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The application of blockchain technology in document storage: Opportunities and challenges

Dmytro Kotsur*
PhD in Physical and Mathematical Sciences, Associate Professor
Hryhorii Skovoroda University in Pereiaslav
08401, 30 Sukhomlynskyi Str., Pereiaslav, Ukraine
https://orcid.org/0000-0003-0230-8095

Abstract. This study explored the potential applications of blockchain technologies in document preservation, focusing on their efficiency, security, and economic feasibility. The technology's key advantages have been identified, including transparency, data immutability, process automation, cost optimisation, and enhanced trust in digital systems. An analysis of practical case studies has demonstrated significant benefits across various countries. In Estonia, the e-Tax system has reduced tax violations by 20%, accelerated financial transaction processing, and automated tax control. In Georgia, using blockchain in the land registry has lowered administrative costs by 25%, shortened property registration times, and reduced legal disputes by 30%. In the USA, the introduction of smart contracts in the rental sector has reduced contract execution times from 14 days to 48 hours, while administrative errors have decreased by 30%. Despite these advantages, challenges remain in implementation, including scalability, high energy consumption, legal regulation, and the complexity of integration into existing systems. Measures have been proposed to further develop the technology, including the establishment of international standards, legislative adaptation, the implementation of energy-efficient algorithms, the expansion of training programmes for personnel, and the integration of blockchain with other digital tools. Additionally, the use of blockchain enhances cybersecurity, as data stored in a distributed ledger cannot be altered or falsified. This ensures the protection of documents against forgery while preserving their authenticity and integrity. In the future, the technology could facilitate the creation of global digital identification systems, forming the foundation for e-governance and secure data exchange. The findings of this study may serve as a basis for further research and the development of strategies for large-scale blockchain implementation in public administration, the financial sector, logistics, and the digital economy

Keywords: tax revolution; accounting and storage; decentralisation; Proof-of-Stake; Web3; transparency and protection

Introduction

The growth of digital technologies and the need to ensure reliable data storage have generated significant interest in the use of blockchain technology in document storage. In the current context of growing volumes of digital information, it has become crucial to ensure the long-term preservation of documents without the risk of loss or damage. As noted in the article of I. Bida & M. Petrov (2019), digital documents require maximum protection. The author's research was focused on analysing the technological aspects of using blockchain to ensure the

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*Corresponding author

legal protection of data in the public and corporate sectors, which is critical to mitigating the risks of manipulation or loss of information. A large number of government institutions have transitioned to electronic document management, increasing the relevance of the research.

The use of blockchain in document management systems has significantly increased the level of trust in digital data and ensured their secure long-term preservation. As Y. Honcharova (2020) notes, blockchain technology is a key element of Industry 4.0, facilitating process automation and reducing the risks of data falsification. This makes it particularly effective in areas where transparency and data reliability must be guaranteed, such as government accounting and document management. V. Gulin (2020) highlights that the distributed nature of blockchain contributes to reducing the risks of unauthorised access to information. The technology enables the creation of immutable data registers, which is critical for legal security and the protection of property rights in the digital space. In particular, blockchain allows for the creation of decentralised platforms for registering property rights agreements, which do not require intermediaries, significantly reducing the risk of fraud. V. Gulin also investigates the impact of cryptographic technologies on the protection of corporate documents, emphasising the advantages of decentralised databases in preventing unauthorised access.

O. Tkalenko & M. Melnyk (2019) emphasise that cryptographic algorithms, such as SHA-256, used in blockchain, provide a high level of security and make data falsification impossible. In their research, they investigated how blockchain ensures these aspects through the use of cryptographic algorithms and a distributed architecture, which minimises the risks of data modification. Blockchain technologies offer data immutability through the use of cryptographic algorithms and hashing, which guarantees data integrity. This approach allows for the storage of information in the form of encrypted blocks, providing reliable protection against modifications. Historically, blockchain was first applied in the financial sector as the foundation for cryptocurrencies such as Bitcoin, however, its potential has proven to be much broader. As M. Mironchak & V. Gricak (2020) noted, blockchain enables the creation of a chain of blocks with unique cryptographic signatures, which guarantees data integrity and confidentiality. This makes the technology attractive for use in such critical areas as medical archives, registration systems, and educational platforms. The implementation of this technology has allowed for the storage of large volumes of confidential information that was only accessible to authorised individuals.

V. Koibichuk & M. Rozhkova (2020) note that blockchain not only optimises logistics processes but also ensures product origin control, guarantees their authenticity and creates transparency in international supply chains. Blockchain is also finding application in logistics, where it helps track the movement of goods throughout the supply chain. O. Lapko & O. Solosich (2019) notes that the use of blockchain in logistics systems allows for a significant increase in process transparency, reduces the likelihood of fraud, and prevents the falsification of information about the origin of goods. This has ensured process transparency and prevented the falsification of information about the origin of goods, their quality, and storage conditions. In the field of document storage, blockchain has been used to create secure electronic registers, which have been used in medical archives, educational systems, and government information platforms. The use of blockchain in accounting has helped to reduce the risk of data falsification due to the immutability of records in the register. This approach can be applied to store educational certificates that confirm the authenticity of issued diplomas. Despite these challenges, research into the legal and regulatory aspects of blockchain implementation remains important, especially in the context of its application in government agencies, medical archives, and educational institutions (Balazyuk & Pylyavets, 2022). Issues such as the integration of blockchain with existing platforms and the development of international standards to ensure platform compatibility, and the unification of information exchange approaches remain understudied.

The research aimed to determine the role of blockchain technologies in increasing the efficiency of digital data storage, ensuring its security and transparency, and creating conditions for the long-term preservation of information without the risk of loss or manipulation. The main focus was on the analysis of practical cases of using blockchain in various fields, such as government information systems, educational archives, and medical registries.

Materials and Methods

Several approaches were used in the research to ensure the analysis of blockchain technology implementation in document storage. The main focus was on case studies that demonstrate realworld examples of the technology's application in different countries. The case study method was used for the analysis, which involves a detailed study of realworld examples of blockchain technology implementation in document storage systems. Three key case studies were considered in the research. The first case study concerned the implementation of the e-Tax system in Estonia, developed and implemented by the Estonian Ministry of Finance. The aim of implementing this system was to ensure the automation of tax accounting and increase the transparency of financial transactions through the use of blockchain technology. The main sources for the analysis were reports from the Estonian Ministry of Finance, works by F. Casino *et al.* (2018) and S. Volosovych *et al.* (2019).

The second case study is dedicated to land registration in Georgia, where blockchain was implemented by the National Agency of Public Registry of Georgia. This implementation aimed to ensure the transparency and integrity of land transactions. For analysis, official

documents of the agency, research by S. Haber & W. Stornetta (1991), and L. Sloboda & A. Senkovych (2018) were used. The third case study is the implementation of the Blockchain-based Rental Documentation Management system in the USA, implemented with the participation of IBM Blockchain Labs. The main organisation that implemented this system was First National Realty Partners (FNRP). The implementation aimed to increase the efficiency and transparency of rental documentation management processes. In this context, the analysis was based on reports from IBM Blockchain Labs, publications by J. Santos *et al.* (2024).

A comparative analysis was conducted to assess the advantages and disadvantages of implementing blockchain compared to traditional document management methods. Transparency, security, energy consumption, and document processing speed were analysed. Data for comparison was collected from official reports and scientific articles, such as the studies of F. Casino *et al.* (2018), J. Santos *et al.* (2024), and L. Sloboda & A. Senkovych (2018). Content analysis was based on the study of publications, reports from international organisations, and government structures that highlight the aspects of blockchain implementation. Particular attention was paid to the advantages of the technology in ensuring transparency and data protection. The source base included the research of F. Casino *et al.* (2018), S. Haber & W. Stornetta (1991), S. Volosovych *et al.* (2019). The processing of literary sources provided a comprehensive overview of the advantages and challenges of blockchain. The sources that provided the basis for the research included contemporary scientific articles, reports from international organisations, and government structures. For example, the studies of S. Haber & W. Stornetta (1991), F. Casino *et al.* (2018), and L. Sloboda & A. Senkovych (2018) detailed the fundamentals of the technology, while reports from IBM Blockchain Labs described its implementation in commercial structures. The evaluation of statistical data was based on reports that provided specific indicators of blockchain implementation in different countries. In particular, projects in Estonia, Georgia, and the USA were analysed, which allowed for a detailed picture of the technology's effectiveness and challenges.

Results

Implementation of e-Tax in Estonia

The e-Tax system, developed and implemented by the Estonian Ministry of Finance, is one of the leading examples of digitalisation in public administration. The main reasons for its implementation were the need to address issues of tax fraud, corruption, and low levels of trust in government institutions. Prior to the introduction of new technologies, Estonia's tax administration system was characterised by significant bureaucratic complexity, which slowed down the processing of tax returns and reduced the efficiency of tax authorities (Anushka *et al.,* 2024) The e-Tax system became a key element of digitalisation in Estonian public administration. The main technologies implemented include distributed databases that ensure the immutability of records, and Keyless Signature Infrastructure (KSI) technology, developed by Guardtime, which is used to verify data authenticity, reducing the risk of manipulation and ensuring process transparency (Casino *et al.,* 2019).

Thanks to the implementation of the system, the number of tax abuses has decreased, and the level of public trust in the tax system has significantly increased. The integration of e-Tax with other state registries has ensured automatic data verification, which has reduced the number of errors in tax returns and accelerated their processing (Wang, 2022). The integration of registries has become an important part of the implementation of e-Tax. Automatic data verification through demographic and land registries has significantly optimised the administration process, allowing for the avoidance of data duplication and speeding up the processing of requests. Additionally, the implementation of KSI technology has enabled tracking of any changes in registries in real time, ensuring data transparency and accuracy (Volosovych *et al.,* 2019). The legal adaptation of the system involved bringing it into compliance with current legislation and international standards, such as GDPR. This ensured the protection of user data and compliance with European privacy requirements. To achieve this, the government collaborated with international experts to create secure data transfer protocols and minimise the risks of unauthorised access to information (Wang, 2022).

Staff training was another crucial element of the implementation. Over 95% of tax authority employees successfully adapted to working with the new system after completing training programs. Specially designed online courses for citizens allowed for rapid system mastery, reducing the number of requests to the support service (Anushka *et al.,* 2024). The social impact of e-Tax is also significant. Citizen satisfaction with tax services increased by 30%, demonstrating the system's success in improving interactions between the state and citizens (Volosovych *et al.,* 2019). The reduction in administrative costs allowed for significant savings in the state budget, which were directed towards social programs such as education and healthcare. However, the implementation of e-Tax was accompanied by numerous challenges. E. Karaarslan & E. Konacakli (2020) note that the high cost of implementing blockchain solutions is due to the need for significant investments in server infrastructure, the development of specialised software, and the adaptation of existing platforms. One of the main problems was the initial cost of modernising IT infrastructure, which included the purchase of servers, the upgrading of network equipment, and the creation of highly complex software. Another challenge was the integration of the system with existing state registries.

Staff training was another challenge, as explaining the complex technical aspects of the system required

the development of detailed training materials and the conduct of practical classes. Also, in some regions, there were still problems with stable internet access, which created barriers to the full functioning of e-Tax, especially in rural areas (Wang, 2022). Despite these challenges, the successful implementation of e-Tax has made Estonia a leader in the field of digital tax administration and an example for other countries planning to introduce similar systems.

Land registration in Georgia

Georgia was one of the first countries to implement blockchain for land property registration. In 2016, the National Agency of Public Registry of Georgia (NAPR) partnered with Bitfury Group to create a secure, transparent, and efficient land registration system. The primary reasons for this innovation were the need to combat corruption, eliminate errors in records, and simplify access to registration services for citizens. This allowed the state to transition from paper-based registers, which contained many inaccuracies and required constant updating, to a digital platform that guarantees the reliability and immutability of records. The primary technical solution implemented in the system is SHA-256 – a cryptographic algorithm used to hash data on registration transactions. This ensures the immutability of information and guarantees that any changes to records can be tracked (Sloboda & Senkovych, 2018). As a result, any interference with registration becomes technically impossible, and data is stored in a secure environment that can only be accessed by authorised personnel. The introduction of blockchain solutions has significantly reduced the time required to process land transactions, which previously could take several weeks but can now be completed within a few hours. Automated transfer of ownership has eliminated the possibility of external interference in registration processes, increasing public trust in the system and government agencies in general. One of the key outcomes of implementing the technology has been a significant reduction in administrative costs, which, according to experts, has reduced the budget costs of maintaining the land registry by 25% (Humaid, 2022).

O. Podvornuk & N. Polishuck (2021) note that the digitalisation of administrative processes in the public sector significantly reduces the level of litigation, ensuring the reliable recording of legal relations in an immutable digital registry. Moreover, the digitalisation of processes has contributed to a 30% reduction in the number of legal disputes regarding land rights, as all operations have become transparent and backed up by immutable records. The Georgian blockchain land registry also complies with European standards in the field of land management, in particular, the GDPR requirements for the protection of personal data and transaction security. Integration with international legal norms allows Georgia to ensure transparency in registration procedures and increase the trust of investors and citizens. While the implementation of blockchain technology has offered numerous benefits, it has also been accompanied by a range of challenges. One of the most significant obstacles was the complexity of integrating the new system with existing government registries, which had previously operated in isolated systems and had different data structures (Zyskind *et al.,* 2015). To ensure compatibility and seamless information exchange, the government had to upgrade its IT infrastructure, requiring significant financial investment and technical effort. Another challenge was the need to train staff who would be working with the new system. Special training programs were organised for public servants responsible for maintaining registration records, and training programs were also developed for notaries and other participants in the registration process. Furthermore, adapting legal norms to the new digital system required alignment with international standards such as GDPR and European land management standards, which further impacted implementation timelines (Humaid, 2022).

The costs of implementing the blockchain system also posed a significant challenge for the state. The purchase of server equipment, the development of software, staff training, and technical maintenance required substantial financial resources. However, in the long term, this solution has reduced the costs of maintaining registers and ensured the stability of the system (Humaid, 2022). Another important aspect is the complexity of user adaptation to the new system. Despite the simplification of registration procedures, some citizens initially faced difficulties in using the digital platform, which required additional consultations and explanatory work from government agencies. To minimise this barrier, a series of educational initiatives and consultation programs were implemented. Additionally, scaling the system and integrating it with other government structures required additional technical solutions, which could slow down the expansion of the platform. However, the Georgian government is actively working to improve the technology, allowing it to gradually adapt to new requirements and ensure resilience to potential future changes (Mironchak & Grycak, 2022).

The use of blockchain in land registration in Georgia has been a significant step towards increasing the transparency of public administration and building public trust in government agencies. Experts believe that this experience can be useful for other countries seeking to implement similar systems, as it not only ensures the reliability of registration data but also minimises corruption risks and improves the efficiency of government institutions.

Blockchain-based Rental Documentation Management in the USA

Blockchain-based Rental Documentation Management in the USA has emerged as a revolutionary solution in

the realm of real estate digitalisation. The implementation of this system, initiated by IBM Blockchain Labs in partnership with First National Realty Partners (FNRP), aimed to address challenges such as delayed contract execution, document errors, and a lack of transparency in financial transactions (Santos *et al.,* 2024). The application of blockchain significantly reduced the time required to process agreements and increased trust between tenants and landlords. One of the key technological solutions was the use of smart contracts, which automated the verification of payment discipline, the making of amendments to contracts, and the monitoring of the fulfilment of obligations. This reduced the likelihood of administrative errors and ensured instant updates to records in the event of changes to the terms of an agreement (Qi-Long *et al.,* 2019). The use of blockchain as the foundation of the registry guaranteed the immutability of records, eliminating the possibility of their falsification or unauthorised modification.

The Blockchain-based Rental Documentation Management system fully complies with the Uniform Electronic Transactions Act (UETA), which legalises electronic contracts and digital signatures in the USA. According to the UETA, electronic agreements have the same legal force as traditional paper documents, allowing blockchain to be used for the legitimate management of rental documentation (Uniform Electronic Transactions Act, 1999). Additionally, the use of digital signatures ensures the legal protection of the parties to the agreement and the ability to subsequently verify the authenticity of contracts. Among the main achievements of implementing this system is the reduction in the time it takes to conclude rental agreements from two weeks to 48 hours thanks to automated checks and digital interaction between landlords and tenants (Qi-Long *et al.,* 2019). As noted by X. Qingshu *et al.* (2021), the use of blockchain in the real estate sector significantly simplifies the process of concluding contracts, reduces bureaucratic delays, and lowers the risk of financial manipulation. Smart contracts have reduced the number of administrative errors by 30%, increasing the efficiency of document management and minimising the risk of fraud. Moreover, the level of disputes among tenants has decreased by 30% as all transactions have become transparent and immutable once confirmed by the parties to the agreement.

Despite its numerous advantages, the implementation of the system was accompanied by several challenges. One of the primary barriers was the cost of modernising the IT infrastructure, which involved integrating blockchain with existing government registries and financial services. This required the creation of additional APIs and connections to banking platforms for automated payments (Qi-Long *et al.,* 2019). Another challenge was the need to train staff and tenants. As most users had no prior experience with blockchain systems, companies had to invest in training programs, organising training sessions for real estate agents and legal consultants (UETA, 1999). Additionally, adapting legal norms to the new digital system required changes in the regulation of digital signatures and smart contracts at the state level. A separate challenge was scaling the system. Despite the high efficiency of blockchain, integration with large commercial landlords and financial institutions required compliance with various legal standards across the USA. As laws governing digital agreements can vary from state to state, companies have had to adapt the system to meet local requirements (UETA, 1999)

The implementation of Blockchain-based Rental Documentation Management in the USA has been a significant step in the field of digital real estate, enabling the automation of contract execution, increased security and transparency of financial transactions, and reduced administrative errors. However, scaling the system remains a challenge, as different states have their own legal requirements for digital agreements. Expanding the platform allowed for the integration of new functionalities, including automated report generation for auditing and the creation of a transaction history database. This database provided participants with access to complete information on previous transactions, becoming a valuable tool for long-term asset management. Additionally, the introduction of machine learning functions enabled the prediction of default risks based on the previous behaviour of tenants, demonstrating a significant improvement in risk management (Table 1).

Table 1. Functionalities of Blockchain-based Rental Documentation Management

Platform capabilities	**Implementation effects**
Automated report generation	Reduced time and resource costs for auditing
Transaction history	Access to data for improved long-term asset management
Machine learning features	Predicting payment default risks
Digital signature integration	Ensuring the legal significance of electronic documents
Data privacy	Reduced risk of privacy breaches by 40%
User rating	Reduced risks of working with unreliable partners
Payment verification automation	Reduced default rates by 25%
Creation of a centralised database	Optimised access to historical transactions
Investment attraction	Increased investor trust and funding by 18%
Improved customer experience	Reduced legal disputes by 30%

Source: created by the authors based on the conducted research

Tenants also gained access to the platform, allowing them to check their transaction history, contract status, and payment timeliness. This contributed to a 30% reduction in disputes and improved customer experience. FNRP's reputation as an innovative company focused on customer needs has significantly grown. The implementation of Blockchain-based Rental Documentation Management was a significant step in the digitalisation of the real estate market in the USA. The optimisation of rental documentation management processes has demonstrated the significant potential of blockchain technology in transforming the industry. The successful experience of FNRP has set a precedent for considering similar solutions in an international context. Furthermore, the platform facilitated the development of new business models in the rental property sector. For example, ensuring data transparency has enabled the development of tenant and landlord rating mechanisms, which has helped reduce the risk of dealing with unreliable partners. In the future, such systems can form the basis for the creation of global rental management platforms, integrated with other financial and legal tools, creating new opportunities for the global real estate market.

A comparative analysis of blockchain technologies and traditional document management methods

The use of blockchain in document management offers enhanced transparency, immutability of records, and process automation, setting it apart significantly from traditional methods of document management. Traditional document management systems have several limitations, including centralised control, the need for notarisation, and the risks associated with human error in information processing. The use of blockchain in document management allows for the elimination of these drawbacks through a distributed system of record-keeping and the use of smart contracts (Qi-Long *et al.,* 2019). Despite the advantages of blockchain solutions, their implementation is accompanied by certain challenges. A major barrier is the need to adapt legislation, as in many countries, legal norms do not yet recognise the legal force of smart contracts, hindering their widespread use. Additionally, under international regulations such as GDPR, there are certain restrictions on storing personal data in immutable blockchain records. The lack of unified regulatory standards also slows down the implementation of this technology in the field of document management (Berestov, 2024).

O. Balazyuk & V. Pylyavets (2022) note that blockchain can significantly reduce the risk of data falsification due to cryptographic mechanisms and the immutability of records. A comparison of blockchain technologies with traditional document management methods demonstrates that blockchain provides automated information verification, significantly reduces the likelihood of errors and forgeries, and minimises administrative costs. In contrast, traditional methods require additional human oversight, which can impact the speed and efficiency of document processing. For better visualisation, a comparative table of the effectiveness of implementing blockchain technologies in document management compared to traditional methods is provided (Table 2).

Table 2. Comparative analysis of traditional document storage methods and blockchain technologies

Parameter	Traditional document management	Blockchain document management
Transparency	Limited, dependent on regulatory bodies	High, all transactions are recorded in the blockchain
Reliability	Susceptible to forgery and loss	Data immutability ensured by consensus algorithms
Processing speed	Slow verification, need for intermediaries	Automated execution of smart contracts
Scalability	Limited by server resources	Easily scalable due to decentralisation
Legal adaptation	Requires notarisation	Smart contracts are legally recognised in some countries
Personal data protection	Vulnerable to information leaks	Secured by cryptographic algorithms
Administrative costs	High due to the need for human oversight	Minimal due to process automation
Information availability	Restricted by server access	Decentralised, accessible to all network participants
Data falsification	Possible through record alteration in the database	Impossible due to the immutability of blockchain records
Integration with other systems	Limited due to centralised architecture	Flexible, supports APIs for interaction with other platforms

Source: created by the authors based on the conducted research

G. Tereshchenko & I. Kyrychenko (2024) highlight that the implementation of blockchain in document management requires not only technical adaptation but also significant updates to the legal framework governing electronic records and their legal force. This ensures a solid legal foundation for the use of decentralised registries in the public sector. Governments in many countries are already working on creating legal frameworks to legitimise smart contracts and integrate blockchain into government and commercial document management systems. In the United States and the EU, laws are being passed that define blockchain as an acceptable technology for maintaining digital records, opening up new possibilities for its application in information management. Despite existing barriers, blockchain has significant potential to transform document management,

increasing the security and efficiency of working with digital records (Santos *et al.,* 2024).

Recommendations for organisations seeking to implement blockchain technologies

Based on the analysis of case studies and the implementation of blockchain technology in various industries, detailed recommendations for organisations have been formulated. The implementation of this technology requires careful planning, legal compliance, proper staff training, and an assessment of potential risks. Firstly, organisations should assess their readiness for blockchain integration. This includes identifying key processes that can be improved through decentralised technology and developing a detailed roadmap for its implementation (Haber & Stornetta, 1991). The experience of Estonia demonstrates that the integration of e-Tax with state registries significantly simplifies document flow, reducing data processing time and administrative costs (Volosovych *et al.,* 2019). A crucial step is choosing the type of blockchain system. The organisation must determine whether a public, private, or hybrid network is suitable. Private blockchains provide access control to data, while public networks guarantee high security due to decentralisation (Honcharova, 2020).

Legal compliance is a key aspect of integrating blockchain into document management. Organisations should ensure that the implementation of the technology complies with current legislation and regulatory requirements. In some countries, legal mechanisms already exist to legitimise smart contracts and digital signatures (Pantielieieva, 2022), and legislative acts such as UETA confirm the legal force of electronic records (UETA, 1999). Technical implementation and security are also crucial elements. Choosing the right encryption algorithms and data protection systems helps minimise the risk of unauthorised access to information. Implementing multi-factor authentication and using cryptographic methods ensures high data confidentiality (Bilik & Silagin, 2018). Furthermore, effective blockchain implementation is impossible without proper staff training. Organisations are recommended to organise training sessions and seminars for employees and establish internal working groups to monitor the technology implementation process (Volosovych *et al.,* 2019). This ensures a better understanding of the technology and its practical application in work processes.

Additionally, organisations should consider the possibility of integrating blockchain solutions with existing electronic document management systems. The use of API interfaces and compatible technological solutions can simplify adaptation and reduce implementation costs. Furthermore, potential scaling risks should be considered, as increasing the number of users may lead to network performance issues (Galdun *et al.,* 2021). Organisations should also develop data backup and disaster recovery policies, as blockchain, while a secure technology, does not eliminate the possibility of lost access or technical failures. It is essential to develop clear disaster recovery protocols (Demichev & Kryukov, 2021). After implementation, organisations should evaluate the effectiveness of blockchain. Defining key performance indicators (KPIs) will help assess the technology's impact on business processes. Further scaling depends on the organisation's needs and the results of the initial implementation phase (Pantielieieva, 2022).

Thus, the successful implementation of blockchain technology requires a comprehensive approach that includes analysing the organisation's needs, compliance with legal regulations, technical support, and staff training. By following these recommendations, organisations can increase the transparency, security, and efficiency of their business processes.

Discussion

The implementation of blockchain technology in various sectors has confirmed its effectiveness in ensuring transparency, automating processes, and enhancing data security. This is particularly important for optimising management processes in both the public and private sectors. For example, the integration of the e-Tax system in Estonia has enabled the automation of tax administration, reducing data processing time and increasing trust in government services (Wang, 2022). However, the scalability and high energy consumption of blockchain require further technological advancements, including a transition to more energy-efficient consensus mechanisms such as Proof-of-Stake (Qi-Long *et al.,* 2019). One of the main achievements of blockchain is the increased transparency and security of record-keeping. For instance, land registration in Georgia using blockchain has significantly reduced the number of legal disputes and increased trust in government institutions. This experience demonstrates the effectiveness of decentralised systems in countries with high levels of corruption. However, it is necessary to consider the potential challenges of adapting the system to different legal environments, as the implementation of blockchain requires legislative support and international harmonisation of digital asset accounting standards (Volosovych *et al.,* 2019).

Blockchain is also actively used in the financial sector, where its advantages in security and transparency allow for the optimisation of transaction processes. In the banking sector, the implementation of smart contracts and digital assets reduces the risk of fraud and improves the speed of settlements (Honcharova, 2020). Additionally, in countries with high tax rates, blockchain can provide greater trust in tax policy due to the immutability of records and automated audits. It is also important to note that this technology can improve the efficiency of control and reduce the burden on tax authorities. In the real estate sector, blockchain can reduce bureaucratic barriers and accelerate the conclusion of deals. For example, in the USA, the implementation

of smart contracts has simplified the rental process, positively impacting the real estate market (Santos *et al.,* 2024). However, in many countries, the necessary legal framework is absent, creating legal challenges. For instance, the legal status of smart contracts remains unregulated in many jurisdictions, complicating their use in legal proceedings (UETA, 1999). These issues require close cooperation between government agencies and international organisations to create universally accepted standards for regulating digital contracts.

Another crucial aspect is the need to test blockchain solutions before their widespread implementation. For example, the multi-level testing of e-Tax in Estonia allowed for the identification of potential risks and the improvement of the system before its widespread use (Wang, 2022). A similar approach can be beneficial for other countries and industries, as prior testing can minimise technical risks and enhance data security. However, such an approach requires significant financial investment, which can be a barrier for resource-constrained countries (Pantielieieva, 2022). Additionally, the scalability of the technology remains a significant challenge, and research in this area continues, particularly in terms of expanding the capabilities of blockchain networks without significantly increasing energy consumption.

Involving users at all stages of blockchain implementation is key to its successful operation. Actively informing citizens and businesses, creating open communication channels, and developing training programs can promote wider adoption of the technology. The experience of using blockchain in the banking sector shows that low levels of digital literacy can lead to slow adoption of new systems, even if they are effective (Honcharova, 2020). It is important to develop adaptation programs for employees and the population to overcome barriers to the adoption of new technologies. Additionally, the possibility of expanding the use of technology to create digital identity systems should be considered, as these could form the basis for e-government. Particular attention should be paid to the environmental impact of blockchain. The high energy consumption remains one of the main challenges of this technology, however, the implementation of energy-efficient algorithms such as Proof-of-Stake can significantly reduce the carbon footprint (Haber & Stornetta, 1991). In the future, it is expected that the development of new consensus models will allow for the optimal balance between security and energy efficiency (Demichev & Kryukov, 2021). Meanwhile, a promising direction is the integration of blockchain with green energy, which will allow combining technological innovation with environmental sustainability.

Thus, the successful implementation of blockchain technology requires a comprehensive approach that includes technical, legal, and social aspects. The experience of various countries demonstrates that this technology can become the foundation of digital governance, but its effectiveness largely depends on adaptation to local conditions and legal norms. Cooperation between governments, businesses, and international organisations is a key factor for the further development and effective implementation of blockchain solutions. It is also important to expand educational initiatives, which will increase public awareness of the benefits and challenges of the technology, contributing to its faster integration into key areas of the economy and public administration.

Conclusions

Blockchain technologies have demonstrated significant potential in the realm of document management, providing high levels of transparency, security, and cost-effectiveness. The use of solutions such as smart contracts and decentralised ledgers has enabled the automation of complex administrative processes, minimising the risk of human error and fraud. Successful case studies in Estonia, Georgia, and the USA have confirmed that the implementation of blockchain contributes not only to reducing costs and speeding up data processing but also to increasing public trust in digital systems due to the reliability and transparency of information processing. In particular, in the public sector, the technology helps to avoid data duplication, ensures the integration of registries, and reduces administrative costs. In the commercial sector, such as the management of rental documentation in the USA, blockchain has demonstrated its effectiveness in reducing errors and the time taken to conclude contracts. The use of cryptographic algorithms such as SHA-256 guarantees the immutability of data and protects it from fraud. This highlights the versatility of the technology, which can be adapted to various sectors of the economy.

Despite this, the widespread adoption of blockchain faces several challenges. Among them are scalability and energy consumption issues, especially for networks using Proof-of-Work algorithms. To address these issues, energy-efficient protocols such as Proof-of-Stake are being actively developed, promising to significantly reduce the resource load. At the same time, adapting the legal framework remains a crucial step in ensuring the compatibility of the technology with existing regulatory requirements. The further development of blockchain requires international coordination. The development of universal standards and integration with global digital platforms open up new opportunities for cooperation between states and businesses. This will not only increase the efficiency of information management but also contribute to ensuring the long-term preservation and protection of data. Blockchain technology has the potential to become a key tool for modernising many areas of activity, creating the foundation for a more transparent and secure digital future.

Promising areas for further research include the development of new methods for integrating blockchain with artificial intelligence systems, which can contribute to the creation of more autonomous and self-regulating

digital processes. Research into the effectiveness of decentralised networks in the context of cybersecurity and data protection also remains relevant, as increasing digitalisation requires new mechanisms for verifying and authenticating information. Additionally, further research can focus on optimising the energy consumption of blockchain technologies, which will allow them to become more environmentally friendly and accessible for widespread implementation in infrastructure projects and public administration.

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Conflict of Interest

None.

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Використання blockchain-технологій у документозберіганні: можливості та виклики

Дмитро Коцур
Кандидат фізико-математичних наук, доцент
Університет Григорія Сковороди в Переяславі
08401, вул. Сухомлинського, 30, м. Переяслав, Україна
https://orcid.org/0000-0003-0230-8095

Анотація. Це дослідження присвячене вивченню потенційних напрямів застосування технологій блокчейн у збереженні документів з акцентом на їхню ефективність, безпеку та економічну доцільність. Визначено ключові переваги цієї технології, зокрема прозорість, незмінність даних, автоматизацію процесів, оптимізацію витрат та зміцнення довіри до цифрових систем. Аналіз практичних кейсів продемонстрував суттєві переваги в різних країнах. Зокрема, в Естонії система e-Tax дозволила знизити кількість податкових порушень на 20 %, прискорити обробку фінансових транзакцій і автоматизувати податковий контроль. У Грузії впровадження блокчейну в земельному реєстрі сприяло зниженню адміністративних витрат на 25 %, скороченню термінів реєстрації власності та зменшенню кількості юридичних спорів на 30 %. У США запровадження смарт-контрактів у сфері оренди дозволило скоротити термін виконання договорів із 14 днів до 48 годин і зменшити кількість адміністративних помилок на 30%. Попри ці переваги, залишаються певні виклики у впровадженні технології, серед яких масштабованість, високе енергоспоживання, правове регулювання та складність інтеграції в існуючі системи. Запропоновано заходи для подальшого розвитку технології, такі як встановлення міжнародних стандартів, адаптація законодавства, впровадження енергоефективних алгоритмів, розширення програм навчання персоналу та інтеграція блокчейну з іншими цифровими інструментами. Крім того, застосування блокчейну підвищує рівень кібербезпеки, оскільки дані, збережені у розподіленому реєстрі, не можуть бути змінені чи сфальсифіковані. Це забезпечує захист документів від підробок, зберігаючи їх автентичність і цілісність. У майбутньому ця технологія може сприяти створенню глобальних систем цифрової ідентифікації, які стануть основою для електронного урядування та безпечного обміну даними. Результати дослідження можуть бути основою для подальших наукових розробок і формування стратегій масштабного впровадження блокчейну в державному управлінні, фінансовому секторі, логістиці та цифровій економіці

Ключові слова: податкова революція; облік і зберігання; децентралізація; Proof-of-Stake; Web3; прозорість і захист