AREAS OF BLOCKCHAIN TECHNOLOGY APPLICATION IN SMART CITY – PART II

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Purpose: The objective of this paper is to highlight the potential of blockchain technology in the context of smart cities. The author examines the current state of blockchain-based solutions and connects them to various aspects of urban operations. Additionally, the paper aims to emphasize the significance of blockchain applications in improving the quality of life for city residents and enhancing the efficiency of industries operating within urban environments, with a particular focus on sectors such as telecommunications, energy, and transportation.

Design/methodology/approach: The purpose of the paper were achieved by analyzing literature, industry reports as well as selected blockchain projects' websites. The theoretical scope of the article is the description of blockchain technology application areas within selected industries.

Findings: The author identified three key areas of blockchain application and discussed several existing blockchain-based solutions related to them, highlighting their potential impact on urban development. In the conclusion, the author outlined areas for further research, focusing on different aspects of city growth and enhancing the quality of life for its residents.

Practical implications: The successful implementation of blockchain solutions requires significant conceptual and technological efforts within organizations. The article outlines potential areas for blockchain application in cities and presents examples of existing solutions that can serve as a reference and inspiration for future innovations.

Social implications: Blockchain technology holds the potential to enhance the quality of life for city residents by creating solutions that eliminate the need to rely on service providers, whose trustworthiness is often compromised by unethical behavior and negligence in ensuring secure and transparent information flow. Consequently, the widespread adoption of blockchain in urban environments is undoubtedly in the best interest of society.

Originality/value: The originality of the paper lies in its comprehensive examination of the use of blockchain in the functioning of modern cities, highlighting both the potential for future implementation and existing solutions in the field. Additionally, the author emphasizes the social benefits, such as enhanced trust and improved quality of life for city residents.

Keywords: blockchain, smart city, telecom industry, energy industry, smart transportation.

Category of the paper: Literature review, viewpoint.

1. Introduction

Blockchain technology is playing an increasingly important role in the development of modern cities, which must face the challenges resulting from increasing urbanization, sustainable development and efficient resource management (Gade, Aithal, 2020). Thanks to its unique features, such as secure and irreversible data storage, blockchain is becoming a tool with great potential to revolutionize the functioning of cities (Alam, 2022). It opens up new possibilities in the areas of urban infrastructure management, provision of services to citizens, as well as in sectors such as transport, environmental protection, public health and digital identification (Ullah et al., 2023). The first part of the author's study, published in one of the previous issues of these Scientific Papers entitled "Areas of blockchain technology application in modern city - parti I", discusses three key areas of blockchain technology application in cities: food supply chain management, the functioning of the tourism industry and smart healthcare for residents (Zaczyk, 2024). Each of these areas has significant transformational potential, which is analyzed in detail, taking into account both the benefits and challenges related to the implementation of this innovative technology. This second part of the study extends this analysis, focusing on other key sectors: telecommunication industry, energy management and intelligent transport systems.

2. Materials and methods

A literature review - in particular bibliometrics - was carried out for research without the publishing time limitation on the topic of blockchain technology for smart city area of research. The first step was to analyze publications included in the Scopus database. However, for a comprehensive study, the analysis was deepened to include the Web of Science database. The following queries were run on September 30th 2024:

- Scopus: TITLE-ABS-KEY ("blockchain AND smart AND city"),
- Web of Science: TOPIC: ("blockchain smart city"); Indexes: SCIEXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCREXPANDED, IC.

The search results showed given numbers of publications in subject area:

- Scopus – 2256,
- Web of Science – 1257.

Figure 1 shows the number of publications on analyzed topics (years 2016-23) in both analyzed databases.
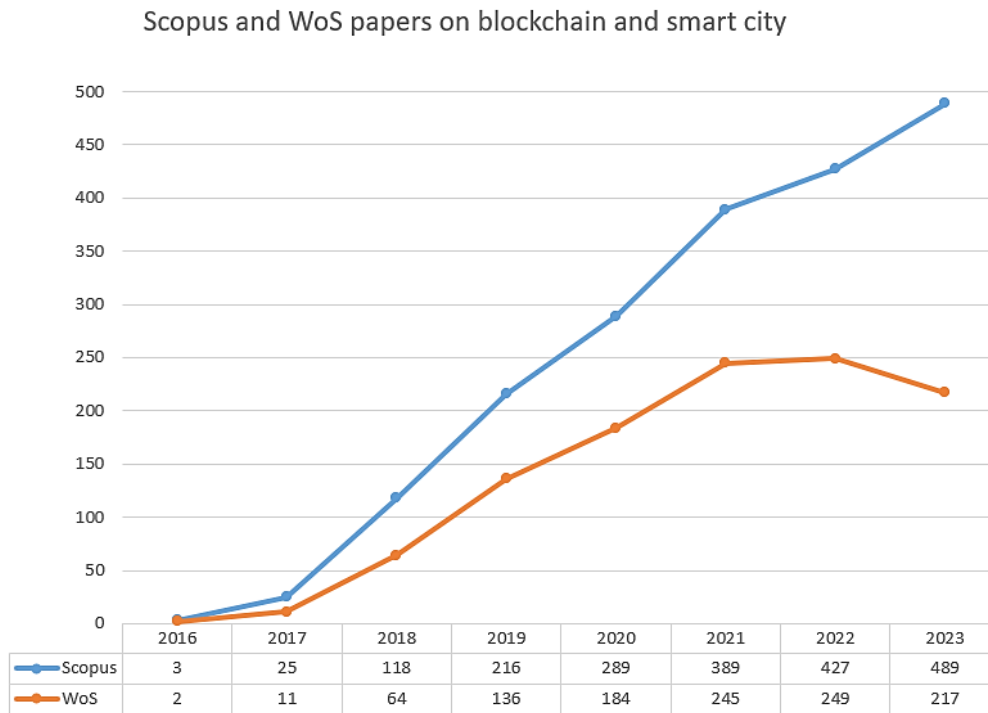
Figure 1. Scopus and WoS papers on Blockchain in Smart City.

Source: own elaboration.

The search results indicate a relatively big number of publications (Scopus – 2256, WoS – 1257) embedding the topic of blockchain technology in the field of smart city, which confirms the author's assumptions about the popularity of chosen topic and legitimacy of in-depth analyzes in this area. The graph of the number of papers in the analyzed area clearly shows an upward trend, signaling the constantly growing interest of researchers in the applications of blockchain technology in the area of city management. During the preparation of this article, the literature review resulting from the above bibliometric analyzes was supplemented with a review of reports from analytical and consulting companies as well as a review of selected blockchain projects websites.

3. Blockchain technology applications in the context of smart city

In the context of rapid advancements in urban development and technology, the concept of Industry 4.0 serves as a cornerstone of the digital revolution, reshaping industrial production processes while simultaneously driving significant innovations within smart city frameworks (Safiullin, Krasnyuk, Kaplyuk, 2019; Lepore, Testi, Pasher, 2023). Blockchain technology, a fundamental pillar of Industry 4.0, emerges as a critical enabler for efficient, secure, and transparent data management within urban ecosystems (Javaid et al., 2021). This study examines contemporary blockchain-based solutions, situating them within the paradigms of

smart cities and Industry 4.0. The analysis emphasizes how blockchain can enhance the development of smart cities by optimizing operational processes, improving infrastructure, delivering resident-focused services, and fostering innovative solutions essential for sustainable urban growth in the digital age (Zaczyk, 2022). While the foundational principles of blockchain technology and smart contracts have been extensively addressed in prior works by the author (Zaczyk, 2021) and other researchers (Warburg, Wagner, Serres, 2019), they are excluded from the scope of this paper.

Modern cities are increasingly being designed to address challenges such as urbanization, the necessity of reducing CO_2 emissions, and enhancing residents' quality of life through the integration of advanced ICT technologies (Yusoff, 2020). ICT advancements are pivotal to the dynamic development of various urban management subsystems, including healthcare, energy management, water resources, urban transportation, tourism, food supply chains, and education (Tcholtchev, Schieferdecker, 2021). The primary components of the smart city concept are illustrated in Figure 2.
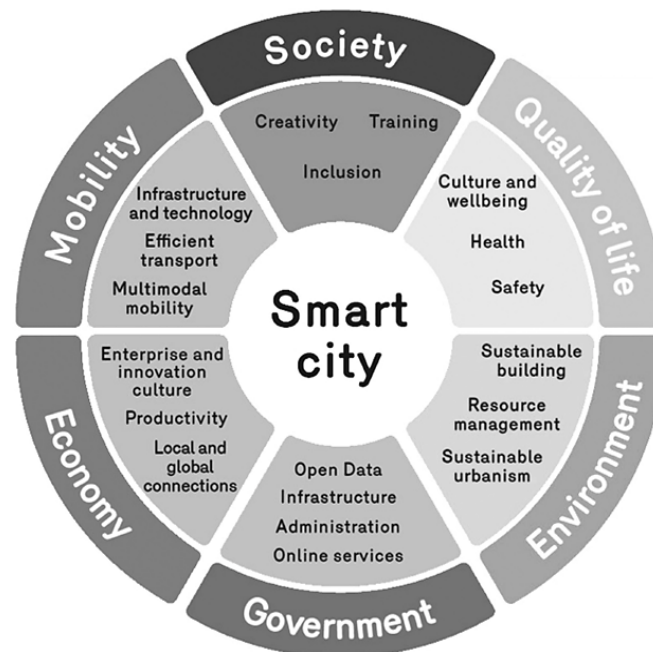

Figure 2. Main components of Smart cities.

Source: Qureshi, Hadi, Haroon, Bashir, Islam, 2020, pp. 75-92.

In this context, blockchain technology, which is one of the pillars of Industry 4.0, plays a key role in managing data in an efficient, secure and transparent manner (Shen et al., 2022). This is discussed in more detail in the first part of this study, where it is indicated how blockchain can support the development of smart cities by optimizing processes, improving infrastructure and providing services to residents (Zaczyk, 2024). Modern cities are designed with increasing urbanization in mind, reducing CO_2 emissions and improving the quality of life of residents, thanks to advanced ICT technologies (Rani et al., 2021). These technologies support the development of various urban systems, such as healthcare, energy management,

transport, tourism, food supply chains and education. Blockchain applications are increasingly mentioned as a key element of the transformation of cities (Treiblmaier, Rejeb, Strebinger, 2020). The combination of IoT technology, 5G (or even 6G) networks and blockchain offers huge potential for increasing security and automating processes thanks to smart contracts. Blockchain is used, among others, in: in supply chain management, tourism, smart healthcare, telecommunications, energy management and transport (Ullah et al., 2023).
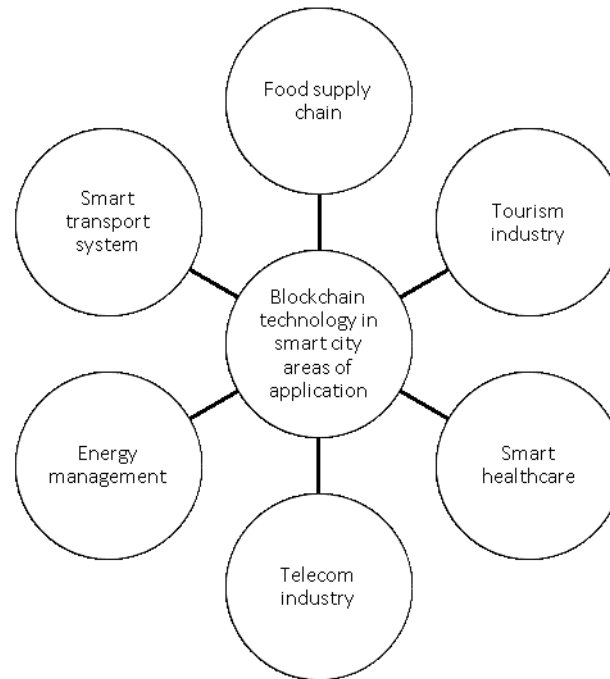
Figure 2. Areas of application of blockchain technology in smart city.

Source: own elaboration based on Ullah, Naeem, Coronato, Ribino, De Pietro, 2023.

The first three areas mentioned above and visible in Figure 2 were characterized in part I of this study, while this part focuses on the remaining three: telecommunication industry, energy management and smart transportation.

3.1.   Blockchain solutions for telecom industry

The role of the telecommunications sector cannot be overestimated in the context of managing the flow of information between people performing different roles in society (Leonelli, Beaulieu, 2021). Moreover, this sector is characterized by a high level of complexity of business processes and a huge amount of data flowing in its area (Al-Alwan et al., 2022). These features result in a growing interest in the use of blockchain technology in the telecommunications industry. Selected areas of application of blockchain-based solutions in the telecom industry are indicated in Table 1.

Table 1.
Selected blockchain-based solutions' in the telecom industry

Area of application	Description	Source
Identity management	Blockchain's cryptographic techniques ensure user authentication and data privacy, allowing customers to have better control over their identities and streamline authentication processes across various services.	- Liu et al., 2020 - Veramo.io - Hyperledger.org
Mobile number portability	Blockchain can improve MNP by establishing a secure and transparent record of mobile numbers. This more efficient system will enable quicker number transfers, minimizing downtime for customers during the switch.	- Shah et al., 2021 - Wipro.com - Zeebu.com
Smart contracts for roaming agreements	Blockchain-based smart contracts can securely automate and enforce roaming agreements between operators. This automation enhances efficiency, minimizes the potential for disputes, and accelerates the settlement process, benefiting both operators and customers.	- Sandholm, Mukherjee, 2021 - Tmforum.org
Billing and settlement	Blockchain's distributed ledger can provide real-time updates of usage and facilitate transparent and automatic settlement between telecom operators. This feature improves the accuracy of billing and ensures prompt payments, leading to better financial management.	- Afraz et al., 2023 - Ledgerinsights.com
IoT connectivity	Blockchain's decentralized architecture offers robust security and authentication mechanisms for IoT Connectivity devices. It enables IoT devices to communicate securely with each other, reducing the risk of unauthorized access and potential vulnerabilities in the network.	- Hewa et al., 2020 - Helium.com - Simbachain.com

Source: own elaboration.

In each of the areas indicated in Table 1, there are already some blockchain-based solutions. Some of them are already in use, others are in the development phase. In the author's opinion, supported by the current analysis of business trends, a further increase in the number of functioning and developing solutions using blockchain is expected in the context of the challenges of the telecommunications sector.

3.2. Blockchain solutions for energy management

Electricity supply is one of the key problems for modern cities, having a broad impact on the quality of life of residents and development conditions for enterprises operating within them (Strielkowski et al., 2020). Blockchain technology appears as a promising tool used to record and streamline transactions between entities generating energy and its consumers (Lv, 2023).

Numerous blockchain-based applications, from peer-to-peer energy trading solutions to energy source verification systems are developed nowadays (Thukral, 2021). Experts predict that blockchain can revolutionize the energy sector by improving value chain operations and managing the diversity of decentralized energy systems (Wang, Su, 2020). Blockchain can impact the energy sector by providing solutions that ensure legitimacy, security and automation of flows between market participants. According to Emergen Research, the value of the blockchain solutions market in the energy sector will reach USD 8.76 billion by 2027 (Emergen Research, 2024).

Blockchain solutions present major opportunities in the energy sector such as (Bao et al., 2020):

- supporting achievements of major European energy objectives, e.g. in the Clean Energy for All Europeans Package,
- promoting energy efficiency, renewables and their integration into energy systems, by mitigating the risk of investments and ensuring transparency, integrity and traceability of technical and commercial transactions and reporting,
- linking consumers and prosumers and enabling exchanges decoupling of any man-in-the-middle control,
- allowing to manage the complexity of future energy markets, i.e. this achieve quasi-real-time coordination of electricity supply and demand data, proper management of energy storage capacities on the energy grids, e-mobility support, etc.
- enabling to report compliance with sustainable finance, ESG criteria, NFRD and CSRD.

Selected blockchain-based solutions for the energy industry are indicated in Table 2.

Table 2.
Selected blockchain-based solutions for the energy industry

Company involved	Description	Source
Siemens Energy	Siemens Energy's Automated Pay-Per-Use is a new service allowing utilities to pay for upgrades only when they are utilized. Part of the cost is covered when revenue is earned from successful electricity sales. Blockchain technology enables this model by ensuring accurate calculation and fair distribution of the power plant's profits on a pro-rata basis.	Siemens-energy.com
Shell	The company is considering blockchain as a way to validate carbon credit programmes. By tracking the effectiveness of nature-based solutions for carbon capture and avoided emissions, blockchain can prevent the double-counting of carbon credits, maintain the quality of reforestation or conservation projects, and ensure the transparency of the carbon market.	Shell.com
Engie	The company manages energy transactions across supply, distribution, and consumption. It also leverages blockchain technology for trading renewable energy certificates (RECs), peer-to-peer energy trading, and electric vehicle (EV) charging.	Engie.com
WePower	An Australian blockchain company enables direct connections between green energy providers and buyers, such as investors and end-users, allowing them to purchase energy in advance at discounted rates. The company has developed Ethereum Smart Energy contract tokens, sold via its e-commerce platform. These tokens aim to simplify and standardize renewable energy transactions, allowing businesses to buy the precise amount they need and sell any excess capacity.	Ledgerinsights.com
Power Ledger	The company partnered with ekWateur, a renewable energy provider in France, to create a blockchain energy trading platform that lets users choose their preferred energy source within the country. In 2021, Powerledger further enhanced its energy blockchain technology by migrating its platform from Ethereum to the more energy-efficient Solana, enabling faster transaction speeds and higher throughput.	Powerledger.io

Cont. table 2.

SunContract	A peer-to-peer energy trading platform utilizing blockchain technology to facilitate the buying and selling of renewable energy. With over 5,000 registered users in Slovenia, the platform caters to environmentally conscious consumers. SunContract aims to establish a Global Energy Marketplace (GEM), removing intermediaries and enabling customers to trade directly with one another. This approach promotes greater energy self-sufficiency and supports the development of a more sustainable energy economy.	Suncontract.org
Iberdrola group	A blockchain-based pilot project that enables real-time verification of the renewable origin of supplied and consumed energy. By leveraging this technology, the company has successfully linked electricity generation plants to specific consumption points, providing full traceability of the energy source. This approach enhances transparency and encourages the adoption of renewable energy.	Iberdrola.com
GreenH2 chain	This platform is designed to ensure that all green hydrogen is produced from renewable sources by enabling users to track and visualize the entire green hydrogen value chain in real time, from anywhere in the world. Additionally, the platform will be used in the Power to Green Hydrogen project, which aims to build a green ecosystem on the island of Mallorca, Spain.	Acciona.com

Source: own elaboration.

The multitude of blockchain-based solutions developed within the broadly understood energy management and the energy industry itself is evidence of the growing interest of industry practitioners in blockchain technology. It has the potential to permanently change the landscape of the energy market, contributing to increased transparency of flows within it and contributing to the implementation of sustainable development goals set for the energy industry.

3.3. Blockchain solutions for smart transport systems

Among the areas of city management, according to many researchers, transport systems occupy a central place (Savin, 2021). They seem to be crucial both at the individual level and at the level of the city's logistics systems. Blockchain technology shows the potential to impact both public and private transportation (Enescu et al., 2022). It can support transport companies in terms of fleet management, route management and overall operational efficiency. It can also help monitor road incidents and other negative situations affecting the smooth movement of people in the city, provides transparency and security for transport companies while minimizing the occurrence of various threats and frauds (Sundaresan et al., 2021). The areas of application of blockchain technology in the transport industry are indicated in Table 3.

Table 3.

Areas of application of blockchain technology for smart transport systems

Area	Description	Source
Data Security	Blockchain makes it difficult for hackers or fraudsters to change or steal data from companies. Because of the nature of a decentralized data management system, there is no central point of failure for malicious parties to exploit.	Zhou et al., 2021
Tracking Systems	Companies can easily track the movement of a parcel for delivery. This also applies to a passenger's journey to a scheduled pick-up or destination. Blockchain makes it easy to trace where delays occurred to improve operations.	Balfaqih et al., 2023
Order Delivery Tracking	Intelligent order delivery tracking systems use blockchain. Many companies now offer same-day or express delivery within one or two hours. Doing this requires a digital solution that can immediately authenticate orders, complete them, and initiate delivery and tracking. A blockchain platform can easily coordinate these processes and provide the information required through a shared database.	El Midaoui et al., 2021
In-Vehicle Payments	Another real-life example of blockchain technology improving transportation is the in-vehicle payments used by IBM in coordination with UBS and ZF Friedrichshafen AG. The Frankfurt-based company worked with IBM to use a blockchain-based transaction platform for their mobility services. It includes in-vehicle payments for motorists to pay tolls, car-sharing app payments, parking fees, and even electric vehicle battery charging fees.	Ibm.com
Transportation payment and dispute resolution	Blockchain technology can streamline payment processes in the transportation industry by providing transparent and secure transactions. It can automate payment terms through smart contracts, ensuring quicker and more efficient settlements while reducing payment disputes significantly. With an auditable record on the immutable ledger, disputes can be resolved more efficiently and accurately, leading to smoother financial operations.	Narayanam et al., 2020
Administrative costs reduction	Blockchain can reduce administrative costs in the transport industry by replacing paper-based processes with digital, decentralized systems. By digitizing documentation, approvals, and communication, blockchain enables seamless information sharing among stakeholders, reducing paperwork, human errors, and administrative expenses. This streamlined approach enhances operational efficiency while cutting down on unnecessary overheads.	Koh, Dolgui, Sarkis, 2020
Transportation of temperature-controlled goods	Blockchain can help solve the challenges of transporting temperature-sensitive goods, such as pharmaceuticals, by offering an unalterable record of temperature data at each stage of the supply chain. By integrating Internet of Things (IoT) sensors with blockchain, temperature conditions can be continuously monitored and recorded, ensuring compliance and minimizing the risk of product loss. This enhances the quality of temperature-controlled shipments and reduces waste.	Vergine et al., 2023
Decentralized freight tracking and load board reliability	By utilizing blockchain's distributed ledger, the transportation industry can improve freight tracking and tracing capabilities. This technology offers secure and authenticated data, leading to more reliable and efficient tracking information. Moreover, blockchain can enhance the reliability of load boards by providing unalterable, time-stamped loads verified by the blockchain network, thereby reducing the risk of incorrect load requests and boosting overall efficiency.	Henesey et al., 2020

Source: own elaboration.

Similarly to the telecommunications and energy industries, as well as the sectors described in the first part of this study, blockchain technology is being heavily explored by entities involved in the development of transport systems. This indicates that blockchain technology is being recognized by specialists in this industry, which can provide a number of solutions to problems affecting transport systems.

From author's perspective, blockchain holds transformative potential for transport systems, offering not only operational improvements but also fostering trust and collaboration among stakeholders. It is strongly believed by the author that blockchain's ability to provide decentralized, tamper-proof data can revolutionize urban mobility, enabling seamless integration of diverse transport modes while addressing inefficiencies and security challenges.

4. Summary

In this, second part of the study, the focus was put on the telecommunications, energy, and intelligent transportation systems sectors. The analysis of these key areas provided deeper insights into the role of blockchain technology in the development of smart cities. This part is the supplement of the first part of the study entitled "Areas of blockchain technology application in smart city". The first part was focused on the usage of the blockchain technology in sectors such as food supply chain, tourism industry and smart healthcare.

The entire study reveals that blockchain technology has already become a crucial element in the operation of many smart city sectors. Its solutions play a significant role in enhancing both the quality of life for residents and the efficiency of industries that are essential for smart city development. By fostering transparency in data exchange between residents, businesses, and city authorities, blockchain enables seamless communication among these groups. The technology's ability to provide secure and transparent access to public services is one of its key strengths. Across the various essential areas that make up a smart city, blockchain introduces numerous innovative solutions, with its rapid evolution suggesting even broader applications in the future.

Looking ahead, blockchain's potential to drive advancements in civic engagement, the job market, cultural identity, urban development, and security systems stands out. Whether it's through resident loyalty platforms, job certification on the blockchain, or the secure management of land and video surveillance, blockchain technology is seen as a foundation for further progress in smart cities and industry 4.0, with promising benefits for both urban life and business environment. This is an interesting direction for further research and certainly directs the author's scientific interests in this direction.

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