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Metaverse, ubi es? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse

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Abstract

Fueled by recent technological developments and reinvigorated through the hype around the Metaverse concept, virtual worlds are becoming increasingly popular as platforms for social interaction, entertainment, and commerce. This study applies transaction cost theory to explore smart contracts' potential in virtual worlds, specifically Decentraland, Sandbox, and Roblox. By assessing process costs, we gauge the feasibility and usability of these decentralized worlds in line with the Metaverse vision. Our findings indicate that the concept and implementation of smart contracts are still nascent and require enhancements from technical, organizational, and user standpoints. Our study contributes to a better understanding of smart contracts' current value in virtual worlds and points to future research directions for optimizing their use.

Keywords: Metaverse, Smart Contracts, Virtual World, Transaction Costs.

1. Introduction

The development of virtual reality (VR) and augmented reality (AR) technologies, alongside the emergence of blockchain and smart contracts, has contributed to an increased interest in virtual worlds for living, learning, and working (Dincelli & Yayla, 2022; Oppenlaender, 2022; Richter & Richter, 2023; Vatiero, 2022). The concept of the Metaverse enables users to engage within three-dimensional virtual worlds through virtual characters (Dolata & Schwabe, 2023; Dwivedi et al., 2022; Park et al., 2023). Within the latter domain, smart contracts, which are self-executing contracts with the terms of the agreement directly written into code, have emerged as a promising tool for secure, transparent, and automated transactions in virtual worlds (Oppenlaender, 2022; Zheng et al., 2020).

However, the adoption of smart contracts varies widely across different virtual worlds, and the factors that drive this variation need to be better understood (Albizri & Appelbaum, 2021; Malik et al., 2022).

To address this knowledge gap, we employ a theoretical framework that can help analyze the use of smart contracts in virtual worlds. Transaction cost theory, which deals with the cost of exchanging resources, goods, or services, is a suitable framework for this purpose (Shahab, 2022; Vatiero, 2022). It can provide systematic insights into the factors that influence the adoption of smart contracts, such as search costs, bargaining costs, and enforcement costs. By applying transaction cost theory to the study of smart contracts in virtual worlds, researchers can better understand the factors driving their adoption, as well as the challenges and opportunities associated with their implementation. This understanding is critical for the development of more efficient, secure, and transparent virtual environments that leverage the full potential of smart contracts and blockchain technologies.

Hence, our research question is how smart contracts can be designed in metaverse from a transaction cost perspective.

We base our analysis of adoption of smart contracts on three of the most prominent virtual worlds. Two of them are blockchain-based virtual worlds (Decentraland and Sandbox) and one platform is not using blockchain (Roblox). Instead, of blockchain, Roblox relies on a centralized server infrastructure to manage its vast array of user-generated content and in-game transactions.

We selected these virtual worlds for their diverse use of blockchain technology and smart contracts within their virtual economy. In addition, we also analyze Roblox to better understand the boundaries and benefits of blockchain-based platforms, i.e., to compare the results with a platform that is not using blockchain.

Blockchain technology can significantly reduce transaction costs through decentralization, eliminating

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intermediaries and automating agreements through smart contracts. We look at the use of smart contracts in virtual worlds from a systematic transaction cost theory perspective to understand these efficiencies compared to traditional transaction methods.

We compare and contrast the adoption of smart contracts across these virtual worlds, identifying similarities and differences in their respective approaches. While the metaverse is a hot topic, our study reveals that smart contracts still have a long way to go. Though implemented, they haven't fully proven their concept, especially in the metaverse context. From a transaction cost theory standpoint, smart contracts have significant drawbacks that need to be addressed before they become relevant in virtual worlds.

The contribution of this study is significant for its detailed investigation of smart contract adoption factors in virtual worlds, such as Decentraland and Sandbox. By providing insights for developers, policymakers, and researchers, our research enhances understanding of challenges and opportunities in integrating blockchain technology into virtual environments. Additionally, by comparing smart contract adoption in Decentraland and Sandbox, the study contributes to academic discussions on blockchain technology's role in shaping virtual economies. Moreover, this study offers a nuanced examination of smart contract adoption factors in virtual worlds and enriches the ongoing dialogue on the impact of blockchain technology on virtual economies.

The rest of the paper is organized as follows: We start with outlining related work with regard to metaverses and blockchain technology followed by smart contracts. We then describe our method for analysis from a theoretical perspective, namely transaction cost theory. The results of our analysis are presented and discussed. We conclude the paper with theoretical and practical implications as well as outlining future research.

2. Related Work

2.1 The Metaverse

The concept of the Metaverse, a virtual realm that coexists with the physical world, has gained significant attention from organizations and academics (Dwivedi et al., 2022). The Metaverse represents a next-level virtual experience, providing users with a fully immersive environment that blends physical and virtual spaces (Richter & Richter, 2023). Cutting-edge technologies offer seamless, believable, multi-sensory experiences. Game engines like Unity and Unreal Engine facilitate the creation of sophisticated virtual environments, while Web 3.0 principles, such as decentralization and interoperability, ensure a more open and accessible metaverse. The integration of VR, AR, AI, and haptic feedback generates immersive experiences that blur the line between physical and virtual worlds, delivering unprecedented engagement and interaction opportunities for users. As fantastic as this all sounds, it is important to remember that at the time of writing this article, this concept of the Metaverse, remains just that, a concept. Significant challenges remain between the current and the utopian vision of what the Metaverse could be. One of these challenges is the level of interoperability between different virtual platforms.

2.2. Blockchain in the Metaverse

The Metaverse uses technologies to create a digital representation of the real world, while blockchain technologies are used to build an economic system. It enables close integration of the virtual and real worlds in areas such as business, social and identity, and allows users to create and edit content (Ning et al., 2023).

Due to its characteristics, blockchain can serve as the basis of the infrastructure for the metaverse on which the virtual world is built and through which user content can be generated and traded virtually (Duan et al., 2021). Previous research already discusses the potential correlation between virtual worlds and blockchain technology through the multi-layered architecture of data, network, consensus, incentive, contract and application layers (Yang et al., 2022).

Some common characteristics of the different blockchain types are Indestructibility, immutability, security and transparency of data (Vo et al., 2021). The differences are mainly the way how transactions are stored and validated, which translates into different scalability, flexibility, transaction speed, energy consumption and transaction costs (Chowdhury et al., 2019).

The role of blockchain technology in metaverses would be ensuring data privacy, security and quality, enabling seamless and secure data exchange, enabling data interoperability, ensuring data integrity, building a financial system as well as enabling the use of smart contracts and NFTs (Gadekallu et al., 2022). There is also an impact of the technology on other key enabling technologies in metaverses: Blockchain technology will enable IoT devices to securely exchange and store real data across multiple virtual worlds. Incorporating blockchain technology into digital twins allows metaverse actors to address concerns about the trust, integrity and security of data. The combination of AI and blockchain will secure the highly sensitive data that AI-driven systems need to collect, store and use. The blockchain holds great potential for the future of Big Data analytics. Users will be able to maintain complete control over their personal data and financial activities in the metaverse (Gadekallu et al., 2022).

2.3. Smart Contracts in Metaverses

Smart contracts are digital contracts that can be written by an "if-this-then-that" code in the blockchain structure. They refer to conditions that have previously been jointly set by the actors of a network and are automatically executed as soon as these contract conditions are fulfilled. Once established, no further management of contracts is required if the conditions are not changing. Smart contracts can thus automate processes and eliminate the need for intermediaries; once defined, direct contract discussions are no longer necessary (Vo et al., 2021).

One potential use case for smart contracts in metaverses is for fundraising and project management. A proposed ecosystem that integrates smart contracts would enable stakeholders to participate in and monitor the progress of a project. Once a shareholder participates in a project through a smart contract, they can keep track of its progress through a digital twin in their respective metaverse. To gain access to this metaverse, participants need to have prepared the necessary token, and they can do so through technologies like augmented reality, virtual reality, or 3D graphics spaces, such as computer games. Progress updates for the project would be collected from IoT-based devices, BIM, and artificial intelligence networks, all of which would be integrated through a software interface and ultimately modelled (Moradi et al., 2022).

There are different concepts on how Smart Contracts can be integrated into metaverses. By using smart contracts, MetaChain (a novel blockchain-based framework for Metaverse applications) can effectively manage and automate complex interactions between the Metaverse Service Provider (MSP) and Metaverse Users (MUs). In particular, thanks to smart contract mechanisms, the blockchain can manage and automate complex interactions between different entities in the metaverse, e.g., between metaverse service providers (MSPs), users and digital content creators (Nguyen et al., 2022). MetaManagement rules are automatically enforced by smart contracts in MetaSocieties (virtual companies and cities that operate parallel to real companies and cities). Depending on the operational results, the MetaManagement rules are continuously adjusted to achieve the expected MetaManagement effect (Wang et al., 2022).

In practice, there are currently only a few actual use cases. Decentraland is a blockchain-based virtual world where users can buy, own, and develop parcels of digital land represented as Non-Fungible Tokens (NFTs) on the Ethereum blockchain. Smart contracts enable decentralized governance of the platform, allowing users to make collective decisions about its development and management. Smart contracts play a pivotal role in enforcing community voting decisions, ensuring that governance processes within the virtual world are transparent, tamper-proof, and decentralized (Oppenlaender, 2022). These contracts provide a trustless mechanism for users to collectively shape the development and management of the Metaverse. Also, in Decentraland, the utilization of smart contracts extends to recording ownership of valuable assets like virtual land parcels and NFTs, creating an immutable and auditable ledger of ownership rights (Dowling, 2022). This application enhances the security and provenance of digital assets, critical in a virtual world where ownership and scarcity are essential.

The CUHKSZ Metaverse showcases an even broader implementation of smart contracts, leveraging this technology to support its ecosystem's core components, including tokens, decentralized autonomous organizations (DAOs), and the trading system (Duan et al., 2021). Smart contracts here facilitate not only asset management but also enable the automation of complex interactions, fostering a self-sustaining virtual environment. It can be seen that smart contracts are primarily used for management and background activities in metaverses so far.

2.4. Transaction Cost Theory

In this study, we apply the Transaction Cost Theory (TCT) as a lens to examine transaction costs in virtual worlds: TCT, as conceptualized by North and North (1992) and (Williamson, 1981), is employed to understand the nature and implications of transactions within these platforms, where transactions are inextricably bound by smart contracts.

Since smart contracts focus on automating transactions, TCT is the best fitting theory that not only provides the necessary theoretical background but also the relevant conceptual framework for our analysis. Our selection, Decentraland and Sandbox, are representative platforms within the realm of Ethereum-based virtual environments. Both platforms facilitate a multitude of interactions that can be understood and analyzed under the premises of TCT. Roblox serves as a comparable virtual environment without employing smart contracts.

The key concept of transaction cost theory aims to increase economic efficiency in the process of exchanging products or services through the market. In addition to the production costs of goods, transaction costs play a decisive role in the search for an efficient economic unit and its decision boundaries (Williamson, 1983). Transaction costs can be divided into (1) information and selection phase with search and initiation aspects, (2) negotiation phase (with contract and communication aspects), (3) the decision making phase with process aspects and (4) the post-contractual phase with monitoring and enforcement costs (Dahlman, 1979).

3. Research Method

We first develop a conceptual framework that links TCT to Metaverse transactions.

We identify the equivalent of the phases for
(1) information and selection,
(2) negotiation,
(3) decision making and
(4) post-contractual and then analyze how they are implemented.

Our methodological approach, which is conceptual in nature, is well-suited for examining the complex transactional dynamics within the virtual worlds. As Gioia, Corley, and Hamilton (2013) suggested, a conceptual analysis allows for a qualitative rigor in inductive research, and it is especially fitting when studying complex systems, such as blockchain-based virtual worlds. Building upon Jabareen's (2009) approach to constructing a conceptual framework, we systematically explore the principles, definitions, and processes that govern these platforms' transactional structures and mechanisms. By engaging with the data and structures like the expanded sourcebook by Miles and Huberman (1994), we can holistically comprehend these virtual environments and delve deeper into the underlying structure and functional rationale.

Table 1 provides an overview on the main characteristics of the three platforms.

Table 1. Comparison of the analyzed virtual worlds.

Aspects	Decentraland	Sandbox	Roblox
Daily active users	Under 1,000	Around 8,000	Around 66.1 million
Launched	2015	2012	2006
Focus	Development of a decentralized and economic platform	Building and sharing content	Create and publish games
Type	Ethereum based decentralized platform	Ethereum based decentralized platform	Centralized online platform, not blockchain based

We delineate the transactional procedures, understand the operational logic of smart contracts, and tease out how these interact with the principles of transaction cost theory. In analyzing the transaction data, we focus on the transaction cost indicators: search and information costs, contracting and communication costs, process costs as well as enforcement and monitoring costs (Dahlman, 1979). These cost variables offer a comprehensive framework to navigate the myriad transactions unfolding in Decentraland, Sandbox and Roblox.

Drawing on these principles, our research involved two primary data collection methods: We created user accounts within each of the virtual worlds and actively engaged in different transactions and interactions within these digital environments. This approach allowed us to immerse ourselves in the platforms, gaining firsthand experience of the transactional processes and challenges users face. Furthermore, we gathered official information provided by the organizations that operate and manage these virtual worlds. This included studying documentation, policies, and materials shared by the organizations to gain insights into their intended operational structures and transactional procedures.

With the transparent nature of blockchain technology, we could access and scrutinize transaction logs and the terms of smart contracts, which were the primary materials for our research. Quantitative analysis of transaction data, including recording, categorizing, and analyzing transaction types and costs, was complemented by qualitative document analysis of smart contracts' terms.

Our focus lies in understanding the 'rules of the game', and how they influence transaction costs in these platforms. The transaction logs and the terms of the smart contracts, both publicly available due to the transparent nature of blockchain technology are the primary documents scrutinized in our research. Our method thus intertwines TCT's analytical potential and the transactional architecture of Ethereum-based virtual worlds, providing a novel perspective on transaction efficiency in these nascent digital spaces. Our conceptual approach allows for a comprehensive understanding of these spaces, and of their structural and operational logic.

4. Results

Transaction cost theory aims to improve economic efficiency in the exchange of products or services through the market. Using the phases of TCT, we assess the three virtual worlds based on own transactions in as well as information provided by the organizations about fees incurred.

The overall results are depicted in Table 2 and described in detail in the following.

In the information and selection phase, Decentraland and Sandbox users navigate the complexities of their respective blockchain-based marketplaces, which includes tasks such as searching for listings and comparing listings. In contrast, Roblox, as a non-blockchain platform, simplifies this phase as users do not need to interact with blockchain-based marketplaces.

Table 2. Comparison of transaction costs in virtual worlds.

Phase	Aspects	Decentraland	Sandbox	Roblox
Information and selection	Search	Offer comparison on the marketplace		
	Initiation	Platform account, crypto wallet and currency exchange necessary		Platform account and currency exchange necessary
Negotiation	Contract	Smart Contract creation (ERC-721 standard: Only fungible tokens)	Smart Contract creation (ERC-1155 standard: fungible and non-fungible tokens)	(Traditional) Contract creation
	Communication	Through the marketplace platform		Through the marketplace platform
Decision Making	Process	Transaction time (30 sec. up to 30 minutes), Ethereum Platform Fee, Listing Fee (100MANA), Marketplace fee (2.5%)	Transaction time (30 sec. up to 30 minutes), Ethereum Platform Fee, Listing Fee (0,05ETH), Marketplace fee (5%)	Marketplace fee (30%)
Post-contractual	Enforcement	Regulation trough Decentralized Autonomous Organization (DAO)	Centralized regulation	Regulation trough company management/ employees
	Monitoring	Control trough DAO	Central control	Support Services

Decentraland and Sandbox introduce additional complexity in the initiation phase as users need to set up accounts on the platform and engage in cryptocurrency activities, including owning crypto wallets and potentially participating in currency exchanges. In contrast, Roblox works with a centralized currency system that simplifies the adoption process.

In the negotiation phase, Decentraland and Sandbox use smart contracts for transactions, but with different standards and token types. In Roblox, transactions are governed by traditional contracts. Communication during trading takes place in all three virtual worlds via the respective marketplace platforms.

The decision phase is characterized by transaction times, Ethereum platform fees, listing fees and marketplace fees. Decentraland and Sandbox have similarities in transaction times and listing fees and differ mainly in their marketplace fees. Roblox, on the other hand, charges a much higher marketplace fee, which affects the overall cost structure.

Decentraland is characterized by its use of decentralized autonomous organizations (DAOs) for regulation and control, embodying a decentralized approach to corporate governance. Roblox, on the other hand, relies on centralized regulation and control by management and employees. Sandbox represents an intermediate approach that has a mix of decentralized and centralized elements in its governance.

The results show, on the example of smart contracts, that the concept of the blockchain based virtual worlds is still in early stages. The current implementation of smart contracts on the platforms studied is far from being a proof-of-concept.

5. Discussion

We used transaction cost theory to systematically illustrate how smart contracts are implemented and to provide a good understanding of the processes behind them. Our research on transaction cost theory provides some new insights in the context of blockchain-based metaverses. Overall, blockchain technology presents both opportunities and challenges in the context of transaction cost theory.

Currently, the transaction costs are high which sets up the bar for non tech savvy users. Especially in the initiation phase, a high level of technical affinity is required in order to create the necessary crypto wallets.

One of the findings concerns the negotiation phase in the iterative implementation of smart contracts. The difficulty of creating smart contracts is directly related to the risk posed by errors in the code. Since the contract code is immutable, the cost of reviewing and testing the code is significantly higher and may even preclude the feasibility of complex smart contracts (due to the exponential probability of errors relative to the code size) (Szczerbowski, 2018). It becomes clear that the costs and risks of creating smart contracts in virtual worlds are higher compared to traditional contracts.

Due to the technical requirements of the blockchain architecture, many transaction costs also arise in the decision phase, which cannot be reduced even if the processes are automated. The decision phase also includes process aspects, such as the maintenance of smart contracts, which are decided by a majority vote of the participating nodes. Depending on the architecture, there are different consensus mechanisms that require different amounts of time and cost. Especially in the case of recurring processes, this could lead to a rejection of the use of smart contracts, as quantity effects cannot be used here. This is a huge disadvantage compared to non-blockchain-based virtual worlds. In addition to blockchain technology, there are other distributed technologies that can reduce or eliminate transaction costs at this point. However, there are no implementations of these yet.

Post-contractual enforcement and monitoring include that the resulting transactions and the new state information are stored in the blockchain and confirmed according to the consensus protocol. Enforcement costs are reduced by the use of smart contracts, as there is almost complete information about the "history" of contract performance (Zheng et al., 2020). However, there are also additional monitoring costs for auditing the smart contract code (Zheng et al., 2020). Furthermore, a smart contract has the disadvantage that it cannot be legally adjusted afterwards. The consensus mechanism is a central problem of transaction cost economics in traditional blockchains. It limits the legally secured application and can thus lead to high ex-post transaction costs (Vatiero, 2022).

6. Research Agenda

Our research agenda is derived from the insights gained so far. It revolves around assessing and refining the integration and usability of smart contracts in virtual worlds on blockchain platforms, identifying areas for improvement, and establishing possible solutions, both technical and otherwise. The application of smart contracts promises to reduce administrative and service costs while enhancing efficiency, security, and transparency. However, the high transaction costs and barriers currently involved pose a significant deterrent. Notably, users require a crypto wallet, must often handle high transaction fees, and need to transfer cryptocurrencies into the virtual platform. The fluctuating exchange rates of cryptocurrencies further amplify the uncertainty surrounding transaction costs. Another layer of complexity is added due to the potential for programming errors and security issues in Ethereum-based virtual worlds utilizing smart contracts.

6.1. Technical perspective

Key research questions that future studies should aim to address from a technical perspective include:

- How can the costs associated with executing smart contracts in blockchain-based virtual worlds be effectively reduced and mitigated to promote wider accessibility and adoption?
- How can different use cases in virtual worlds influence the design and instantiation of smart contracts?
- How can smart contracts be designed to connect the virtual and real world seamlessly, and what would be the implications of such integration?

In order to address these research questions, we elaborate and extend these as follows. Our study found that the use of smart contracts in blockchain-based virtual worlds incurs high fees compared to non-blockchain alternatives. This highlights an important technical consideration, as these fees can limit the accessibility and adoption of smart contracts within virtual worlds. Researchers should discuss potential ways to mitigate these costs, such as exploring scalability solutions (e.g., layer 2 protocols) or alternative blockchain architectures that offer lower fees.

By leveraging layer 2 protocols, virtual worlds can accommodate a larger user base and support a higher volume of transactions without sacrificing efficiency. To enhance scalability and throughput of smart contracts in virtual worlds, researchers should investigate and compare different layer 2 scaling solutions, such as state channels and sidechains, and develop practical strategies for integrating them into virtual world platforms.

Gas optimization techniques can be employed to minimize the costs associated with executing smart contracts in virtual worlds. This involves optimizing the code and reducing unnecessary computations to decrease the amount of gas consumed per transaction. Research should focus on identifying best practices for gas optimization in smart contract development, developing automated tools for optimization suggestions, measuring gas savings and their impact on transaction fees, and striking a balance between optimization and code readability, maintainability, and security.

Exploring alternative consensus algorithms that offer better efficiency and scalability can be beneficial for virtual worlds. Traditional Proof-of-Work mechanisms can be resource intensive and limit scalability. Moving to more efficient consensus mechanisms such as Proof-of-Stake or delegated Proof-of-Stake can reduce computational requirements and improve the scalability of virtual world platforms. Researchers should evaluate the suitability of different consensus algorithms, design mechanisms tailored for virtual worlds, measure their performance and resource requirements, and consider their impact on governance and decision-making processes within virtual worlds.

The discussion should touch upon the interoperability challenges faced by virtual worlds utilizing smart contracts. Researchers should explore the importance of industry-wide standards, protocols, and interoperability frameworks to enable seamless interaction and asset transfer between different virtual worlds and ecosystems. The potential benefits of cross-chain communication protocols or standardized smart contract templates can be discussed in this context.

6.2. Organizational perspective

Key research questions that future studies should aim to address from an organizational perspective include:

- What are the essential considerations for companies to effectively offer their products and services through smart contracts in virtual worlds?
- What are the organizational strategies and practices that enable continuous improvement within virtual worlds, ensuring the evolution of the virtual world according to user needs and market dynamics?

Future research should identify requirements for designing smart contracts, considering different virtual products and services. Furthermore, as more companies venture into the virtual space, it is crucial to understand the requirements for offering products and services via smart contracts. An in-depth analysis of how automated contracts are designed, possibly linking the virtual and real worlds, is necessary.

Emphasizing continuous improvement and feedback loops within the organization ensures that the virtual world evolves according to user needs and market dynamics. Regularly soliciting feedback from users, developers and stakeholders enables iterative improvement of virtual world, user experience and smart contract features. This iterative approach would allow companies to adapt to changing requirements, overcome new challenges and create an optimized experience for users and should therefore be explored and implemented for use in virtual worlds.

This endeavor necessitates the examination of specific use cases for these virtual worlds, ranging from attending concerts or lectures to gaming. Each use case may necessitate a unique instantiation of smart contracts, a topic that warrants a detailed investigation.

Optimizing the use of smart contracts in blockchain-based virtual worlds from an organizational perspective involves implementing effective strategies and practices that enhance collaboration, governance, and ecosystem development. Building strategic partnerships and collaborations with other projects, platforms, or blockchain networks can enhance the capabilities and reach of the virtual world. Specifically, synergistic benefits should be explored, such as the shared user base and cross-platform functionality that can be achieved through partnerships. The role of partnerships in accelerating ecosystem growth and the diffusion of smart contracts in virtual worlds should also be explored.

Regulatory and legal considerations are vital for the responsible and compliant use of smart contracts in virtual worlds. Researchers should highlight the need for clear regulatory frameworks that address data privacy, intellectual property rights, and jurisdictional challenges. Collaborative efforts involving policymakers, legal experts, and blockchain industry stakeholders can help establish guidelines and regulations that foster innovation while safeguarding the rights and interests of users.

6.3. User perspective

Key research questions that future studies should aim to address from a user perspective include:

- What is the role and acceptance of intermediaries, like banks or financial service providers, in managing virtual accounts and facilitating transactions in the virtual world?
- What are the unique requirements for setting up smart contracts based on the type of user (occasional, permanent, purpose-specific)?

As the popularity of these virtual worlds expands beyond the technologically adept users, it becomes essential to understand diverse user groups' requirements and expectations. Similar to the evolution of real-world payment options, such as Apple Pay and Google Pay, transaction processes need to be simplified, keeping in mind the technical necessities of smart services. Our research findings pertaining to distinct transaction phases can provide a foundation for designing targeted questionnaires to understand varied user groups’ requirements for smart contracts.

Moreover, intermediaries, such as banks or other financial service providers, could play a significant role in facilitating the interaction between users and smart contracts. Research exploring the viability and acceptance of these mediators managing virtual accounts for individuals or groups could provide valuable insights into improving user interaction in virtual worlds.

It is important to recognize that an intuitive and user-friendly interface is crucial for wider adoption.

Researchers should discuss the importance of designing user interfaces that facilitate interaction with smart contracts and consider the potential for collaboration between UX designers and blockchain developers to create seamless experiences.

The study identified the complexity involved in creating smart contracts for virtual worlds. This complexity stems from the need for a high level of technical understanding and expertise. Researchers should discuss the implications of this finding, such as the potential barriers it presents to users or developers who may lack the necessary skills or resources to create or interact with smart contracts effectively. Possible solutions, such as user-friendly development frameworks or improved developer tooling, can also be discussed.

For the use of blockchain-based virtual worlds, an elaborate procedure is necessary to gain access to the world and to be able to carry out transactions. In addition to the account for the virtual world, a crypto wallet must be created and currencies exchanged. Future research should focus on developing user-friendly solutions that reduce technical barriers. One possibility is to explore new wallet solutions that simplify the process of creating and managing crypto wallets. The development of intuitive and user-friendly interfaces could also enable non-technical users to use smart contracts more easily.

In addition, future studies should examine the impact of cryptocurrency volatility on user experience and transaction costs. Developing mechanisms to mitigate or minimize currency risks could help reduce uncertainty in transaction costs and increase user trust. Besides technical aspects, it is also important to investigate the legal and regulatory framework for the use of smart contracts in virtual worlds. The development of legal standards and best practices could increase user trust and enable the smooth operation of smart contracts.

7. Conclusion

Theoretical implications of our study first provide insights from a TCT perspective that can be used to better understand the role of smart contracts in the metaverse (Halaburda et al., 2019). Our application on the three dominating virtual worlds reveals additional insights beyond purely theoretical analyses. Second, we provide a detailed research agenda on the topics to be researched with regard to smart contracts in virtual worlds. Third, our study establishes a foundation for future research in blockchain technology and its applications in virtual worlds, offering a comprehensive framework for assessing the viability and impact of smart contracts. This includes the potential for reducing transaction costs (Eickstädt et al., 2020), improving operational efficiency, and enabling seamless interaction between the virtual and real-world environment.

Practical implications are that virtual worlds can use our results to further explore how to develop their platforms further with the aim of attracting new customers. Our research agenda also provides avenues for practical evaluation in which direction smart contracts and the underlying blockchain usage should be developed. For service providers who are present in the metaverse, transforming their products and services from the real world to metaverse can be informed by our analysis. And for financial transaction providers, the analysis offers the potential to explore new service models that are not present so far (Masla et al., 2021).

Limitations of our study include the following: The study only investigated three virtual worlds, of which two were based on similar blockchain technology. This limited sample size raises concerns about the generalizability of the findings, as there may be other virtual worlds with different characteristics or features that were not included in the analysis.

Another limitation is the focus on Ethereum as the primary blockchain technology in the study. While Ethereum is widely used, other distributed ledger or blockchain technologies might offer lower transaction costs. However, these alternative technologies were not implemented in the virtual worlds examined in this study, and their potential impact remains unexplored.

It is important to acknowledge that these limitations reflect the scope of the present study and may not encompass all possible constraints associated with virtual worlds and their blockchain technologies.

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