges of smart contracts includes security vulnerabilities (Ante, 2021). Numerous studies have provided analysis on issues related to the security, reliability, and performance of smart contracts (Zou et al., 2019). Smart contracts, due to the substantial value of assets they hold and transfer, are attractive targets for attackers (Tann, 2018). The prevalence of security flaws and assaults on Ethereum smart contracts has hindered their wider adoption (Ivanov et al, 2023; Gherghelas, 2024). According to Franciscu et al. (2023), Common vulnerabilities include reentrancy attacks, race conditions, integer overflows, and logical errors, which pose substantial risks to the security and functionality of smart contracts.

Also, Sayeed et al. (2020) explores various attack vectors that can compromise smart contracts. The author stated that although blockchain has implemented several security advancements and technologies, it still has difficulties in dealing with a wide range of malicious assaults.

As reported by DAppRadar.com, hackers abused smart contracts and deceive investors, resulting in a loss of $13.6 million in crypto assets. This is the smallest monthly loss in value since 2021.

The development of Ethereum decentralized applications, including Crypto Collectibles games, involves addressing various security issues (Bhujel, 2022). Implementing security verification standards and following best practices can mitigate vulnerabilities that arise during the application design process ensures the secure execution of decentralized gaming applications (Trojanowska et al., 2020). Formal verification techniques, such as alternating-time temporal logic (ATL) model checking, are employed to identify and mitigate flaws in smart contracts, ensuring their reliability and correctness (Nam & Kil, 2022). Also, Franciscu et al. (2023) introduces the "GRIFFIN" Smart Contracts Vulnerability Detector, using state-of-the-art static analysis techniques and machine learning algorithms. This tool has been tested on a diverse dataset of 12,000 real-world Solidity smart contracts, demonstrating superior accuracy rates compared to existing solutions.

Hall-Andersen & Schwartzbach (2021) introduce a model for blockchain games where players use smart contracts, changing traditional ideas about player behavior. Their model shows that smart contracts can enforce credible threats, making the game more complex by allowing multiple contract interactions.

Studies have discussed existing protective measures to mitigate such risks (Sayeed et al., 2020). Role-based access control mechanisms could enhance security by managing user roles and permissions within smart contracts (Yang et al., 2020; Liu et al., 2022). A novel framework is introduced by Motaqy et al. (2021) for orchestrating collaborative cyber-attacks, specifically focusing on Distributed Denial of Service (DDoS) attacks. The framework employs a betting mechanism to ensure trustless collaboration among (pseudo)anonymous attackers, motivating them to contribute proportionally to their bets.

Technical Challenges

Apart from security issues, there is a need for scalable solutions to accommodate growing player bases (Ante, 2021). To solve this problem, Rafaj et al. (2023) propose and evaluate a DeFi gaming platform that leverages layer 2 solutions to address common challenges such as high transaction fees and scalability. They propose using state channels, a layer 2 solution, to reduce on-chain transaction fees. By moving interactions off-chain, the platform can handle a higher volume of transactions more efficiently and at a lower cost.

Identifying and rectifying bugs is another obstacle encountered by smart contract developers (Wang, 2019). In fact, contracts are opaque in the sense that it is challenging to determine the value of a specific contract attribute once it has been deployed in the blockchain (Bragagnolo et al., 2018). Improvements in off-chain execution of smart contracts can also address performance and cost issues associated with on-chain execution, making complex gaming applications more feasible (Solaiman, 2021; Frassetto et al., 2022). Also, Liu et al., 2020 explains that Smart contract vulnerabilities can lead to significant financial losses, as they are often tied to the management and distribution of digital assets. Researchers have developed frameworks like FairCon to verify the fairness properties of smart contracts.

Fairness and integrity, legal issues

A key fairness issue in decentralized gaming is ensuring the generation and verification of randomness, which is critical for game mechanics like loot drops (Yin, 2024). Blockchain-based gaming addresses this by using decentralized random beacons or verifiable random functions (VRFs) that can be audited by participants (Chen et al., 2023). Chen & Xu et al. (2017) explore the use of game theory to analyze and prevent strategic manipulations by users in decentralized gaming ecosystems. They suggest that introducing financial penalties and incentives can discourage dishonest behavior, thereby ensuring that smart contracts are executed fairly.

Despite such advancements, fairness issues persist due to the potential for smart contracts to be exploited through collusion or the deployment of side contracts (Liu, Ye, et al., 2020). Such vulnerabilities can disrupt the intended fairness by allowing players or miners to manipulate outcomes or transactions for their benefit (Landis & Schwartzbach, 2023).

Moreover, the challenge of maintaining integrity is compounded by the complexity of decentralized platforms, where multiple independent players interact without central authority. This interaction often leads to a need for game theory-based validations to ensure that contracts remain fair and resistant to manipulation (Bigi et al., 2015).

Apart from these, studies shown potential legal implications and challenges associated with smart contracts, including enforceability, jurisdiction, and liability which might lead to an unfair gameplay (Giancaspro, 2017). These problems exist along with the difficulty of aligning smart contracts with existing legal frameworks, the limitations of smart contracts in handling complex contractual agreements, and the technical limitations related to security and interoperability (Drummer & Neumann, 2020). Standardizing smart contracts and developing frameworks for their proper management can enhance reliability, and addressing misconceptions related to their legal aspects (Capocasale & Perboli, 2022).

Conclusion and future work

Smart contracts are pivotal in shaping the future of decentralized gaming ecosystems, offering unprecedented transparency, security, and efficiency. They empower players with genuine ownership of in-game assets and pave the way for innovative economic models that could redefine the gaming industry.

These contracts, however, are not without challenges. Security vulnerabilities, like side contract commitment attacks, highlight the need for robust security measures to prevent exploitation (Landis & Schwartzbach, 2023, Sayeed et al., 2020). Franciscu et al. (2023) emphasizes the need for user-friendly tools that provide developers with actionable insights, code snippets, and real-time feedback to enhance the robustness of smart contract ecosystems.

Despite the challenges, the potential of smart contracts in decentralized gaming ecosystems remains vast, promising a new era of gaming that is more open, interconnected, and rewarding for players around the globe.

About the Authors

GOLSHID JAFERIAN is a Ph.D. student in Digital Media at the Antoinette Westphal College of Media Arts & Design at Drexel University. Her work focuses on computer games, educational games, and Blockchain and Metaverse technology. https://orcid.org/0009-0008-8706-3018

DARYA RAMEZANI is a PhD student at the Antoinette Westphal College of Media Arts & Design at Drexel University. She has been working on serious games, Blockchain and Metaverse, AI and immersive media. https://orcid.org/0009-0008-1686-5865

MICHAEL G. WAGNER (Ph.D.) is a professor and Department Head of Digital Media at the Antoinette Westphal College of Media Arts & Design at Drexel University. His work focuses on the theory and practice of the educational use of digital media, immersive audio, computer games, and Blockchain technology. https://orcid.org/0009-0004-8464-8126

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