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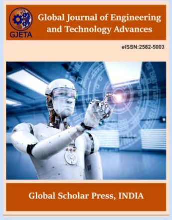

(Review Article)

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Application of blockchain to underground utilities

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Abstract

Blockchain technology enables encrypted and secure logging and transactions for information and data. This technology is expected to revolutionize computing in several areas, mainly where centralization is unnatural, and privacy is important. We are driven by circumstance and the complexity of underground utilities, which need measures to record information, secure data, and utilize new technologies with recorded information and store it into a secure digital platform. The platform must be able to deal with different types of files and documents with high efficiency and workability. Current problems due to uncertain information regarding the location of existing underground utilities often leads to striking of such utilities. This study describes blockchain technology and a proposed application to manage infrastructure utilities. The paper compares blockchain with Underground Infrastructure Management (UIM) and One Call System 811, and the potential advantage of this technology to manage underground utilities. Potential integration with blockchain and UIM is described to maximize infrastructure sustainability in underground utilities with respect to security and management. The research presented is focused on exploring the possibilities that blockchain has to offer with regard to protection of underground utilities.

Keywords: Blockchain; Data management; One Call; Underground utilities

1. Introduction

Today, we need to look beyond legacy methods and innovate if we are to adopt new technologies for underground Utility Infrastructure Management (UIM). Blockchain technology is currently being used to make service industries more efficient, thereby contributing to better economic inclusion and even better economic wealth distribution [1]. There are many proposed use cases of this technology ranging from health care to finance, with promising results. Blockchain technology promotes the idea that information and transactions can be systematically recorded in a public or private database via a cryptographic process where all involved parties in the network can validate the information [2, 3]. It is much more than software for cryptocurrency as it offers a secure way to exchange any service or transaction. By facilitating intelligent contracts, engagements, and agreements with inherent, robust cybersecurity features. Industrial growth increasingly depends on trusted partnerships; however, increasing regulation, cybercrime and fraud inhibit expansion. To address these challenges, blockchain enables more agile value chains, faster product innovations, closer customer relationships, and quicker integration with Internet-of-Things (IoT) and Cloud technology. Furthermore, blockchain provides a lower cost of trade with a trusted contract monitored without intervention from third parties who may not add direct value [4]. Blockchain also provides immutability of the transactions, thereby ensuring every transaction between generators and consumers will always be executed. It also provides immutability to transaction history, which can be used for auditing purposes or solving a transaction dispute [5].

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This paper discusses blockchain technology within the context of underground utility infrastructure management practices. Data collected from various sources are analyzed including case studies, published blockchain research, and articles or journal entries as part of a literature review of blockchain utilization in various industry sectors to examine applications to the management of underground utilities.

1.1. Conceptual Understanding of Blockchain

Blockchain technology promotes the idea that information and transactions can be systematically recorded in a public database via a cryptographic process so that all involved parties can securely validate the information. In other words, relevant data is collected in digital "blocks" that are "chained" together to keep the information sequential and protected. This technology could, therefore, provide solutions to many of the current technological management issues. Bitcoin was the first blockchain technology implementation application. Blockchain was created as a decentralized data storage and transaction technology. Interest in this technology has grown since the concept was coined in 2008. A reason for its growth is its central attributes that ensure protection, confidentiality, and data integrity without any control. Subsequently, this has led to attractive research areas, particularly from a technical and new perspective. Blockchain is a distributed database solution with an ever-expanding list of data records validated by the network nodes. The information is registered in a public repository that includes information about each activity [6].

1.2. How Blockchain Works

In some regards, blockchain is analogous to any computer system that records and stores information that can be retrieved later on such as Google index. Google index is an algorithm that stores data from websites so that when a user searches on a Google search engine, the information is easily retrieved and accessible from a wide range of websites in the database. The difference between Google index, or similar systems, and blockchain is that the data in Google index can be updated or deleted, whereas in blockchain, the information stored cannot be edited or deleted. The blockchain algorithm and structure ensures safety and privacy of information with fast and easy accessibility. For this reason, this technology is currently being utilized in several platforms and applications.

Blockchain allows information stored in the system to be accessed on any device by anyone that has been granted access to one's "block". If a user uploads any information into the "block" and another user has access to the block, they can view that information. For example, if two or more people working in the same company have access to the same block, they can share and see each other's work; however, as mentioned earlier, this information cannot be changed or deleted. The information stored can consist of any file regardless of the extension such as documents, videos, audio, and AutoCAD files. Files are converted into a cryptographic hash, which is a code with 256 characters. Those 256 characters and numbers between 1-9 and A-F are called hexadecimal. These are characters that represent whatever the user wants to upload inside the block. There are four main fields inside each block (Figure 1) in which users can duplicate any of these fields, if desired. The first field is called *cryptography hash* representing stored data. The second field is called *timestamp* for recording time and date for all inputs inside the block. The third field called *nonce* is a random number that calculates the random number as a key between each block. The fourth field is called the *cryptographic hash* for the previous block and connects the block and previous blocks by connecting each block with another chain or series of blocks. By this concept, we have a blockchain.

There are no limitations for how many blocks are contained in a system. When information is inputted, it is uploaded to the Cloud driver; and then notifies all connected blocks. For example, if User X wants to store files or any other storage information, data will be hashed and subsequently saved in the block. Based on the type of block, whether it is a permissionless blockchain system or a permission blockchain system; it will then require an agreement from all connecting users in that same block, especially as a private blockchain system. When transferring codes from block to block, it is verified by sending random numbers and characters to desired computers that can differ in a network. These random numbers and characters are something that other computers in the network have to receive and verify. Authenticating a code correctly will then permit the user to obtain and add data. Data will permanently stay in a block, which helps in maintaining historical records for underground utilities, as all data is securely stored. All users in the same block can view all stored information. However, if they need to add a new file, they cannot change the file currently uploaded in the block thereby maintaining a level of integrity.

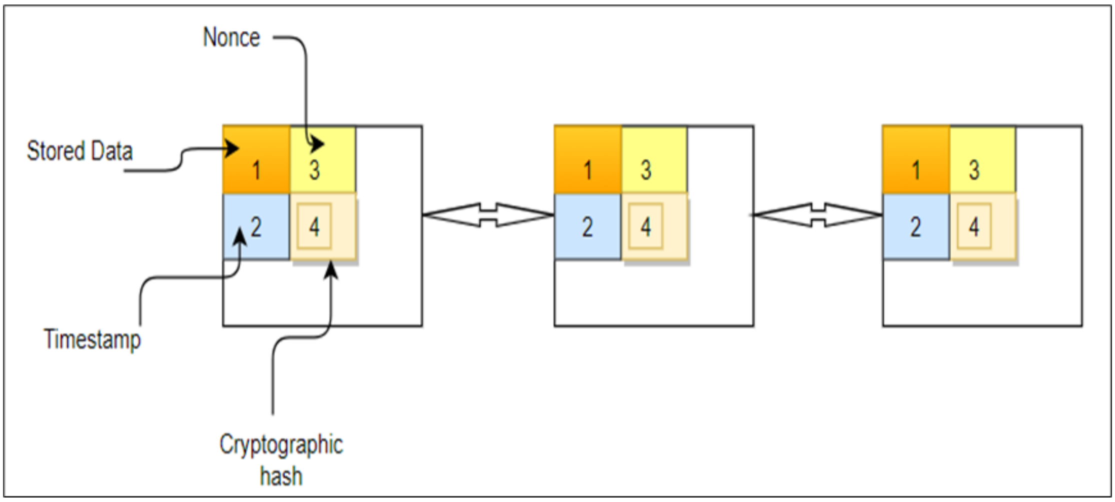

Figure 1 Main fields inside each block

2. Blockchain applications

Blockchain technology is used in multiple industry applications including the healthcare industry, construction contracts, data management, tracking and recording data, operation processes, government management systems, to minimize cyber-attack in infrastructure, real estate transactions, and land registration. The concepts and the application of blockchain are transferable to a wide range of finance, government, and manufacturing industries where security, scalability, and efficiency are essential.

2.1. Blockchain in Healthcare

Since the introduction of blockchain through Bitcoin, researchers have been working to expand its applications to non-financial use cases. Healthcare is one of the fields where blockchain is predicted to have a large impact [7,8]. Blockchain enables businesses to have total control over their individual components, thereby providing clearly articulated, factually supported information regarding its operations both internally and externally. This transparency in the supply chain owing to blockchain has brought changes in healthcare. Patient-centric electronic health records are one of the cases of blockchain used in medical management [9]. Blockchain allows patients to store their medical history on an electronic device and readily share it with their physician. This has a positive impact on a patient's health by allowing physicians to better diagnose and prescribe necessary medicine. Roman-Belmonte et al., [10] explains the current and possible uses of blockchain in several domains of healthcare such as health data analytics, biomedical research, and patient-centric electronic health records.

2.2. Blockchain in Construction Contracts

Construction projects involve collaboration of various stakeholders such as owners, contractors, designers, material suppliers, and others. Subsequently, it is imperative that transparency exists in the communication process [11]. Current technologies including Building Information Modeling (BIM) identify several barriers such as ownership of databases, who pays for them, and responsibility for their accuracy and correctness [12]. Other legal and organizational issues pose difficulties to BIM including, but not limited to, the difficulties in assigning responsibilities and liabilities, collaborative nature of the design process, risk allocation, and integrating of responsibilities and roles. Many current management strategies, such as Building Information Modeling (BIM), can be replaced with blockchain. Other capabilities can be added by using blockchain to track all of the project phases in case of future issues related to documentation [13]. On a construction site, blockchain can strengthen the validity and trustworthiness of construction records, operations completed, and material quantities tracked, as well as in the facility maintenance stages [14]. Many management problems in construction could be avoided if there are timely, transparent, and unalterable records of all activities (i.e., scheduling, cost, risk, design, supply chain) [15]. Blockchain offers solutions to many present-day problems in Building Information Modeling that could be used directly by developers of construction-related software or transactions. It has the potential to decentralize construction processes, thereby opening new opportunities for researchers [11,16]. Blockchain can provide a reliable foundation for information management at all stages of the building life cycle [13,16].

2.3. Blockchain in Data Management

In recent years, there has been efforts to use blockchain in a wide variety of applications and domains such as infrastructure [17]. Blockchain can be used to provide a fair and transparent data sharing environment in which non-approved data changes can be identified and verified and [18].

According to Wang et al. [19], one of the primary responsibilities of government, private sector, and regulatory authorities are controlling and monitoring underground infrastructure. Consequently, developing a comprehensive information management system specifically for underground utilities can help governments and industry to improve their management and processing efficiencies. Furthermore, recording information of underground infrastructure using advanced technology will allow overall system supervision and improve infrastructure safety. "The blockchain is used for data storage through cryptography that ensures only eligible participators can access the corresponding data. The change in sensitive characteristic of blockchain can ensure data authenticity as well" [20].

Advanced underground utility management systems have many valuable applications such as improving government accessibility, facilitating civic engagement, optimizing the use of resources, improving sustainable livelihoods, and improving quality of life. An example to illustrate the ability of blockchain to manage data is in supply chain management. Zhang et al., [22] designed a system for food supply chain based on blockchain technology with a multimode storage mechanism. The planned system differs from previous systems in terms of data security and reliability, information connectivity and intercommunication, real-time exchange data, dynamic and reliable whole-process tracing by using the Internet of Things and blockchain [21,22].

2.4. Blockchain capabilities to track and record data

In recent years, there has been an increase in interest in businesses targeting data and AI marketplaces with varying goals and business models. Many of them emphasize the benefits of blockchain with live data [23], provide a platform for running AI predictions on real-time data, and use blockchain to incentivize accurate forecasts. Wang et al. [24] demonstrate the ability of blockchain to track and record data to achieve long-term preservation of records. They developed a behavioral model, followed by the development of a distributed blockchain data structure for storing output documents directly in line with the approaches and strategies. Furthermore, data were uploaded onto the blockchain to efficiently control quality and safety of intelligent water project construction. Experiments revealed that the proposed strategy decreased time and labor costs while creating production data and ensuring the security and traceability of electronic document preservation [24].

2.5. Blockchain in operation processes

Data scientists typically spend 80% of their time collecting, preparing, cleaning, and organizing data for analysis [25]. Data on blockchains are associated with a participant's identity, timestamped, incorporated, and validated into daily operations such that data on blockchain automatically will be distinguished, collected, and prepared in a standard manner and structure. This creates a large database for analytics and could involve technologies such as artificial intelligence (AI) to gather information and improve predictions [26]. According to Sharma and Sharma [27], the appearance of "*Big Data"* is substantial in operation processes and the emergence of blockchain technology enhances the arrival of "*Big Data"* because it helps in recording and storing data for long period. "*Big Data"* and blockchain technologies are envisioned as a game-changer that is capable of revolutionizing the business practices.

2.6. Blockchain in government management systems

Many companies continue to struggle with information security and dependability. As a result, setting management standards and providing a generic application or platform are critical. According to Hou [28], blockchain technology has the following advantages: 1) enhanced quality and quantity of public services; 2) increased transparency and accessibility of government information; 3) development of information-sharing across different organizations; and 4) assistance in the development of an individual credit system. The Chinese government published a white paper on the development and deployment of blockchain technology, covering the basic technologies, typical applications of blockchain, and standardized usage of blockchain in many areas [29]. Their experience revealed that blockchain technology may assist in developing an individual credit system in society, not just for citizens, but also for institutions, and could enhance service delivery, governance, and government legitimacy. This provides a comprehensive method for increasing the efficiency of government services and standardizing the mechanisms that are required for further advancements [29].

2.7. Blockchain to minimize cyber-attack in infrastructure

Infrastructure systems in the modern era are rapidly growing into sophisticated cyber-physical systems that require a secure, effective, and robust cyber infrastructure. Blockchain, as a developing distributed computing technology, provides a secure environment for such interactions [19], [30]. Demirkan et al. [31] analyzed the current and potential applications of blockchain technology in business, focusing on construction financing and cybersecurity. They used blockchain applications to contemporary cybersecurity and financial concerns. They also investigated the use of "*Big Data*" in accounting as well as the use of blockchain in financial security and cybersecurity as a way of tracking financial misconduct. The U.S. Department of Homeland Security's cybersecurity plan was studied to better understand the necessity of cybersecurity development. They found that blockchain is a suitable fit for various aspects of cybersecurity and accounting systems.

2.8. Blockchain in real estate transactions

As real estate transactions grow more diverse with the launch of digital currency payment systems, the use of cryptocurrencies ensure financing and investment stabilization into payment systems [33~~,34~~]. The real estate industry is notorious for being one of the most pen and paper reliant sectors in any country, therefore susceptible to loss and fraud. The challenges for consumers and owners are numerous as the intermediaries often cost clients time and money. Also, as demand is driven up for large metropolitan areas, affordability becomes an issue for residents. Blockchain technology, specifically the *Ethereum* blockchain, which is a decentralized blockchain for tokenized smart contracts, can address the pain points that currently exists. By tokenization of the real estate assets, they become digital belongings that are safely tradeable on any platform that supports Ethereum blockchain and reduces the intermediaries' influences. Furthermore, it opens the realm of possibility to a wider pool of investors and buyers from around the globe, thereby making it almost impossible for a supplier to face issues like loss or dishonesty [34]. Smart contracts can also provide affordable housing solutions by providing partial ownership of assets, so that a house can be bought by more than one person. Ownership fractionalization can also promote better upkeep of an asset since more people will seek to keep their share. As for transparency, every property would be entered into ledgers with assigned IDs readily available for reviewing online, thereby making it easier for appraisers to quickly access all data related to a transaction or property maintenance. This avoids surprises for the buyer and expedites due diligence for pre-lease or pre-sell. Owner fractionalization could also support investment in projects as reduced prices per share would drive a larger pool of investors to real estate development projects. The blockchain tokenization process is faster and cheaper than traditional methods and allows for customized issuance of shares depending on the investor, thus making it beneficial for developers as they will have access to secondary markets for project funding. Moreover, new real estate projects are plagued with high development costs and interest rates as their investments may come from several financing bodies. Blockchain technology introduces alternative decentralized financing solutions through management of investors and high transparency levels as well as providing live Return on Investment (ROI) metrics for each project [35].

2.9. Blockchain in digitized land registration

Property fraud is one of the most serious issues in many countries. For example, in India, many cases of document forgery have been reported which are exacerbated by the lack of effective land records management systems. Blockchain technology can be used to prevent property fraud incidents [36]. It also helps large property owner companies reduce their low oversight of all of their assets. Through data sharing and streamlined methods for rent and payment collections, companies are able to cut costs related to inefficient localized systems for their properties. Through blockchain, data is distributed in a digitalized land registration system and these distributed nodes are connected through the network. The record of transactions is transparent to the public and immutable in nature (not changeable). Many features of blockchain technology contribute to the integrity, reliability, and efficiency of a digitalized land registration system [37].

3. Scenarios for blockchain

There are two main types of blockchain: 1) private and 2) public. These are further dividing into public, private, consortium, and hybrid blockchain. Figure 2 illustrates the four types of blockchain features and use cases [38,39]. Scenarios for blockchain are classified as chained, very decentralized chained, and slightly decentralized. According to Turk and Klinc [40], chained and very decentralized are similar to a Dropbox folder, except that version of all files are preserved and that a valid last version of every file is maintained. In chained and slightly decentralized blocks, at least one project partner would need to host the blockchain to allow every project partner to have access to the chain. Unchained would be to distribute the blockchain across a few key partners in the project and to offer just a "wallet software" to the clients on the workstations. The unchained scenario does not store the files themselves in the blockchain but rather just their identification.

Table 1 Four Types of Blockchain

Type of Blockchain	Requirements	Description
Private	Requires permission to join	Full privacy High efficiency Stability Low Fee
Public	Allows users to validate the chain, like Bitcoin and Ethereum	Decentralized Fewer transactions per second More secure as it contains active involvement
Hybrid	Develops the supreme part of both public and private	Hybrid IoT Global finance and trade Banking Supply Chain Governments Enterprise Services
Consortium	Multiple organizations govern the platform. Unlike private blockchain, only a single organization on the platform	More validation: Due to number of participants More control: Specific of authentic participants governs the blockchain platform More security: The information on the authentic blocks is private

3.1. Blockchain vs. Utility Infrastructure Management (UIM)

This section illustrates the potential of blockchain for underground utilities as a management system. Currently, there are large amounts of data being collected from various sources at extremely high speeds. However, there is not a sufficient and effective platform to manage this data for long periods of time with transparency and security. Blockchain is about unlimited spaces where data can be stored and documented with a high level of confidence among all stakeholders. It is projected that more than seventy-five billion devices worldwide will be connected by 2025 and represents a significant challenge for the new digital technology period that the world is about to enter [41].

Utility Infrastructure Management (UIM) assists electrical, communications, gas, water, and sewer companies in running all elements of their business, from invoicing to consumer outreach. UIM, like any other technology, helps to decrease costs, expedite utility operations, and offer excellent services to customers. A major limitation is that the stored data can be modified without documentation of who made the changes. On the contrary, in blockchain, these issues do not exist because all information is collected and stored forever, with a clear history of all changes. Furthermore, blockchain protects important information that can be used in case of future conflicts or claims.

3.2. Blockchain vs. One Call 811

One Call 811 is the national number in the United States designated by the Federal Communications Commission (FCC) in March 2005 to protect underground utilities during excavation activities. Prior to digging, an excavator dials 811 and reaches a Call Center in the specific jurisdiction (State) of the project. The One Call operator then contacts all potential utility owners in the area of excavation who then have 48 business hours to physically locate and mark the approximate location of their existing lines with either paint or flagging.

Time could be reduced if every operator or utility owner were to register the location of their utility on blockchain systems. Blockchain is excellent in storing data, as well as being reliable, fast, and saving time and money. Its capability as an advanced system could manage and locate underground utilities using virtual reality (VR) or as-built documents to take advantage of all storage files. To avoid damages to underground utilities, the data needs to be stored for a project from start to finish. Some of the damages in utilities are due to loss of data. Figure 2 illustrates an example of files that could be stored as references during and after project completion. This would contribute to enhancing utility management to avoid loss of data and documents. Blockchain brings several benefits to infrastructure utility management systems. Table 2 presents differences between One Call 811 and blockchain. This paper proposes a new method for storing data for underground utilities by incorporating blockchain technology into utility management practices to assist contractors and other public and private agencies in managing, monitoring, and tracking all documented data.

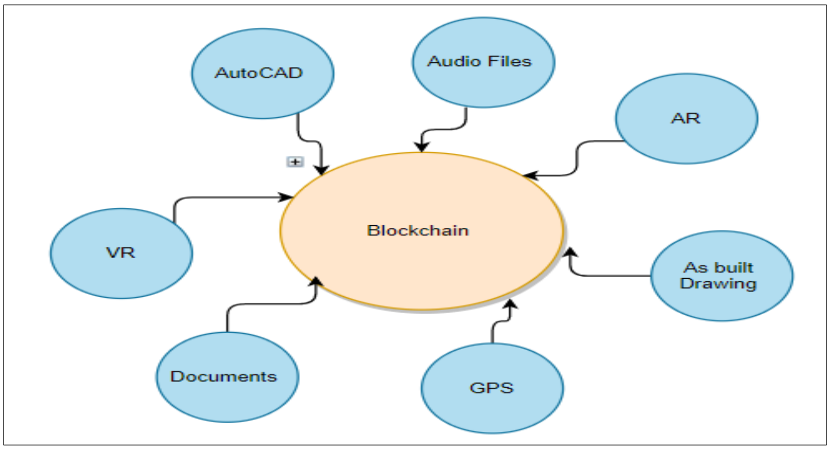

Figure 2 Storage files within one blockchain

Table 2 Comparison of One Call 811 and Blockchain

	811 (US National One Call)	Blockchain
Definition	811 is the national number designated by the Federal Communications Commission to help prevent landowners, landscapers, and contractors from accidentally reaching underground power lines.	Information and transactions of data can be systematically recorded so that all involved parties in the network can validate the information and use it.
How it works	Advanced notice: 2 working days before you begin any digging	You can check any time
How long it takes	Wait a few days for utilities to respond to your request and confirm that all utilities have responded.	A few seconds
Type of information	Marked on and in the ground indicate that various utilities have been to the scene and make marked on and flags placed in the ground indicate that various utilities have been to the scene and make Utilities marked on, and flags put in the field.	All files and information for the project and location with from draft up to final drawings.
Accuracy	A mark out can just be based on records without actual locating, which may not be accurate it has up to 28" of uncertainty	By using VR files and,3D models and GIS, all documents like Bill of Quantities (BOQ)and Request for Inspection (RFI)...etc. All together will help to increase certainty.
Operation Cost	It needs a lot of manpower to operate.	It does not need a lot of operators.
Limitation	It is slow and not 100% accurate	Need a lot of effort to store or upload existing data
Who can get access to data	Only 811 employees	Anyone has permission

As mentioned previously, blockchain can address different types of underground utilities such as public, private, consortium, and hybrid. Each one of these types have their own description that varies based on local country regulations. The United States, China, and India have their own systems for public and private utilities. For example, China's government owns most of the utilities, whereas in the U.S., there are different owners for different utilities. In China, it is easier to manage utilities since there is generally only one owner. In India, some utilities are managed by private companies, while some are controlled by the government. Neither China nor India has a formal One Call system to help identify existing underground utilities. Table 3 presents a breakdown of utility ownership in the U.S., China and India.

China and India have both had major underground utility infrastructure development over the past few decades. Blockchain could be the solution for storing and managing underground utility data since it adds value to infrastructure management.

Table 3 Ownership of Utilities

Utility Type	United States		China		India	
	Private	Government	Private	Government	Private	Government
Water pipelines		✓		✓	✓	✓
Sewer pipelines		✓		✓		✓
Natural gas pipelines	✓	✓		✓	✓	
Electrical lines	✓	✓		✓	✓	✓
Telecommunications	✓			✓	✓	✓

4. Underground Infrastructure Complexity

One of the core challenges today regarding infrastructures within Anthropocene change is the obstinate systems of the past and future. With evolution of technology, modernization of infrastructure is essential within Anthropocene. The core technologies that make up the electrical power system have been in existence for more than 70 years, which includes certain types of generators, long distance conveyance or transmission, substations, distribution lines, and transformers. Water pipes, pumps, treatment technologies, and roadway asphalt and concrete technologies have also been in existence for decades. In general, all of these technologies have existed for over 100 years, Unfortunately, we are missing a lot of data on older infrastructure thereby making the processes more complex for future analysis. It is true there has been some change, but at its core, the backbone of these technologies remains the same. We are starting to see some incremental change because of emerging technologies. Certain societal activities have become more disassociated such as banking, virtual classroom experience, control technologies, and sensing systems in terms of physical presence. Such remote options will likely remain are certainly part of the infrastructure transformation. The need for a robust management system in terms of recording data and reliability is imperative. Turk and Klinc [40] found blockchain to offer solutions to many of the emerging issues management systems. On the other hand, blockchain is more likely to be used in infrastructure and construction applications. It can improve the efficiency of infrastructure management processes by filling in the gaps in present Utility Infrastructure Management and 811 procedures as management systems.

5. Conclusions

Underground utility management is an integration of a sustainable planning framework with respect to need-based user convenience, security, long-term solutions, short-term solutions to urbanization-induced problems, securing financial transactions, reliable monitoring, and improving environmental conditions. Sustainability of underground utilities depends on how the issues today are handled using available technology solutions and management. Some of the main elements of underground utilities that need to be designed include electrical, communications, gas, water, and sewer pipes. Each of these infrastructures should incorporate cybersecurity, which is one of the main strengths of blockchain.

This research highlights potential applications of blockchain with comparison between the current practice of One Call 811 and Utility Information Management (UIM), underlining gaps such managing data manipulation. Blockchain technology enables encrypted and secure logging and transactions for information and data. The technology promotes the idea that information and transactions can be systematically recorded in a public database via a cryptographic process. Blockchain is more likely to be integrated into current technologies on which construction applications are designed using underground infrastructure-related software. Blockchain has good applications for future research in underground infrastructure management.

As blockchain technology improves, the likelihood of integration into other applications including supply chain systems, healthcare, and even election voting in the near future will increase. The increase in security and data storage that comes with blockchain could potentially integrate with infrastructure. There is complexity in which infrastructure and subsurface utility components are connected. The key features of blockchain that can be utilized for technology development and management of underground utilities are privacy, interdependency, efficiency, and transparency. Blockchain is an advanced structure capable of handling and managing underground utilities with accuracy by considering all recorded information and documents. With all different types of blockchain operators, project managers will be able to store all necessary data in a trusted and secure management system, thereby reducing damages to buried infrastructure.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest.

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