Blockchain Technology and Its Potential for Supporting Sustainable Urban Development

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Abstract. Blockchain is a key innovation that has revolutionized our understanding of data storage, transmission and processing. It allows the creation of systems that do not depend on central authorities or intermediaries, significantly increasing the security, transparency and sustainability of these systems. This study uses a combined methodology of both qualitative and quantitative approaches, including the use of bibliometric metrics and systematic literature reviews. The study aims to analyze the potential of blockchain technology to support sustainable urban development, particularly focusing on the opportunities it offers to improve urban governance and improve the quality of life for residents.

The research findings highlight that blockchain can be an effective tool for improving societal well-being while acknowledging its potential risks and challenges. The study examines the international experience of institutionalizing blockchain technology and sheds light on the legislative initiatives of various countries regarding its regulation. It also explores the characteristics and examples of blockchain implementation in countries where the technology is most widespread, including Ukraine.

However, the study notes the uneven legal regulation and adoption of blockchain technology around the world. Moreover, at the moment there is no single standard for the legal regulation of this technology, as regulatory models are still being developed and gradually implemented in various spheres of public life. Blockchain has the potential to increase transparency, ensure product traceability and promote efficient use of resources, thereby supporting equitable economic growth and environmental protection.

Keywords: smart contract, urbanization, sustainable development, smart cities.

INTRODUCTION

Since its inception, blockchain technology is constantly becoming more complex, the number of its applications is growing, and the level of user awareness is increasing. While some governments are exploring the use of blockchain in pilot projects, many have yet to consider its unique features and advantagesovertraditional database systems. Blockchain is typically associated with cryptocurrencies; however, its use has the potential to revolutionize processes across various sectors, including finance, trade, public services, and humanitarian and development aid. This innovation creates opportunities to accelerate progress toward the Sustainable Development Goals. Nevertheless, several challenges hinder the realization of blockchain's full potential, such as scalability issues, privacy concerns, regulatory uncertainty,

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and difficulties in integrating blockchain technology into existing systems.Blockchain technology can also be applied to implement the Mobility as a Service (MaaS) system, where citizens can access multipletransportationoptions from a single platform to increase efficiency. In the energymarket, blockchain can utilize data stored within the network to optimize water and energy consumption, transforming every building into a healthier and more profitable environment for its occupants. Citizens and businesses, regardless of size, can leverage blockchain for faster cashtransfers and instantpayments to peers and business partners (Swan, 2015). Governments can employ smart contracts to automate bureaucratic processes. Alongside digital IDs, smart contracts can facilitate the elimination of paper-based state institutions, enabling digital methods for citizen identification, voting, taxpayments, and more.

Research Problem

Given the importance of blockchain technology across various sectors, including the economy, it is crucial to assess both potential threats and opportunities for blockchain development in the near future. This assessment involves examining how current and future technological and regulatory challenges may impact the evolution of blockchain technology. Conducting trend analysis using statistical data and processed information is an effective approach to understanding these prospects and opportunities. Such analysis helps identify potential threats and progress in the field, guiding strategic decisions and fostering innovation in blockchain technology.

Research Focus

This study focuses on the use of blockchain technology in city management and public service delivery. It analyzes how blockchain can be applied to improve efficiency, transparency and sustainability in these areas of public administration. The study aims to assess the potential benefits and challenges of implementing blockchain-based solutions in various cities and public sector processes.

Research Aim and Research Questions

This research paper focuses on the use of blockchain technology in city management and public services. She explores how blockchain can be applied to improve efficiency, transparency and sustainability in these areas of public administration. The study aims to assess the possible benefits and challenges of implementing blockchain-based solutions in various cities and public sector processes. To achieve this aim, the following objectives are addressed:

- Effective integration of blockchain technologies into city management systems to enhance efficiency and transparency.
- Analysis of the potential benefits and challenges of using blockchain in public services, with examples from both foreign countries and Ukraine.
- Examination of the possible implications of blockchain technology for future research and practice in urban planning and public administration.

LITERATURE REVIEW

This study utilized46 sources to analyze the challenges of blockchain technology in the sustainable development of cities. All the works are comprehensive; let'sexamine some of them. Ahluwalia, Mahto, and Guerrero (2020) highlight the role of blockchain in startupfinancing, finding that blockchain can reduce intermediation costs and promote transparency in financial transactions. Angelis and daSilva (2019) examine factors influencing blockchain adoption, emphasizing integration challenges and high adoption costs. Anosova (2019), in herdissertationtitled*"Formation and Development of Fortification Technologies of Defense Complexes of Western Ukraine (12th-18th Centuries),"*draws attention to approaches to studying blockchain technologies; however, this work takes only a general approach to research. Balcerzak et al. (2022) define the role of blockchain technologies and smart contracts in decentralized governance systems, noting the potential for significant improvements in management efficiency while acknowledging the technical and legal challenges that require further investigation. Bondarenko (2018) discusses the implementation of blockchain in public administration, highlighting the lack of a clear regulatory framework. Khanfar, Iranmanesh, Ghobakhloo, Senali, and Fathi (2021) identify significant potential for improving transparency and efficiency, though they emphasize the need

for further research to address existing limitations. The Law of Ukraine (2021) provides a review and analysis of legislation regarding blockchain regulatory mechanisms.
The reviewed scientific papers confirm that distributed ledger technologies have significant potential for implementation in urban planning, with the prospect of improving transparency, efficiency and sustainability in various fields, including supply management, energy, education and healthcare. However, significant challenges remain, such as technical limitations, integration problems and the lack of a clear legal framework. Based on this analysis, the identified research gaps indicate the need for further study of the concept of "smart city" and distributed ledger technology to identify common key characteristics and explore new technological solutions, particularly for public administration.

METHODS

This study uses a methodology that combines both qualitative and quantitative approaches. In particular, bibliometric indicators were used to obtain a comprehensive understanding of the knowledge base in the study of blockchain technology, the study of new trends, cooperation models and intellectual structures. In addition, a systematic literature review (SLR), a rigorous method widely used in management and social sciences, was conducted to further analyze blockchain technologies. The literature review followed a well-defined and reproducible protocol aimed at evaluating scientific concepts, identifying existing gaps, and suggesting future directions for research in this area.

Sample and Participants

The research process began with an initial review of the literature on smart cities and blockchain technology. Brainstorming was conducted to determine the most accurate combination of keywords representing the knowledge domain in this field. The Web of Science (WoS), one of the largest bibliometric databases containing high-quality peer-reviewed journals, was chosen as the research platform. This database contains comprehensive citations and most of the scientific articles relevant to the field. The keywordcombinations used in the searchincluded "SMART CITY," "BLOCKCHAIN," and "DISTRIBUTED LEDGER TECHNOLOGY." All articles within the database were considered for inclusion, covering the period from 1950 (the earliestyear available in this field) to 2022. The searchyielded 1,010 documents from 2016 to 2022.

Instruments and Procedures

WoSfiltering tools were used to refine the selection to include only articlespublished in English, focusing on research articles and review papers. This stepensured the scientific quality of the finalsample, as conferencepapers and bookchapters may not be subject to rigorouspeer review. Further refinementinvolvedselectingarticles from WoScategories such as telecommunications, transportationscience, urban studies, management, business, finance, economics, environmental sciences, and multidisciplinary sciences. This approach excluded more technical papers on blockchain applications in fieldslike engineering or computer science. The finalfocus was on research related to the role of blockchain technology in developing innovative and sustainable smart cities, resulting in a finalsample of 359 articles.

Data Analysis

To evaluate the final sample of 359 articles, the study conducted a bibliometric analysis that included: (i) performance analysis to describe the characteristics of the sample and identify the most influential authors, journals, and documents; (ii) co-authorship analysis; (iii) co-citation analysis; and (iv) co-occurrence analysis of partially used keywords. To further refine the scope of the study, the sample was narrowed down to articles in specific WoS categories, such as business, finance, management, and economics. This approach allowed the systematic review to focus on studies discussing the role and application of blockchain technology in smart city financial systems. After applying these filters and conducting a thorough review, the systematic literature review (SLR) was completed with a sample of 46 documents.

RESULTS

Blockchain technology can be characterized as a securely protected history of transactions that is distributed among user agents and does not require coordination by an external server or central authority (Konashevich, 2020). This

technology is a departure from traditional centralized management systems, where a central authority was responsible for ensuring data security and controlling its distribution. The central authority had to be highly reliable in order to maintain trust between agents, which was particularly evident in financial systems. As long as the central authorityremainedtrustworthy, the system functionedcorrectly; however, a singleerror, failure, or breachcould lead to the collapse of the entire system. Moreover, only the central authoritycould ensure the uniqueness of stored data or transactions, but instances of fraudinvolving the alteration of central servers, with significant repercussions for all system participants, have occurred. Blockchain technology fundamentallyaddresses this issue by eliminating the central authority and guaranteeingtransactionimmutability through the distributed storage of information among agents. Each agent acts as a custodian of the information, and changes made by one agent do not affect the system since it relies on the consensus of the majority. Consequently, blockchain technology can be considered a self-regulating system.

Blockchain systems are based on threeprinciples: transparency, security, and safety (Khanfar, 2021). They can be categorized into open, regulated, and closed systems. In closed systems, the number of participants is limited, and their actions may be restricted, with different roles for reading and writing data. Regulated systems represent an intermediatetype where user access is unrestricted, but data usage is controlled by the system. Open systems have no restrictions and are self-regulated. The initial development of blockchain systems sawsignificant growth in cryptocurrency, which fully showcased the technology's potential and offered opportunities previously unimaginable in the financial world. The advent of blockchain 2.0 and the concept of "smart contracts" enabled the application of the technology across various sectors. Today, blockchain'scapabilities and the technical feasibility of using DistributedLedger Technology (DLT)—which involvesshared information storage based on consensus—present blockchain as a reliable technology applicablewherevertransactions and a network of agentsexist (Jiang &Zheng, 2021; Kaushik&Sharma, 2024). Technically, blockchain capabilities are realized through technologies such as peer-to-peernetworks and digital signatures. Each network agentstores a portion or the entirety of the database of all created transactions. Thus, any changes in the database can only occur with individual user consent, making them immediatelynoticeable and suspicious. Using consensus information from the majority ensures data integrity without relying on a central authority. Essentially, each user can independentlyverify the accuracy of information by automaticallyquerying other users. Digital signatures help verify who creates a new transaction and whether they have the authority to do so (Howson, 2020).

Blockchain technology is anticipated to impact various applications in the development of smart cities and advance sustainability. These applications encompass smart governance, smart mobility, smart assets, smart utilities, and smart logistics, as depicted in Figure 1.

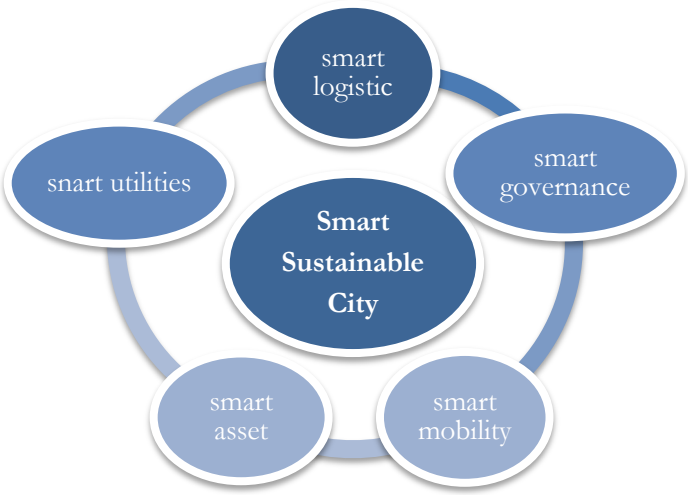

Figure 1. Smart sustainable city-blockchain (SSCB) integration framework
Source: compiled by the authors based on analysis from Kouhizadeh et al. (2021)

Smart Governance

Blockchain technology can significantly enhance governance in smart cities (Yermack, 2017). It promises to streamline public service delivery and operations by recording and linking government records, such as financial transactions and contracts, to improve transparency and prevent corruption. Additionally, blockchain can enable the creation of a decentralized voting system to combatvoterfraud. Smart contracts ensure that each voter can cast only one vote and verifyvoteridentities, thereby preventing the manipulation of voting results. Blockchain can securelystore citizen identities and personal information, including national IDs, birth and deathrecords, passports, healthrecords, and employmenthistories, making it easier to combat identity fraud. This secure, encrypted storage allows for efficient management of personal information, reducing paperwork and improving detection and documentation processes (Wang et al., 2021).

Smart Mobility

Blockchain technology is increasingly being used for mobile solutions (Angelis & RibeirodaSilva, 2019). The rise of the sharing economy has created trust issues that blockchain can solve. For example, in ride-sharing services, blockchain can store data about vehicles and users, building trust through verified digital identities. This provides easy verification of the identity of drivers and passengers. In addition, blockchain can improve ticketing systems for public transport (e.g. buses, trains, bicycles) by providing a single platform for purchasing digital tickets and transactions using digital tokens. This integration simplifies operations by eliminating the need for multiple ticketing systems. City planners can use blockchain to reward users of shared rides or public transportation with digital tokens based on immutable records. Integrating blockchain with IoT sensors can also help manage traffic by providing real-time data that helps eliminate congestion and reduce emissions, promoting sustainable development.

Smart Asset Management

Blockchain can improve real estate and housing transactions through the use of smart contracts that replace traditional intermediaries and reduce risks such as asset transfer issues, double registration, and fraud (Marsal-Llacuna, 2018; Wang & Kogan, 2018). It promotes real estate development by collecting and storing information related to land registry, design, construction and maintenance. Blockchain provides an immutable record throughout the life cycle of an asset, ensuring accurate record keeping and transparency. As noted by Lund et al. (2019), smart contracts can automate payments after construction work is completed, and blockchain records can facilitate ongoing maintenance and repairs by providing easy access to historical data (Hunt et al., 2022; Yermack, 2017).

Smart Utility

Blockchain can significantly increase the efficiency of intelligent utilities, particularly in the field of energy management, thanks to accurate accounting of electricity consumption and demand forecasting. Ahluwalia et al. (2020) propose a blockchain-based Smart EnergyGrid concept where devices connect to energy batteries and a mobile application to access a trading platform. Users can view energy volumes, sales data and monitor their consumption patterns. Similarly, the blockchain can regulate the use of water resources in different areas of the city. In addition, blockchain combined with IoT can facilitate energy transactions by allowing users to sell excess energy from solar panels directly to neighbors. All transactions are recorded in the blockchain registry, which creates a decentralized energy market and tracks the carbon footprint of products. This information supports the introduction of carbon taxes and incentivizes companies to reduce their carbon footprint. Through integration with IoT and artificial intelligence, blockchain can also improve waste management by identifying waste levels and optimizing collection schedules, ensuring the rational use of resources.

Smart Logistics

Blockchain technology has great potential for increasing supply chain transparency and traceability (Anosova, 2019). Because materials often come from different suppliers, blockchain can trace the origin of each product at all stages of the supply chain, from mining to manufacturing and transportation. It creates an immutable record of product status, which simplifies operations and provides customers with information about its origin and path (Rui et al., 2021). This level of transparency helps quickly identify sources of contamination in the event of problems and reduces the need for multiple checks by multiple parties.

The use of blockchain in Ukraine has grown significantly in recent years. According to the Blockchain Association of Ukraine, 32% of all blockchain-related companies were founded in 2021. The majority of Ukrainian blockchain companyfounders have backgrounds in programming and development (38%), finance, investment, and trading (38%), cryptography and cryptocurrencies (32%), as well as marketing and advertising (12%) (Ministry of Digital Transformation of Ukraine; Bachynskyy&Radeiko, 2019). National policies on the organizational and legal regulation, implementation, and application of blockchain technology varywidely across countries. While some nations are making strides in addressing these issues, progress on a globalscaleremainsslow. Like other countries, Ukraine is justbeginning to adopt blockchain technologies (Ministry of Digital Transformation of Ukraine, 2022). A significant steptowardsregulating the legal relationships arising from the use of blockchain technology was the development of the draft Law of Ukraine "On Virtual Assets" (Verkhovna Rada of Ukraine, 2022). This law is intended to regulate the legal relations related to the circulation of virtual assets in Ukraine, defining the rights and responsibilities of market participants, as well as the principles of state policy in this area. Once the "On Virtual Assets" law comes into effect, both foreign and Ukrainian cryptocurrencyexchanges will be able to operatelegally in Ukraine. Ukrainian banks will have the right to open accounts for crypto companies, and investments in virtual assets will be protected by law, with the Ukrainian government guaranteeing judicial protection of rights to virtual assets (Verkhovna Rada of Ukraine, 2022). The President of Ukraine has proposed classifying virtual asset services as financial services. These steps aim to fully legalize the use of blockchain technology in Ukraine. The Ministry of Digital Transformation of Ukraine has announced its intention to expand international partnerships with blockchain networks in other countries and join the European Blockchain Services Infrastructure. Additionally, the Ukrainian government has expressedinterest in launchingpilot projects for cross-border public services based on blockchain technology. These efforts are aimed at promoting the integration of blockchain technologies into the government operations of the state (Ministry of Digital Transformation, 2022).

Examples of successful implementation of blockchain technology in Ukrainian companies are presented in Table 1.

Table 1. Successful implementation of blockchain technology in Ukrainian companies

Company	YearFounded	Core Activities	Project	Goals and Mission
BitfuryGroup	2011	Providing blockchain hardware and software solutions	Implementation of the eGovernance blockchain program in Ukraine	To foster innovation in the blockchain sector by creating secure and scalable blockchain services and products
Attic Lab	2019	Developing blockchain-based software products	CODEX, Attic Lab EOS BlockProducer	Participation in disruptive projects, collaboration with banks and companies worldwide, certification of software by central

				banks
Bloqly	2018	Developing blockchain platforms for businesses and governments	SMART CITY, anti-counterfeiting and fraud protection, anti-corruption programs	Ensuring transparency and data security through blockchain, implementing solutions for smart cities and government services

Source: Compiled by the authors based on analysis from Anosova (2019).

A review of the scientific literature highlights that the implementation of blockchain technology (BT) in sustainable development initiatives faces significant challenges. These challenges have been explored in detail in Mulligan et al. (2021), Khanfar et al. (2021) and others, and are extremely important aspects to consider when discussing the promotion of BT in the context of sustainable development.

Table 2. Challenges of Blockchain Technology in Sustainability Initiatives

Challenges	Description
Scalability and Security	Increased transactionvolumes can reduce performance, and security concernspersist, including vulnerabilities to attacks.
Energy Consumption	Proof-of-Work (PoW)-based blockchain networksconsume significant energy, raising environmental concerns, particularly regarding carbon emissions.
Regulatory and Ethical Issues	The decentralized nature of blockchain complicates regulatory compliance across borders; ethical concernsinclude data privacy and illicit activities.
Resistance to Adoption	Resistance to new technologies, along with the complexity and cost of integration, poses significant barriers to widespread adoption, especially for smaller organizations.
Economic Implications	Blockchain's potential to disruptemployment and incomedistributionrequirescareful regulation and educational efforts to ensure equitable benefits.

Source: Compiled by the authors based on analysis from Bhushan et al. (2020), Fan et al. (2018), Fleener (2022).

Successful and long-term adoption of blockchain technology (BT) depends on effectively overcoming these challenges. This requires developing more energy-efficient consensus mechanisms, implementing robust security protocols, creating a stable regulatory framework, and educating stakeholders on the benefits and practicalities of BT. Table 3 presents comprehensive strategies developed to address the various challenges associated with integrating blockchain technology into sustainability initiatives. These strategies include technological innovation, regulatory change, ethical considerations, educational initiatives, and economic policy, emphasizing the importance of joint action by all stakeholders to maximize blockchain's potential for sustainable development.

Table 3. Strategies for Integrating Blockchain Technology into Sustainability Initiatives

Challenge Category	Solution	Description
Scalability and Security	Layeredarchitecture and off-chain solutions	Research off-network solutions and develop a multi-tiered blockchain architecture to increase scalability by reducing congestion and improving efficiency while maintaining security.
	Advanced consensus mechanisms	Utilizestreamlinedconsensus methods likeProof of Stake (PoS) or DelegatedProof of Stake (DPoS) to lowercomputational and energydemands, addressing both scalability and security challenges.

EnergyUtilization	Transition to energy-efficient consensus mechanisms	Shift from the Proof of Work (PoW) consensusalgorithm to more energy-efficient models, such as Proof of Stake (PoS), to significantly reduce blockchain energy consumption, thereby contributing to sustainability goals.
	Adoption of renewableenergysources	Promote the integration of renewableenergysources into blockchain operations by introducing regulations and incentives to reduce environmental impact.
Ethical and Regulatory Considerations	Development of international regulatory frameworks	Develop a unified international regulatory framework to effectively manage the decentralized aspects of blockchain, ensuring data protection, privacy, and prevention of illegal activities.
	Establishment of ethical standards and guidelines	Develop ethical standards and guidelines for using blockchain to guarantee user privacy and promote sociallybeneficialgoals.
Resistance to Change and Adoption	Capacity building and education	Initiate educational programs and provide resources to explain blockchain technology, reducing resistance and emphasizing the importance of training for developers, users, and stakeholders.
	Collaborations and pilot programs	Implement pilot projects and support collaboration between industry, government agencies, NGOs, and blockchain developers to demonstrate the practical benefits of the technology, simplify integration, and reduce costs.
Economic Consequences	Inclusive economic policies	Develop policies that support financial inclusion and small and medium-sized businesses to mitigate the negative impact on employment and incomedistribution, ensuring equitable benefits from blockchain technology.

Source: Compiled by the authors based on analysis from DiVaio (2020), Jiang &Zheng (2021), Rajput (2021), and Dubey et al. (2017).

Invest in workforce training and retraining programs to prepare individuals for new blockchain opportunities, positivelyimpactingemployment and incomedistribution.

DISCUSSION

The adoption of blockchain technology across various industriesholds the potential to enhance supply chain transparency, optimize the distribution of renewableenergy, and improve resource management. Smart contracts and decentralized applications can play a crucial role in upholding sustainability standards. Governments have a critical role in shaping the future of blockchain in sustainability, requiring legal frameworks that foster innovation while addressing potential risks, such as concernsover data privacy and financial stability. Policymakers can promote the use of blockchain in sustainable practices by offeringincentives, such as subsidies for companies that utilize blockchain for sustainable supply chaintracking or by providing legislative support for blockchain-based renewableenergy projects (BarellaMigliorini et al., 2021).

The sustainable development of cities is of key importance for national economies, technologies and public services, as they are the concentration of productive forces, industrial enterprises and a large part of the population (Bai & Satir, 2020). However, cities face a number of challenges affecting their digital transformation, such as the implementation of

blockchain technologies in public services, outdated infrastructure, limited budget resources, and the need for new technological solutions for city services (Sultan et al., 2018). In addition, cities are forced to deal with increasing environmental pollution and meet increasing demands for a high-quality urban environment and safety for both infrastructure and residents (Brilliantova&Thurner, 2019; DiVaio&Varriale, 2020).

Today, there are no generally accepted criteria for assessing the level of intellectualization of cities. The development of smart cities depends on many factors, including the progress of information city networks (Heigl et al., 2019; Chaudhary et al., 2019). The difficulty of assessing the prospects and directions of the digital transformation of cities lies in the fact that the specific set of technologies that make up the technological package related to the formation of a smart city is still at the stage of active development and is not yet fully defined (Soni, 2020; Fu et al. ., 2021).

In the conditions of modern challenges to urban development, especially in the context of sustainable development, the issue of data storage and transportation, as well as ensuring the transparency and security of information flows, becomes relevant. Blockchain is increasingly recognized as an optimal evolutionary step in this direction, offering cities the potential to overcome the many challenges of integrating infrastructure and improving the technological, social, and financial environment in urban communities (Christidis & Devetsikiotis, 2016; Cioffi et al., 2020 ; Rana et al., 2022). It is essential for localgovernments today to focus on several key areas where blockchain technology couldbring about significant progress in the development of smart cities (Alajlan et a. These areas include smart healthcare, supply chains and logistics, mobility, energy, government administration and services, e-voting, manufacturing, housing, and education (Hayes, 2014; Wang et al., 2018). These sectors representcrucial areas of blockchain application in advanced countries, even beyond the context of smart cities (Cole et al., 2019). Therefore, implementing blockchain technology in managing these sectors serves as the "central building blocks" of a smart city (Khanfar et al., 2021).

Thus, the scientific novelty of our study lies in the review of the main professional publications in the subject area of research, which provides grounds for asserting that the concepts of "smart city" and blockchain technology sharetwocommon key properties. First, they are broadconcepts that describe a vision of a functional environment more suitable for comfortableliving and conducting business than traditional models (Corbet et al., 2020; Crosby et al., 2016; Dai et al., 2019). Second, both concepts are currently in the developmentalstage, involving the creation of new technological solutions, particularly for public administration bodies (Davidson et al., 2016; Dutta et al., 2020). Technological progress opens up new opportunities for updating innovative tools for the development of large urban communities, particularly in implementing the concept of smart cities. Blockchain technology can serve as a technical platform that enhances the capacity of public administration bodies and all participants in the urban development process. This enhancement is achieved by implementing effective solutions that ensure the scalability of transactions without relying on energy-intensive mechanisms to achieve consensus among key stakeholders.

CONCLUSIONS

This article offers a detailed analysis of the potential of blockchain technology (BT) to significantly impact sustainable development in the environmental, economic and social spheres. Blockchain plays a key role today as it enables information and communication technologies (ICTs) to function effectively in an optimal anthropological, social and political environment. Blockchain is a system that can help create a fully democratic society because it allows each individual to hold others accountable rather than relying solely on specialized governing bodies. This creates the conditions under which management develops both from the bottom up and from the top down at the same time, and not exclusively from the top. Thus, blockchain not only provides applications for "smart cities" that benefit bureaucrats, but also facilitates direct coordination of actions by residents, supporting self-organization.

The prospects for blockchain development are

extremely broad and diverse. From uses in the economic and financial sectors to applications in medicine, cyber security and government, blockchain can greatly contribute to various industries and facilitate many processes in everyday life. One of the key areas of blockchain development is its ability to reduce costs and increase the efficiency of business processes. This is achieved by reducing operational costs and eliminating intermediaries in business operations. In addition, blockchain can provide an increased level of data security and privacy, which is especially important for businesses and government agencies. Another advantage of blockchain is its ability to provide faster and easier access to information, which promotes innovation and the implementation of new technologies.

Thus, the study showed that blockchain is actively integrated into urban structures. Based on an objective assessment of the potential of this technology, a clear tendency to increase the efficiency of enterprises can be observed, despite the significant costs of its implementation and the need for additional investments for further development. It was also found that blockchain has the potential to significantly enhance the economy and improve the quality of life in cities. This technology offers the possibility of fostering a more ethically and intellectually healthy society that is continually evolving.

Limitations of the Study

The limitations in research and implementation of recommendations are largely due to the ongoing state of war, which significantly restricts the development of blockchain technology in Ukraine and other affected countries. These circumstances lead to increased capital costs, heightened risks, reduced investment, and limited government support, all of which increase uncertainty about the future adoption of blockchain technology. Despite these challenges, it is important to recognize the strategic importance of blockchain technologies for government institutions and services and to take all possible measures to support their developers, even under martial law.

Suggestions for Future Research

Further research in the context of blockchain technology couldfocus on facilitating access to financing and loans for urban projects and technologies on preferential terms. It would also be relevant to study the investmentattractiveness of urban initiatives, particularly thoserequiring infrastructure renewal and technological upgrades. This is especiallypertinent for projects that utilize blockchain to enhance the management of city resources, services, and infrastructure.

References

Ahluwalia, S., Mahto, R. V., & Guerrero, M. (2020). Blockchain technology and startupfinancing: A transaction cost economicsperspective. *Technological Forecasting and Social Change*, 151, 119854. https://doi.org/10.1016/j.techfore.2019.119854

Angelis, J., &RibeirodaSilva, E. (2019). Blockchain adoption: A valuedriverperspective. *Business Horizons*, *62*(3), 307–314. https://doi.org/10.1016/j.bushor.2018.12.001

Anosova, V. S. (2019). Formation and development of fortification technologies of defencecomplexes of Western Ukraine (XII-XVIII centuries) *[Dissertation for the degree of Candidate of Historical Sciences]*. State University of Infrastructure and Technology, Kyiv, Ukraine.

Bachynskyy, T., &Radeiko, R. (2019). Legal regulations of Blockchain and cryptocurrency in Ukraine. *Hungarian Journal of Legal Studies*, *60*(1), 3–17. https://doi.org/10.1556/2052.2019.60102

Bai, C., &Satir, A. (2020). Evaluatinggreensupplier satisfaction. *Modern Supply Chain Research and Applications*, *2*(2), 63–81. https://doi.org/10.1108/mscra-02-2019-0008

Balcerzak, A. P., Nica, E., Rogalska, E., Poliak, M., Klieštik, T., &Sabie, O.-M. (2022). Blockchain technology and smart contracts in decentralized governance systems. *Administrative Sciences*, *12*(3), 96. https://doi.org/10.3390/admsci12030096

BarellaMigliorini, I., DeHoyosGuevara, A., DeMeloConti, D., &CatarinaDib, V. (2021). Blockchain technologies in smart cities: A proposal for autopoietic smart cities. *Journal on*

Innovation and Sustainability RISUS ISSN 2179-3565, *12*(4), 04–12. https://doi.org/10.23925/2179-3565.2021v12i4p04-12

Bhushan, B., Khamparia, A., Sagayam, K. M., Sharma, S. K., Ahad, M. A., &Debnath, N. C. (2020). Blockchain for smart cities: A review of architectures, integration trends and future research directions. *Sustainable Cities and Society*, *61*(102360), 102360. https://doi.org/10.1016/j.scs.2020.102360

Bondarenko, O. V. (2018, August 27). *Zaprovadzhenniatekhnolohiiblokcheyn u derzhavnomusektori* [Implementation of blockchain technology in the public sector]. Protocol. https://protocol.ua/ua/zaprovadgennya_tehnologii_blokcheyn_u_dergavnomu_sektori/#google_vignette

Brilliantova, V., &Thurner, T. W. (2019). Blockchain and the future of energy. *Technology in Society*, *57*, 38–45. https://doi.org/10.1016/j.techsoc.2018.11.001

Chaudhary, R., Jindal, A., Aujla, G. S., Aggarwal, S., Kumar, N., &Choo, K.-K. R. (2019). BEST: Blockchain-based secureenergytrading in SDN-enabledintelligenttransportation system. *Computers& Security, 85*, 288–299. doi.org/10.1016/j.cose.2019.05.010

Christidis, K., &Devetsikiotis, M. (2016). Blockchains and Smart Contracts for the Internet of Things. *IEEE Access*, *4*, 2292–2303. https://doi.org/10.1109/access.2016.2566339

Cioffi, R., Travaglioni, M., Piscitelli, G., Petrillo, A., &Parmentola, A. (2020). Smart Manufacturing Systems and Applied Industrial Technologies for a Sustainable Industry: A Systematic Literature Review. *Applied Sciences*, *10*(8), 2897. https://doi.org/10.3390/app10082897

Cole, R., Stevenson, M., &Aitken, J. (2019). Blockchain technology: implications for operations and supply chain management. *Supply Chain Management: An International Journal*, *24*(4), 469–483. https://doi.org/10.1108/scm-09-2018-0309

Corbet, S., Larkin, C., Lucey, B., &Yarovaya, L. (2020). KODAKCoin: a blockchain revolution or exploiting a potential cryptocurrencybubble? *Applied Economics Letters*, *27*(7), 518–524. https://doi.org/10.1080/13504851.2019.1637512

Crosby, M., Pattanayak, P., Verma, S., &Kalyanaraman, V. (2016). Blockchain technology: BeyondBitcoin. *Applied Innovation, 2*, 71. https://www.scirp.org/reference/referencespapers?referenceid=2525044

Dai, H.-N., Zheng, Z., & Zhang, Y. (2019). Blockchain for internet of things: A survey. *IEEE Internet of Things Journal*, *6*(5), 8076–8094. https://doi.org/10.1109/jiot.2019.2920987

Davidson, S., DeFilippi, P., &Potts, J. (2016). Economics of blockchain. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2744751

DiVaio, A., &Varriale, L. (2020). Blockchain technology in supply chain management for sustainable performance: Evidence from the airport industry. *International Journal of Information Management*, *52*(102014), 102014. https://doi.org/10.1016/j.ijinfomgt.2019.09.010

Dubey, R., Gunasekaran, A., Papadopoulos, T., Childe, S. J., Shibin, K. T., &Wamba, S. F. (2017). Sustainable supply chain management: framework and further research directions. *Journal of Cleaner Production*, *142*, 1119–1130. https://doi.org/10.1016/j.jclepro.2016.03.117

Dutta, P., Choi, T.-M., Somani, S., &Butala, R. (2020). Blockchain technology in supply chainoperations: Applications, challenges and research opportunities. *Transportation Research Part E: Logistics and Transportation Review*, *142*(102067), 102067. https://doi.org/10.1016/j.tre.2020.102067

Fan, K., Ren, Y., Wang, Y., Li, H., & Yang, Y. (2018). Blockchain-based efficient privacy preserving and data sharingscheme of content-centric network in 5G. *IET Communications*, *12*(5), 527–532. https://doi.org/10.1049/iet-com.2017.0619

Firdaus, A., Razak, M. F. A., Feizollah, A., Hashem, I. A. T., Hazim, M., &Anuar, N. B. (2019). The rise of "blockchain": bibliometric analysis of blockchain study. *Scientometrics*, *120*(3), 1289–1331. https://doi.org/10.1007/s11192-019-03170-4

Fleener, M. J. (2022). Blockchain Technologies: A Study of the Future of Education. *Journal of*

Higher Education Theory and Practice, *22*(1). https://doi.org/10.33423/jhetp.v22i1.4956

Fu, Z., Dong, P., Li, S., Ju, Y., & Liu, H. (2021). How blockchain renovate the electricvehiclecharging services in the urban area? A case study of Shanghai, China. *Journal of Cleaner Production*, *315*(128172), 128172. https://doi.org/10.1016/j.jclepro.2021.128172

Hayes, A. (2014, June 13). *Blockchain facts: What is it, how it works, and how it can be used*. Investopedia. https://www.investopedia.com/terms/b/blockchain.asp

Heigl, M., Doerr, L., Tiefnig, N., Fiala, D., &Schramm, M. (2019). A resource-preservingself-regulatingUncoupled MAC algorithm to be applied in incident detection. *Computers& Security*, *85*, 270–287. https://doi.org/10.1016/j.cose.2019.05.010

Howson, P. (2020). Building trust and equity in marineconservation and fisheries supply chain management with blockchain. *Marine Policy*, *115*(103873), 103873. https://doi.org/10.1016/j.marpol.2020.103873

Hunt, K., Narayanan, A., &Zhuang, J. (2022). Blockchain in humanitarianoperations management: A review of research and practice. *Socio-Economic Planning Sciences*, *80*(101175), 101175. https://doi.org/10.1016/j.seps.2021.101175

Jiang, Y., &Zheng, W. (2021). Coupling mechanism of green building industry innovation ecosystem based on blockchain smart city. *Journal of Cleaner Production*, *307*(126766), 126766. https://doi.org/10.1016/j.jclepro.2021.126766

Kaushik, K., &Sharma, I. (Eds.). (2024). *Next-generationcybersecurity: AI, ML, and blockchain*. Springer Nature Singapore.

Khanfar, A. A. A., Iranmanesh, M., Ghobakhloo, M., Senali, M. G., &Fathi, M. (2021). Applications of blockchain technology in sustainable manufacturing and supply chain management: A systematic review. *Sustainability*, *13*(14), 7870. https://doi.org/10.3390/su13147870

Konashevych, O. (2020). Constraints and benefits of the blockchain use for real estate and property rights. *Journal of Property Planning and Environmental Law*, *12*(2), 109–127. https://doi.org/10.1108/jppel-12-2019-0061

Kouhizadeh, M., Saberi, S., &Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoreticallyexploring adoption barriers. *International Journal of Production Economics*, *231*(107831), 107831. https://doi.org/10.1016/j.ijpe.2020.107831

Lund, E. H., Jaccheri, L., Li, J., Cico, O., &Bai, X. (2019, May). Blockchain and sustainability: A systematic mapping study. In *2019 IEEE/ACM 2nd International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB)* (pp. 16-23). IEEE. doi.org/10.1109/WETSEB.2019.00009

Marsal-Llacuna, M.-L. (2018). Future living framework: Is blockchain the next enabling network? *Technological Forecasting and Social Change*, *128*, 226–234. https://doi.org/10.1016/j.techfore.2017.12.005

Ministry of Digital Transformation of Ukraine. (2022). The Ministry of Digital Transformation of Ukraine: The IT industry in Ukraine continues to growdespite the war. https://ukraine.ua/invest-trade/digitalization/

Rana, S. K., Rana, S. K., Nisar, K., AgIbrahim, A. A., Rana, A. K., Goyal, N., &Chawla, P. (2022). Blockchain technology and artificial intelligence based decentralized access control model to enablesecureinteroperability for healthcare. *Sustainability*, *14*(15), 9471. https://doi.org/10.3390/su14159471

Rui, L., Zhang, M., Gao, Z., Qiu, X., Wang, Z., &Xiong, A. (2021). Corrigendum to "Service migration in multi-access edge computing: A joint state adaptation and reinforcement learning mechanism" [J. Netw. Comput. Appl. 183–184 (2021) 103058]. *Journal of Network and Computer Applications*, *186*(103085), 103085. https://doi.org/10.1016/j.jnca.2021.103085

Soni, N. (2020, July 22). *Evolution of blockchain - NehaSoni*. Medium. https://medium.com/@nehasoni1812/evolution-of-blockchain-f243f7509fe6

Sultan, K., Ruhi, U., &Lakhani, R. (2018). ConceptualizingBlockchains: Characteristics & Applications. In *arXiv [cs.CY]*. http://arxiv.org/abs/1806.03693

Swan, M. (2015). *Blockchain: Blueprint for a new economy*. O'ReillyMedia.

Verkhovna Rada of Ukraine. (2022). *On virtual assets:Law of Ukraine No. 2074-IX of 17.02.2022*. Retrieved from https://zakon.rada.gov.ua/laws/show/2074-20#Text

Wang, H., Zheng, Z., Xie, S., Dai, H. N., & Chen, X. (2018). Blockchain challenges and opportunities: a survey. *International Journal of*

Web and Grid Services, *14*(4), 352. https://doi.org/10.1504/ijwgs.2018.10016848

Wang, J., Huang, Q., Li, Y., &Gu, J. (2021). Reducing transactionuncertainty with brands in web stores of dual-channelretailers. *International Journal of Information Management*, *61*(102398), 102398. https://doi.org/10.1016/j.ijinfomgt.2021.102398

Wang, Y., &Kogan, A. (2018). Designingconfidentiality-preserving Blockchain-based transaction processing systems. *International Journal of Accounting Information Systems*, *30*, 1–18. https://doi.org/10.1016/j.accinf.2018.06.001

Yermack, D. (2017). Corporate governance and blockchains. *Review of Finance*, rfw074. https://doi.org/10.1093/rof/rfw074