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The Application of Blockchain Technology to Smart City Infrastructure

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Abstract: A smart city can be defined as an integration of systems comprising a plethora of task-oriented technologies that aim to evolve and advance with city and infrastructure needs while providing services to citizens and resolving urban challenges through intersystem and data-driven analytical means, with minimal human intervention. Applications of technology include management, operations, and finance. One such technology is Blockchain. A main advantage of Blockchain is the simplification of processes that are costly and time-consuming. This is accomplished by simplifying operations to minimize costs resulting from the decentralization of assets. Blockchain has been proven to facilitate transparency, security, and the elimination of data fragmentation. However, as a relatively new technology, it poses regulatory obstacles. This issue can be attributed to the fact that many infrastructural governing organizations have incomplete knowledge of their infrastructure, which can lead to confusion when attempting to comprehend the different elements of the infrastructure, resulting in a lack of direction when trying to solve a problem. This paper explores the different applications of Blockchain technology in the sectors of energy, transportation, water, construction, and government, and provides a mechanism for implementing this technology in smart cities. As a present component of infrastructure management systems, Blockchain may potentially serve as the initial step toward upgrading infrastructure technology.

Keywords: blockchain applications; case study; smart infrastructure; smart city

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1. Introduction

A smart city is an integration of multiple systems, comprised of an assembly of task-oriented technologies that aim to evolve and grow with the city and climate needs, while providing services to citizens and resolving urban challenges through analytical and inter-system data-driven means, with minimal human intervention. Privacy, interdependence, efficiency, and transparency are the primary characteristics of Blockchain that can be applied to the technology, development, and management of a smart city infrastructure. Among the several ambitions that Blockchain focuses on achieving is infrastructure implementation; the elimination of intermediaries is one of its primary objectives for achieving sustainability [1]. Consequently, the purpose of this study is to comprehend what a Blockchain integration with a city's infrastructure and operations would look like in a future smart city, whilst addressing the complicated future of infrastructure sustainability in terms of security and resource management. According to the authors of [2], Bitcoin was the first application of Blockchain technology that was implemented. Blockchain is a decentralized data storage and transaction technology. Since 2008, when the term was invented, interest in Blockchain technology has increased rapidly. This can be attributed to the fundamental characteristics of Blockchain, which enable privacy, confidentiality, and data integrity without any kind of physical control, thereby creating intriguing research fields [3]. Blockchain is a distributed database solution with a continuously growing list of data entries validated by network nodes. Each activity's information is recorded in a public or confidential database depending on the requirement [4]. All nodes and available information about Blockchain-based activities are shared. This paper conceptualizes a hypothetical city as a sustainable smart city. To meet the requirements for such a smart city, it is necessary to consider expanding human demands, increased urbanization, increasing interdependent and interconnected systems, rising complexity, and the growing significance of cybersecurity. A smart city in terms of infrastructure is thus characterized by smart governance, smart mobility, smart environment (power and water), and smart living [5]. In the meantime, sustainability is described by the authors of [6] as the capability of a system to function and perform regular operations while upholding the balance of an ecosystem. Governance, environment, and infrastructure are the primary aspects to be considered when combining a smart city with sustainability. The long-term viability of infrastructure is contingent on how the needs of the present are met using existing technology and management. This necessitates a decentralized governance framework and, hence, the potential integration of Blockchain technology with infrastructure.

In general, a smart city consists of a sustainable design framework that prioritizes user convenience based on their needs, security, long-term and short-term solutions to urbanization-induced problems, secure financial activities, and enhanced data monitoring. The primary objective in defining the concept of a smart city is to improve the quality of life of people through conventional infrastructure development by utilizing cutting-edge technologies such as Internet of Things (IoT), Artificial Intelligence (AI), etc., which are being used to create a user-friendly environment that enables interaction with a wide range of digital services and devices. This integration necessitates a cyber secure environment so that the security of various infrastructure components or an asymmetric warfare medium is not compromised. Moreover, as we progress in an age of data automation, each of these components must embrace cybersecurity as a fundamental component of the system to uphold data security.

The main pillars of a smart city are comprised of physical infrastructure, institutional infrastructure, social infrastructure, and economic infrastructure [6]. The natural and constructed environment of smart cities is defined by clean energy production, intelligent distribution, intelligent water treatment and management systems, intelligent transit networks, and green construction infrastructure. The institutional framework responsible for regulating the city's affairs governs the city [7]. In a smart city, the institutional infrastructure takes decisions from the perspective of sustainability by incorporating the opinions of citizens and stakeholders, which are then utilized to define objectives and identify solutions by satisficing. Social infrastructure is a combination of human capital, technical and management tools that improve the quality of life, and instruments that make the concept of sustainability widespread in society. Finally, economic infrastructure refers to the financial components that support the best e-business practices and help sustain economic growth. Figure 1 illustrates the application of Blockchain within the infrastructure of a smart city.

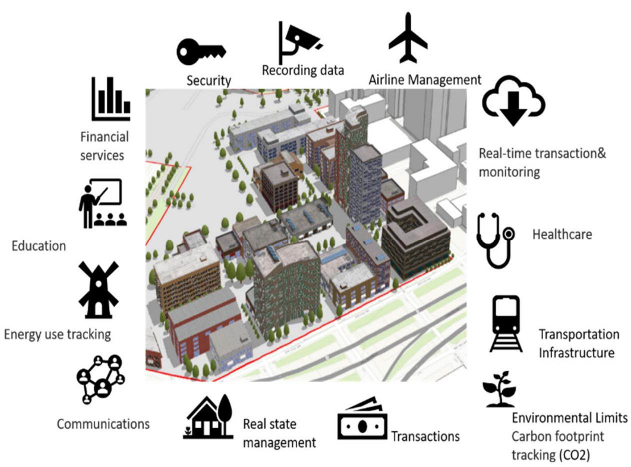

Figure 1. Blockchain in the infrastructure of smart cities.

Blockchain Integration in a Smart City

For a smart city to become a reality, numerous technological and management tasks must be completed including safeguarding data and addressing sustainability challenges such as pollution, climate change, and urbanization. Blockchain offers various inherent features for application in urban infrastructure management [6], which can mitigate or solve the aforementioned problems. One of them is *decentralization*, which is based on the concept that a Blockchain operates in a peer-to-peer (P2P) way without the need for trusted central intermediaries. As a result, the likelihood of a central body's operation collapsing can be substantially reduced. Another essential quality is *immutability*. A system is considered immutable if it is not easily corruptible. Since the security of Blockchain is built on cryptography with digital signatures for certifying transactions and hash functions for linking the blocks, the system is difficult to mess with and hence, immutable. In addition, a Blockchain system demonstrates *democracy* as an additional link to the existing Blockchain. It establishes the requirement of consensus among existing nodes, incorporating each new link into the decision-making procedure. In the infrastructure area, *pseudonymity*, *security*, and *transparency* are also highly significant characteristics. These enhance the security of the system by issuing each Blockchain node a pseudonymous address that conceals the node's true identity. This simultaneously boosts transparency and security.

2. Methods

One of the purposes of this paper was to illustrate the potential applications of Blockchain technology in sustainable infrastructure. This was accomplished by proposing a possible smart city design that incorporates Blockchain technology into urban infrastructure such as healthcare, cryptocurrency, supply chain, banking, web services, cellular network, reputation, and electricity. This is illustrated in Figure 2 as formed by examining case studies and the perspectives of various researchers regarding the implementation of the same. Once the data obtained from numerous sources such as case studies, published Blockchain research, and journals were examined, this information was used to draft a literature review highlighting the usage of Blockchain technology in numerous industries and the use of those techniques to improve sustainability.

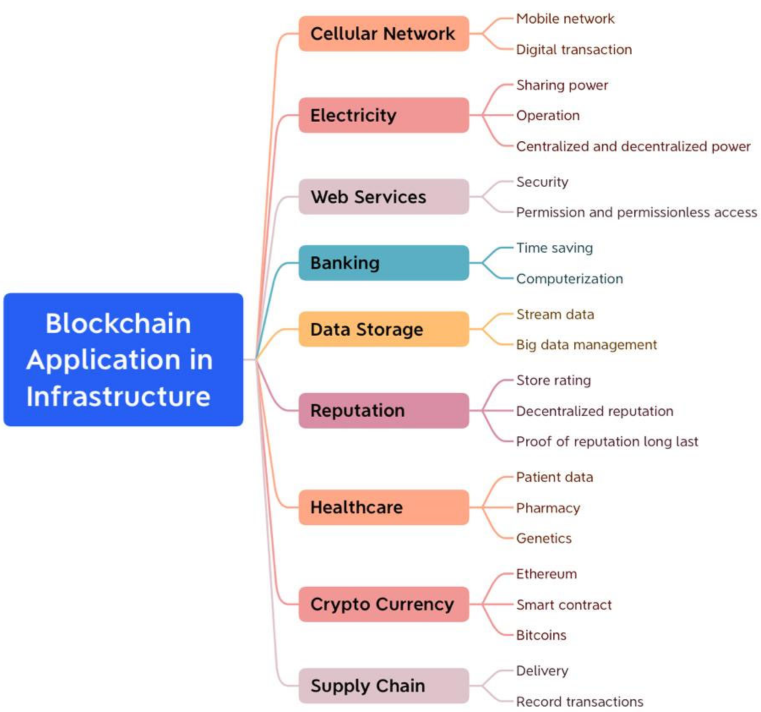

Figure 2. Applications of Blockchain in infrastructure.

First, a study on Blockchain as a technology and its existing applications in various industries was conducted. Understanding this technology provided us with an insight into how it may be incorporated into infrastructures that prioritize sustainability. With knowledge of Blockchain from previous research and examples of its use in other industries, we investigated the potential sustainable applications of this technology.

3. Hypothetical City Scenario: Application of Blockchain in Different Infrastructure Domains

This section proposes a framework for a smart city employing Blockchain technology in multiple infrastructure disciplines.

3.1. Infrastructure and Utility Industry

3.1.1. Utility Contracts Using Blockchain

Taking care of accountability and transparency are among the greatest obstacles faced by the utility industry. As a result of inadequate planning and antiquated budgeting techniques, budget and time overruns are almost a constant for every construction project. Statements of Qualifications (SOQs) on urban infrastructure projects seldom include a budget section. When a contractor is selected based on merit, the Guaranteed Maximum Price (GMP) is rarely the best available offer. The issue of budget overruns can be resolved by smart contracts based on the Ethereum Blockchain, as each investment token may be generated and customized at each phase of the project to promote accountability and a better budgetary scope [8]. Additionally, the success of a project is virtually always contingent upon the level of detail in each phase, which specifies the appropriate resources to be deployed. When each company tokenizes its previous projects, it becomes easier for clients to audit each bidder and monitor the development of their assets. A reputation ledger powered by Ethereum eliminates the need for projects to conduct due diligence.

3.1.2. Environmental Regulations/Limits (Contracts on Carbon Dioxide CO_2)

The introduction of Blockchain technology can also assist governments in addressing environmental restrictions pertaining to carbon-emitting sectors. Recently, countries have devised programs that deal with the trading of carbon emissions so as to progressively reduce emissions and avoid rigid environmental legislations [9]. In this system, the government issues "credits" to businesses or industries, which reflect the limits of CO_2 emission restrictions the industry can emit. The trading mechanism is activated when companies that emit carbon levels lower than their allotted credit sell their "credit" to enterprises that need to emit higher carbon levels. Considering that this is a way of trading and exchanging credits, Blockchain technology would be ideal for this practice. Blockchain might add security, efficiency, and inclusivity to the platform in future deployments such as the government controlling a smart city. Blockchain has the potential to "constantly update the best trading route and schedule based on previous trading experience. In this way, the carbon emission quota utilization rate will increase, and the efficiency greatly improved" [10].The installation of Blockchain would prove to be extremely beneficial for the management of future trade systems. Additionally, it should be considered when addressing the management of infrastructure systems by the government.

3.1.3. Data Management

A smart city offers numerous advantages such as enhanced government accessibility, facilitation of civic engagement, active infrastructure, optimal resource utilization, more sustainable livelihoods, enhanced quality of life, and environmental and educational services. According to the authors of [10], a smart city focuses on improving individuals' living standards by using innovative new technologies such as Blockchain to sustain comfortable environmental conditions. Through the profile management concept developed by the authors of [11], it was shown that a platform built on top of the Hyperledger Fabric permissioned Blockchain system is feasible and effective. The design concept exhibited a relevant analysis and capacity of Blockchain to manage data with a Blockchain network that offers complete data protection. Any violation is irrevocably recorded and easily discoverable by linked parties.

Blockchain has the potential to enhance the self-defense capabilities of a prospective smart city by monitoring and recording data storage against cyberattacks and security breaches. Implementation of this technology could be used to enhance the security and stability of intelligent cities. The data management of intelligent city infrastructure has attracted the interest of both academic and professional fields with this infrastructure being characterized by numerous detection and defense procedures for cyber-attacks [12]. Therefore, a Blockchain-equipped intelligent city would be able to implement the technology into its data management systems, which monitors and logs unlawful data modifications, hence promoting a transparent and trustworthy environment for data sharing.

3.1.4. Blockchain to Improve Infrastructure Cyber Security

For a very long time, city databases with records of demographic data, infrastructure data, environmental data, etc., have collected and organized data manually for record-keeping purposes. Therefore, it is difficult for individuals who are not directly related to it to gain convenient access. Wikipedia, for example, is a website based on a collated database on a server. To ensure the security of all content, only Wikipedia operators are permitted to make changes; operators can be held accountable for any editing and approval. This demands a great deal of labor from specialized individuals within the business and results in a high cost with it. With the benefits of Blockchain technology, such as data security and simple storage and management, we can implement it with greater confidence and convenience. This is because all information is stored securely, making it difficult for anyone to alter it or break the system's cybersecurity [13]. Therefore, selecting Blockchain as a management system for smart cities would be a remarkable accomplishment. Using Blockchain, we can always rely on all available information and recorded data. Moreover, updating it is a lot easier. The only way data are updated is with the knowledge of all operations managers and employees; thus, it would be difficult to contest the authenticity of the recording. Thus, we can decentralize the operation systems in smart cities and shift our confidence away from a single individual or management agency. The cities' management systems might face problems with manipulated information either by managers or other unknown parties and this could lead to a failure in management systems due to incorrect information from the database [7]. Since the distributed system is extremely independent, the security of the network requires trustworthy encryption technology. For the increasingly intricate interactions between many types of infrastructure, a safe, efficient, and strong cybersecure infrastructure is necessary. Blockchain offers a stable environment as an emerging, distributed computer technology for supporting such interactions [14].

3.1.5. Smart Cities Improving Government Management Systems with Blockchain

In an ideal situation, smart cities would employ information technology to integrate, run, and deliver better services for inhabitants by maximizing the use of available physical, social, and business infrastructure resources. Through the development of technologies such as Blockchain, cloud infrastructure, and connected networks, smart cities can provide inhabitants and local governments with simpler connectivity and collaboration. According to research presented by the Institute of Electrical and Electronics Engineers, digital disruption presents a variety of possible advantages in protecting information and confidentiality in an integrated security context for Blockchain technology [15].

3.2. Water Infrastructure

3.2.1. Water Pollution and Blockchain Tracker

Blockchain technology could be used to track water pollution as a potential application in the water infrastructure sector. With the ability to offer accurate timestamps, Blockchain enables the correct tracking of information in cumulative succession. Consequently, the use of this technology for the tracking of pollution could aid in providing real-time information regarding pollution sources. Suitable sensors might be deployed in problem areas of water infrastructure and be coupled with Blockchain technology to gather and store sensor data. This data would then arrive with time and location stamps, allowing engineers to respond appropriately. The implementation of Blockchain would not only enable real-time tracking and therefore, a speedy response, but it would also provide a comprehensive history of pollution in specific regions. Apart from the ability to respond, possession of this data could allow an increased nature of data transparency, stricter enforcement of pollution limits, and backing of environmental decisions [16,17]

3.2.2. Trade of Water Access Rights

As demand increases and supply falls, the future of water management in many counties and states is uncertain due to the trading of water access rights. Regarding the Colorado River in the United States, a recent report asserts, "Despite the complexities of how we reach the solutions, the problem is quite simple. It's a mass balance equation. We have too many demands and not enough water" [18]. Even if the trend of diminishing water availability may be inescapable, appropriate management and subsequent technical support is vital for the future of water infrastructure. Water availability is being heavily discussed as an asset to trade where "trading involves the voluntary exchange of water access rights between a buyer and a seller. One entity holds the license to collect a certain amount of water from a river, groundwater lake or reservoir. That entity can also sell some of its quota at a market-defined price" [19]. Such a system could, therefore, benefit significantly from the use of Blockchain as it could "help water area organizations to oversee adjusting and settlement all the more effectively, in contrast with the currently applied techniques" [20]. To foresee a future in which water exchange becomes increasingly prevalent, this system would require digitization. Blockchain would be the ideal option for storing and precisely tracking these transactions in a market where it is crucial to keep track of every drop of water used. Moreover, the use of Blockchain in water transfers requires additional security measures. Due to the aforementioned security provided by this technology, Blockchain could prevent competing governments, states, or enterprises from attempting to tamper with transactions through cyberattacks [21].

3.3. Power Infrastructure

Modern power systems are distinguished by their decarbonization, decentralization, and digitalization [22]. This section focuses on a few methods for achieving these objectives and discusses examples.

3.3.1. Energy Internet

Integration of energy consumption equipment, for example, those used in homes such as smart lights, smart home devices, smart plugs, and smart security systems with the internet through the "Internet of Things (IoT)" has become a common practice today, and requires assets with physical infrastructure as well as digital assets, which are usually available through traditional technologies [23]. In addition to these assets, Blockchains provide an irreversible collective decision, which facilitates the execution of logical functions and algorithms to produce outputs. After a consensus has been reached, the likelihood of human errors decreases as a result of the the provision of a safe interface between all Blockchain pieces to execute a new algorithm as a hash. The hash is a new algorithm that is designed to be a one-way function—the Blockchain can feed data into a hashing algorithm and obtain a unique string. A smart contract, for example, can be defined as a collection of self-verifying, self-executing, and self-enforcing state response rules that are stored and secured by the Blockchain. Once a group of parties agrees on a set of predefined terms or rules, they can codify them as a smart contract, cryptographically sign it, and broadcast it to the peer-to-peer network for verification. The verified contract will be packaged into a ledger block that is designed to act as a one-way function—a Blockchain can put data into a hashing algorithm and obtain a unique string [24]. Through the use of Blockchains, the application of unmanned intelligence becomes feasible. A basic example would be the execution of a contract once it has been signed by both parties, such as in a distributed energy system, and the execution of energy supply would occur automatically at the moment of delivery following an agreement.

3.3.2. Decentralized Energy Market (Tokenization)

Some predict for the future that the ratio of power generated using renewable energy to that generated from fossil fuels is going to increase [25]. Therefore, in addition to the existing centralized power infrastructure available, it would require a system of decentralized and distributed power generation and distribution that would incorporate peer-to-peer (P2P) selling and transfer of energy [26]. For example, the existing power system allows users to sell excess energy generated by their solar power systems to suppliers. This energy then enters the grid when the transaction has been completed. By incorporating Blockchain in this process, we can expect that the requirement of the external company subsides, and transactions can take place directly between users. For example, homes that have solar panels installed can sell the excess electricity to their neighbors [27]. A transaction is completed when the seller and buyer agree and the transaction is recorded in the digital Blockchain ledger, thereby allowing the establishment of a decentralized energy market without the need for a third party.

3.3.3. Energy Consumption Tracking

Another Blockchain feature that can be used to encourage sustainability is the safe data tracking and storage it provides, which can be utilized in a number of ways. One of the applications could be real time data handling and the management of data such as the energy consumption data of each user being tracked and reported back to them [21]. Data security in Blockchain is centered around the idea that once data inputs are made, they are immutable and easy to trace, thereby leaving very little room for errors to occur or to be overlooked. The incorporation of this Blockchain feature into power infrastructure can be illustrated through mobile applications that inform consumers of their power consumption and associated costs. Real-time tracking of energy consumption by consumers is not only beneficial for information transparency, but also aids users in establishing and sticking to a budget for their usage. Using mobile applications, several additional interactive components can be provided for consumers. Figure 3 represents what a real time application of Blockchain looks like with the introduction of a digitalized platform that allows the trade of a commodity between its users who may take up the roles of sellers, purchasers, or investors.

An online energy trading platform was created that runs simulations using Python and artificial intelligence for the face recognition of a user to allow access to its trade features. This platform, or application, connects various consumers and purchasers of a commodity, say electricity, across a city. The agents connected via this electricity exchange platform may be sellers or investors. As shown in Figure 3, the example of an 'N seller' is similar that of a user who may want to store part of the excess electricity produced and sell the remainder to other users based on their preference. Selling electricity units to a residential consumer may be preferred by a specific user; however, in case of the absence of a potential residential buyer, then they would have to switch to an industrial customer, or rather to the state grid. The user is allowed to choose the rank of his potential consumer based on his preference. Another type of user involved in this online exchange of electricity would be an investor, who could initially buy units of the commodity at a lower price, store them for a while, and then sell them later at a higher price. The example of an 'N + 1 user' in this scenario has been included in the diagram to emphasize the fact that a seller is given a variety of options on the platform itself that allows the storage, sale, and donation of electricity to other users. An auto-selling showcase in the energy trade market can be used to sell a percentage of energy automatically to investors interested in its purchase. Regarding the storage of electricity, a storage bank or grid is used to store the electricity for a certain period until it is further sold to another user or investor [28]. Normally, this would require payments to the storage facility to be through a third party. However, a Blockchain-integrated energy trade platform eliminates the need for third party payments and payments can be made online through the platform itself. Localized energy production and consumption can also reduce the transmission energy losses and therefore, reduce the total cost [22]. Although the amount of electricity consumed with the implementation of Blockchain needs more study, current research shows that the environmental impact decreases along with it in direct proportion. According to one study [29], a Blockchain-based sustainable microgrid can increase profitability and consumer satisfaction by 1.68 and 2.61 percent, respectively, while reducing environmental impacts by 0.97 percent.

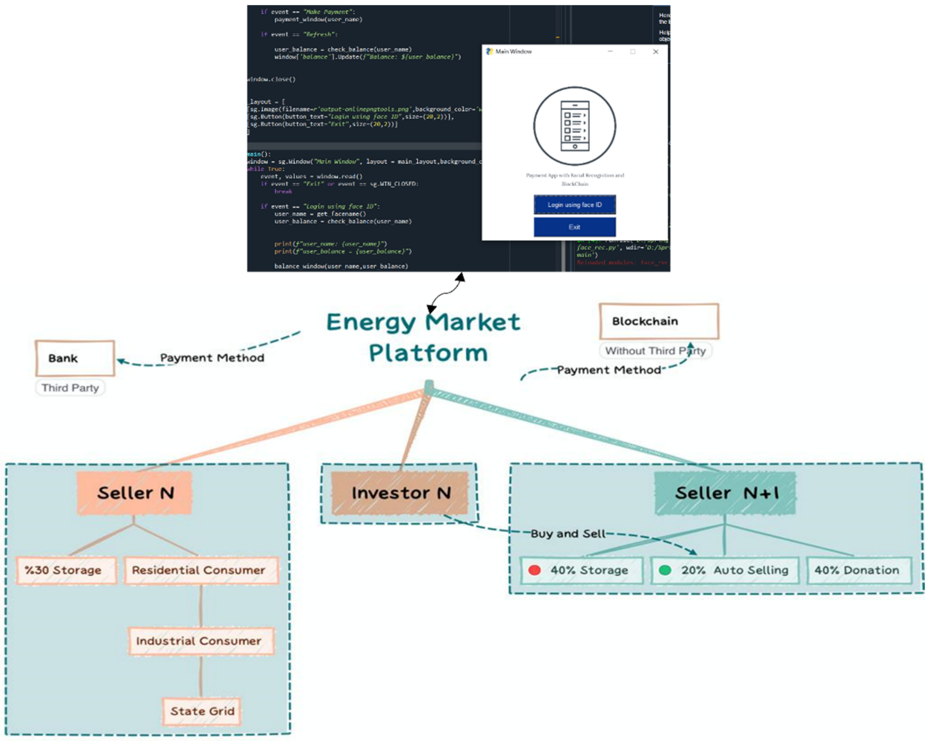

Figure 3. Energy trading market.

3.3.4. Carbon Footprint Tracking

One of the applications of Blockchain towards sustainability in power infrastructure is the tracking of the carbon footprint from energy appliances [26]. For this purpose, Blockchain characteristics such as data security and storage can be utilized. Once recorded, the amount of carbon produced cannot be altered, which ensures the reliability of data generation. It is possible to study the environmental impact of a product's carbon footprint, and the information should be made available to both the maker and the consumer. To discourage the use of such appliances, management or governing services could apply a price proportional to their carbon footprints or establish a threshold above which a 'carbon' tax would be imposed. This would raise the public's awareness of the environmental effects of their actions. To limit the total number of products in use, a further step could be to implement the tax after analyzing the products and making them more expensive if a larger footprint is observed. This could also bring about a change in the supply–demand relationship of such products, taking us towards a sustainable future led by Blockchain technology [30].

3.3.5. Intelligent Renewable Energy in a Smart Grid

One can also envision the incorporation of a smart grid in a smart city, as it would be a crucial step in the development of a sustainable future due to its ability to integrate renewable energy more efficiently. This would also be a suitable application of Blockchain because of the benefits it provides. A smart grid allows for the bidirectional flow of electricity, enables energy trading without the need for third-party approval, and provides a larger market for both suppliers and consumers. Despite the fact that smart grids may appear to be a combination of the aforementioned technologies, they are an essential component when the concept is implemented on a wider scale, as they require a robust communication infrastructure to facilitate trade in a single market. Using Blockchains, we can consider users as nodes and a device at each node manages the transactions and handles smart metering [31]. These are considered small nodes. Full nodes can be attributed to devices such as transformers that are utilized prior to the transmission of electricity to distribution lines. They are responsible for transaction validation, tracking consensus, and power transmission via the most efficient route. A system for tracking energy sources can also be used to encourage the automatic shift of energy from renewable sources.

3.4. Transportation Infrastructure

3.4.1. Personal Car Ownership with Blockchain

In the United States, it is estimated that each household possesses approximately two automobiles [32]. This is becoming a significant concern for the nation's infrastructure as more and more land is required for parking spots to meet this ever-increasing demand, thus making downtown American cities less suitable for business and residence. Automobile sharing, particularly peer-to-peer (P2P) car sharing, is an expanding industry with proven benefits for cutting down on car ownership. Currently, applications such as Turo are valued at hundreds of millions of dollars, and automakers such as Chevrolet are producing their own automobile rental software. A major concern for users of this software is the availability of insurance and the rental company's hefty service fee. By digitizing the primary shareable asset, the need for a middleman to collect insurance and service fees will be eliminated. The Blockchain token is live 24/7 and gathers all data such as mileage and location of the vehicle, thus preventing theft and helping insurance companies to customize fees based on the use rather than keeping constant rates for all [33,34].

3.4.2. Blockchain and Intelligent Traffic Systems

As the trend of the Internet of Things (IoT), Intelligent Transportation Systems (ITS), and the popularity of autonomous vehicles is growing, Blockchain technology can serve as the link between them. An autonomous vehicle that is registered as an asset on the Blockchain, will be in communication with the traffic systems and all other cars at all times, making it a trackable asset [35]. Using the collected data, a navigation system can handle rush-hour traffic problems by guiding traffic through alternative routes so that the average trip time remains the same for everyone. Moreover, if a vehicle is about to lose control and collide with oncoming traffic, the communication system powered by Blockchain is capable of directing vehicles that are about to collide and reroute the traffic in a way that prevents or mitigates the collision [36].

4. Implementation of the Hypothetical City: A Case Study of Tempe

This section presents cases highlighting potential issues with the implementation in a real city using the city of Tempe, Arizona in the United States as an example. Figure 4 describes seven major systems of infrastructure, which include communication, energy, citizens, urban services, commerce, transportation, and water systems.

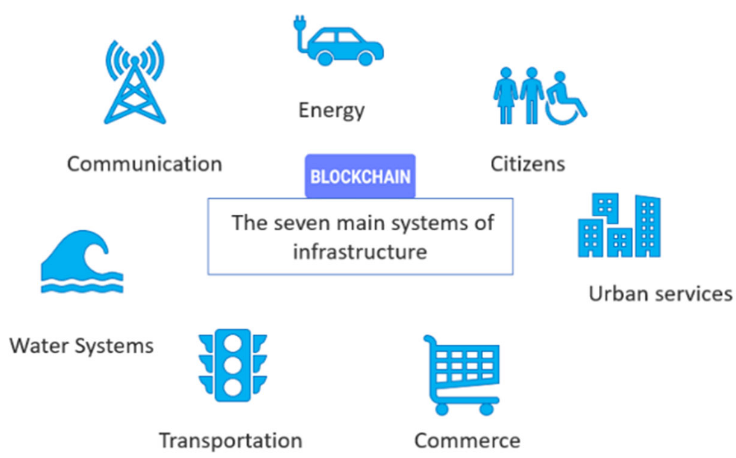

Figure 4. The seven major systems of infrastructure.

4.1. The Construction and Building Industries

A city-wide Blockchain implementation would enable the development of Blockchain-powered ledger systems (or smart contracts) in the city of Tempe. Using the Ethereum Blockchain, the most reliable platform for the creation of smart contracts, the city could offer tokens that would digitize the assets of its residents and businesses. A surveying team would be necessary to verify the accuracy of the entered data. Connecting the Building Information Modelling (BIM) system and tools to the Tempe Blockchain would ensure that all construction project data, both current and historical, is covered. After this initial step, the remainder of the updates could occur via the network, as every digital asset, and essentially anything and anyone participating in the construction industry's perimeter, will be an ever-updating agent, since their professional judgments will be recorded on the Blockchain. Using Blockchain technology, Tempe officials could now track life cycle updates and procurement processes for all active or completed projects, thereby enabling clients to construct more efficiently, while adhering to building codes. The tokenization of all construction assets would help generate passive revenue and garner community support. In exchange for trading Tempe tokens for annual returns, not only will construction companies discover a new source of financing for their projects, but the city will also have more control over project cost overruns and procurement fairness, which are now unaddressed owing to a lack of data.

4.2. Water Infrastructure

One of the best applications of Blockchain technology in the city of Tempe would be the aforementioned concept of trading water rights. A significant portion of the initial implementation process could involve establishing the market for firms, industry sectors, and landowners. This would be a substantial initial expenditure, but as previously noted, it might provide numerous benefits for Tempe. The implementation of a water system in Tempe would (1) reduce inequity by facilitating water systems with surplus water to trade with systems that have a deficit; (2) develop new revenue streams and local water sources by incentivizing water systems to explore opportunities to tap into new supplies such as rainwater, wastewater, and stormwater; (3) improve resilience to climate change impacts by facilitating water systems to diversify its supplies; and (4) create incentives for water systems to recycle wastewater [37]. Therefore, one of the subjects of discussion for the implementation of Blockchain in Tempe is not only the implementation of the technology, but also the order and procedures that accompany implementation. As discussed previously, Blockchain serves as a vehicle to carry an entire market that should drive Tempe towards policies that promote sustainability, diversify water technologies, and provide sufficient data management for any information received by water infrastructure [37]. Reiterating costs and setup offers the following procedures and costs to establish a system in increasing cities: (1) initial cost of setting up an enabling mechanism of water markets; (2) development and deployment of water entitlements; (3) connecting buyers and sellers; (4) monitoring and evaluation of water use and externalities; and (5) enforcement mechanisms for penalty and reward. Transaction costs include: (1) participation fees; (2) information search costs of willing buyers and sellers; (3) negotiation and bargaining costs; (4) cost of registration for an exchange; (5) enforcing contracts; and (6) cost of checking the veracity of the product [37].

Again, the setup in Tempe may require a substantial investment to integrate Blockchain; however, the integration of Blockchain with a principle such as water trading would yield a number of benefits, including system order, increased data availability on water usage, and future promotion of other sustainable practices related to Tempe's water infrastructure.

4.3. Power Infrastructure

The deployment of energy infrastructure with Blockchain technology will necessitate the design and building of a new form of energy infrastructure in order to realize the various scenarios described in the preceding section. This will necessitate additional tailored Information and Communications Technology (ICT) infrastructure, which could increase the cost of energy generation in Tempe, given the presence of large power companies such as Salt River Project (SRP) and Arizona Public Service (APS). Additionally, the integration of a system of renewable energy generation at closer places, such as within the city, would prevent transmission losses and cut costs even further. The city of Tempe would be required to create new regulatory rules and policy decisions that would also permit peer-to-peer (P2P) trading of electricity. The implementation of the technology presented in the preceding section has not yet occurred, and it is crucial to evaluate its potential for implementation and operation. These must be initially tested on a small scale in order to comprehend the unanticipated consequences that may occur. Before executing investigations on a broad scale, it is important to understand the uncertainties they present. Among the consequences that can be foreseen are trade-offs of the conventional power technology's advantages. One of them is that although the proof of work (PoW) algorithm offers security, it is slow and resource intensive at the same time [22]. This issue might be a considerable concern in the energy sector, as speedy transactions are essential for energy trading. There must be a backup system for emergency situations and technological solutions for situations in which renewable energy sources become scarce. In the case of Tempe, for example, there should be backup options for stormy and rainy days. Since Blockchain is an emerging technology that relies heavily on the coding of algorithms, small errors in the coding script could lead to major issues and the unintended corruption of power infrastructure. Execution of a technology prior to its development can result in significant security breaches and render the system more susceptible to break.

4.4. Implementation of Blockchain

While discussing a cutting-edge technology that potentially adds to the complexity of our infrastructure, it is crucial to evaluate both its immediate and long-term impacts. The majority of Blockchain's potential consequences are unknown. However, the technology overcomes some of our infrastructure's greatest difficulties in terms of complexity and future adaptability [38]. Approximately, 86% of 600 major global companies have been involved Blockchain in one way or another [39]. It may be argued that Blockchain is one of the most reliable and safe solutions, which makes the risk of a security breach extremely low for enterprises that use it in their infrastructure. Some past studies [39] have pointed to a Return-on-Investment (RoI) of 590% as a result of the complete implementation of Blockchain in complex systems, as it tends to reduce most unnecessary complexities that were created as a result of accretion through decades and are redundant going forward. In order for government bodies to comprehend the (RoI) of employing Blockchain, a business case must be identified and then established via mapping.

5. Discussion

In this study, a design framework has been proposed to understand what a Blockchain integration within a city's infrastructure and operations would look like in a future smart city, while addressing the complicated future of infrastructure sustainability in terms of security and resource management that prioritizes user convenience based on their needs, security, secure financial activities, and enhanced data monitoring. True, Blockchain technology has not yet been widely adopted. Despite the ongoing hype surrounding Blockchain, many critics have questioned the use of Blockchain technology and its necessity. Indeed, many existing publications are ambiguous about the exact configuration of their proposed systems, market design choices, Blockchain implementation costs, and, most importantly, the value of the Blockchain [40]. According to a study titled "Business models for peer-to-peer energy trading in Germany based on households' beliefs and preferences" by [41] self-consumption and electricity sharing within a community of prosumers are becoming more profitable, allowing consumers and prosumers to trade with each other without requiring a utility or retailer as a middleman (broker). Consumers are more likely to participate in such a platform if they understand all of the technical information provided about P2P energy trading and also understand that they can choose who they want to sell their excess electricity to. These developments have resulted in a fundamental shift toward a more decentralized market, as well as ambitions to build peer-to-peer (P2P) markets in which owners of excess electricity can sell it to other consumers on the local low-voltage distribution system. This brings attention to the creation of a competitive environment for distributed generation. Although the amount of electricity consumed by Blockchain implementation requires further study, current research indicates that the environmental impact decreases in direct proportion. According to one study [29], a Blockchain-based sustainable microgrid can increase profitability and consumer satisfaction by 1.68 and 2.61 percent, respectively, while reducing environmental impacts by 0.97 percent. After summarizing various studies on major infrastructure sectors in modern cities such as data management, cyber security, improving government management systems, water pollution and blockchain tracker, trade of water access rights, and power infrastructure, we assembled the majority of Blockchain applications and applied them to a design framework to understand what a Blockchain integration with a city's infrastructure and operations would look like in a future smart city. In a recent article, it was discovered that Blockchain could bring security, efficiency, and inclusivity to the platform in the case of future implementations, such as a government managing a smart city [39].

6. Conclusions

Infrastructure with better resilience in smart cities is a concept that has been studied for some time now. There is a need for professional data recording and management technologies to assist researchers and governments in analyzing situations and developing new solutions and recommendations for the future of developed cities. This paper contributes to the design of future electricity markets and opportunities for Blockchain technology in smart cities. This paper has reviewed the main publications in infrastructure sectors in modern cities such as data management, cyber security, smart cities improving government management systems with Blockchain, water pollution and Blockchain tracker, trade of water access rights, power infrastructure, and then we gathered most of the application of Blockchain.

A design framework to comprehend what a Blockchain integration within a city's infrastructure and operations would look like in a future smart city has been proposed in this research, whilst the complicated future of infrastructure sustainability in terms of security and resource management that prioritizes user convenience based on their needs, security, secure financial activities, and enhanced data monitoring has been addressed.

The implementation of Blockchain technologies in urban data management could have a profound impact. It is suitable for the fast-paced management of different sectors in infrastructure. In the future, these could be referred to as smart cities. It would be a great idea for a city such as Tempe, Arizona to begin applying these principles to its infrastructure and buildings. This paper concludes that Blockchain has the potential to "constantly update the optimal trade route and timetable based on historical trading data". Blockchain could transform the entire infrastructure into a corporate entity. Consequently, the infrastructure's entire business model would change. The introduction of Blockchain technology to any industry or infrastructure would result in a massive shift in framework, rendering the current regulations obsolete. Regulatory organizations must join forces to ensure a smooth transition, as this technology, quite explanatory by the term itself, consists of a chain and will cease to exist if even one link is missing. Moreover, as tokenization is made possible, tokens may be exchanged for monetary value. Although this paper arrived at the conclusion that Blockchain is a viable technology, regulatory issues could be an obstacle that must be overcome before it can be implemented in our infrastructure. Cost of installation, absence of a governance model, and the question of where to begin are all long-term obstacles to the widespread adoption of Blockchain infrastructure links. Due to a lack of knowledge and access to the technical resources of Blockchain-integrated infrastructure projects, it may be assumed that the conventional deployment of Blockchain in infrastructure is at least a decade away.

Numerous questions keep arising with the idea of implementing Blockchain on how governing bodies for infrastructure can handle organizations that deal with an overhaul of cost value requirements for their corporate roles which may prove to be costly and slow. Risk management schemes need to be designed to allocate the associated risks and model changes appropriate for each use case. The solutions must manage all obstacles and associated issues. These issues open up the scope for future research on the implementation of Blockchain in the infrastructure of smart cities.

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