Blockchain technology conception in digital data collection for damage assessment and L.C.A

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Blockchain technology conception in digital data collection for damage assessment and L.C.A.

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ABSTRACT: In the modern transportation networks, such as metropolitan infrastructures, advanced technologies play a crucial role in enhancing efficiency. Infrastructure management is paramount for safety and sustainability. The integration of IoT and digital technologies in smart infrastructures poses challenges in the evolving digital landscape, particularly in ensuring the security and integrity of monitoring data. This study explores the potential applications of blockchain technology to enhance data authenticity and security in real-time subways monitoring. By leveraging blockchain, the study aims to establish a secure digital twin, ensuring the accuracy and integrity of acquired data. The technology's decentralized and tamper-resistant nature makes it well-suited for safeguarding critical monitoring data, offering a reliable foundation for proactive maintenance strategies. The findings indicate a promising avenue for blockchain in fortifying data management and information security in infrastructure assessment. For these reasons, blockchain could represent a valid solution to the modern challenges involved in the lifecycle management of infrastructure such as subways.

1 INTRODUCTION

In recent years, the development of our cities has increasingly focused on maximizing the use of existing built space. In this perspective, the creation of ever-expanding and efficient metropolitan networks allows us to harness technological advancements while respecting environmental criteria and the demand for effective and rapid transportation means.

Similarly, one of the significant challenges of this century is related to the adaptability of our infrastructure to the ongoing climate changes. The application of Internet of Things (IoT) technologies in recent years has resulted in the generation of numerous data, the analysis of which is crucial for the management and implementation of smart cities (Xiaoming, 2022). It becomes indispensable to acquire data with the absolute certainty of its accuracy and security, a necessary objective given the strategic and economic importance that infrastructures such as subways have demonstrated for our cities and societies.

Blockchain technology, originally arising from the financial sector, has recently exhibited such versatility that its application has extended to various fields. Currently, there are three types of blockchains (Swan, 2015):

Type 1.0 associated with cryptocurrencies;

Type 2.0 typically linked to economic, marketing, and financial applications;

Type 3.0 associated with other applications.

The proliferation of IoT devices has ushered in an era of unparalleled connectivity, enabling seamless communication and data exchange. However, this interconnectedness also amplifies concerns related to data security, integrity, and authenticity. Blockchain technology,

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characterized by its decentralized, distributed ledger system, provides an innovative framework to address these challenges. IoT systems simplify a real-time data collection and provide automatic and remote control mechanisms, for this they generate massive volumes of data that require network connectivity and power, processing and storage resources to transform these data into information. (Lokshina et al, 2019).

The proliferation of increasingly widespread IoT sensors has led to the generation of large amounts of data that not only need to be protected but also properly managed, maintained, and archived. In the perspective of a vision of interconnected structures and infrastructures aimed at implementing the resilience of our cities, the so-called smart cities (A. R. Javed et al., 2022).

With this scenario in mind, the need to track and certify data becomes indispensable. For this reason, it is crucial to envision consent systems, typical of blockchain technology, that can seamlessly integrate with Big Data management. We can speak about Big Data when the quantities are on the order of petabytes (Al Nuaimi et al., 2015).

Moreover, the application of blockchain technology would not only certify data related to structural monitoring but can also be extended to the broader concept of project monitoring, encompassing cost management and maintenance planning. This would result in the creation of a system characterized by a high level of traceability of actions and transparency, enabling the reduction of the complex bureaucratic processes that typically characterize the management of such infrastructure projects.

The study has therefore set the ambitious goal of identifying a possible architecture that not only ensures data security but also enables its transparent and efficient use at all levels and throughout the entire lifecycle of the infrastructure.

2 BLOCKCHAIN TODAY

Today, blockchain technology has found substantial application in both financial realms, with established projects like Bitcoin and Ethereum, and in the industrial sector. Several companies utilize blockchain for data security and traceability. The strength of this technology lies in its versatility, allowing seamless integration and ensuring interoperability with various data types, especially evident in applications related to Digital Twins used by industries for product development (Götz et al., 2020).

Numerous works in the literature explore the possibility of developing models that integrate blockchain frameworks for applications in Digital Twins and IoT sensors. In the construction industry, the adoption of blockchain has been slower, with many potential applications yet to be explored and evaluated. Certainly, integration with Building Information Modeling (BIM) models has allowed for optimal utilization of BIM methodology, originally designed to facilitate collaboration and information transmission among different processes and stakeholders in the design phase (Krämer et al., 2018).It is noteworthy that for BIM methodology to achieve its maximum potential, data sharing and processing are required by both technicians and stakeholders, who play distinct roles and have different data needs. The success of decision-making processes is precisely determined by the quality of data and the type of communication established. Consequently, over the years, models have been developed that involve the integration of blockchain technology, ensuring the security and traceability, and providing tracking throughout the project's lifecycle, which extends beyond its construction phase.

One of the less-explored applications, which will be examined in the following paragraphs, is the possibility of tracking the various stages that data undergoes. When referring to data, it encompasses not only physical data but any type of information, such as the occurrence of maintenance processes, the entities involved, quantities, and materials utilized.

With the development of new sensors and connected technologies such as 5G, the implementation of Information and Communication Technology (ICT) in Building Information Modeling (BIM) processes has become feasible. Similar to industrial processes, frameworks have been initiated to facilitate integration not only with BIM models but also with sensors that enable real-time data collection from the structure, enhancing decision-making processes in emergency situations or refining maintenance procedures in consideration of the real-time evolution of the structure. (Pasini et al., 2016).

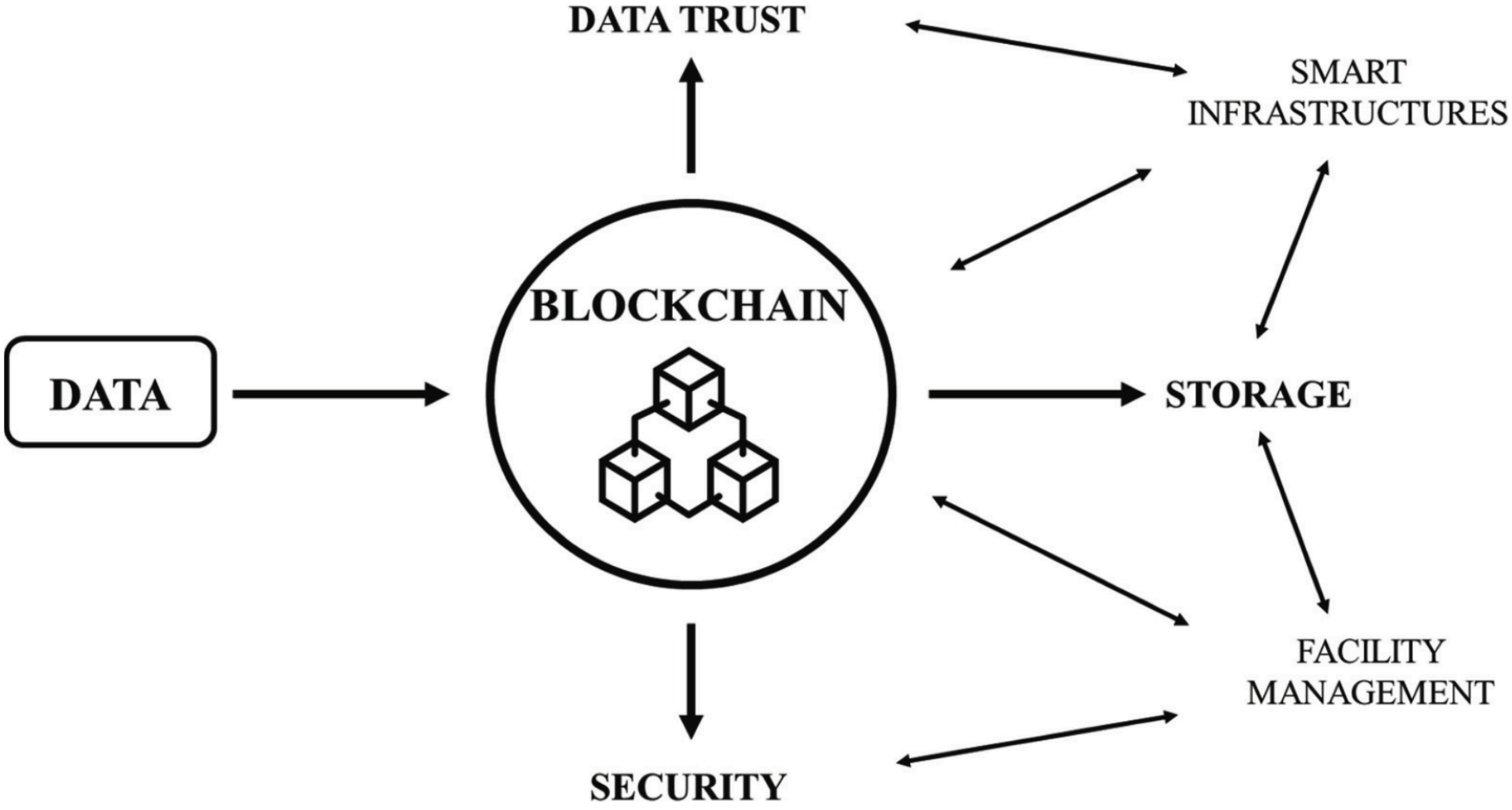

Figure 1. Potential uses of blockchain for data management.

In this context, various authors concur in asserting that blockchain technology presents undeniable advantages when applied to the construction sector.

Consider, for instance, a system combining Cloud computing, IoT, and BIM, which not only requires ensuring data interoperability but also its integrity and accuracy. Tracking the various stages that the data undergoes throughout the project is crucial, along with addressing the significant issue of security, especially concerning critical structures and infrastructure like subways. Such challenges could be effectively tackled with the utilization of blockchain technology would serve as an immutable method to store data and information and use and reuse it at different times. (Kshetri, 2017).

Otherway some of these applications may be affected by one of the still partially unresolved issues of blockchain related to scalability. The term scalability refers to the ability to handle a growing number of transactions without compromising performance. Factors influencing this capacity can be identified by the consensus mechanism used, the block sizes representing the amount of exchanged data, and the number of nodes. That is, the extent, also understood as the physical extension, of the network; each node corresponds to a computer.

Next-generation blockchains have partially addressed these challenges by adopting solutions such as sharding. Sharding is a technique that allows the subdivision into smaller and more easily manageable parts (Zamani et al., 2018).

Alongside sharding, complementary solutions are usually implemented, involving the creation of secondary blockchains alongside the main one with specific tasks; in this case, they are referred to as sidechains (Lohachab et al., 2022).

In any case, it is evident that blockchain technology and the applications arising from it require the resolution of what is defined in the literature as the 'blockchain trilemma,' which involves scalability, decentralization, and security. The trilemma highlights how it is currently impossible to simultaneously implement all three aforementioned characteristics, each of which in turn affects the consensus system (Buterin, 2015), as highlighted by Figure 2.

The trilemma underscores how the implementation of one of the three fundamental characteristics can impact one or even both of the remaining features. Over the years, various solutions have been developed to address this ongoing and evolving trilemma.

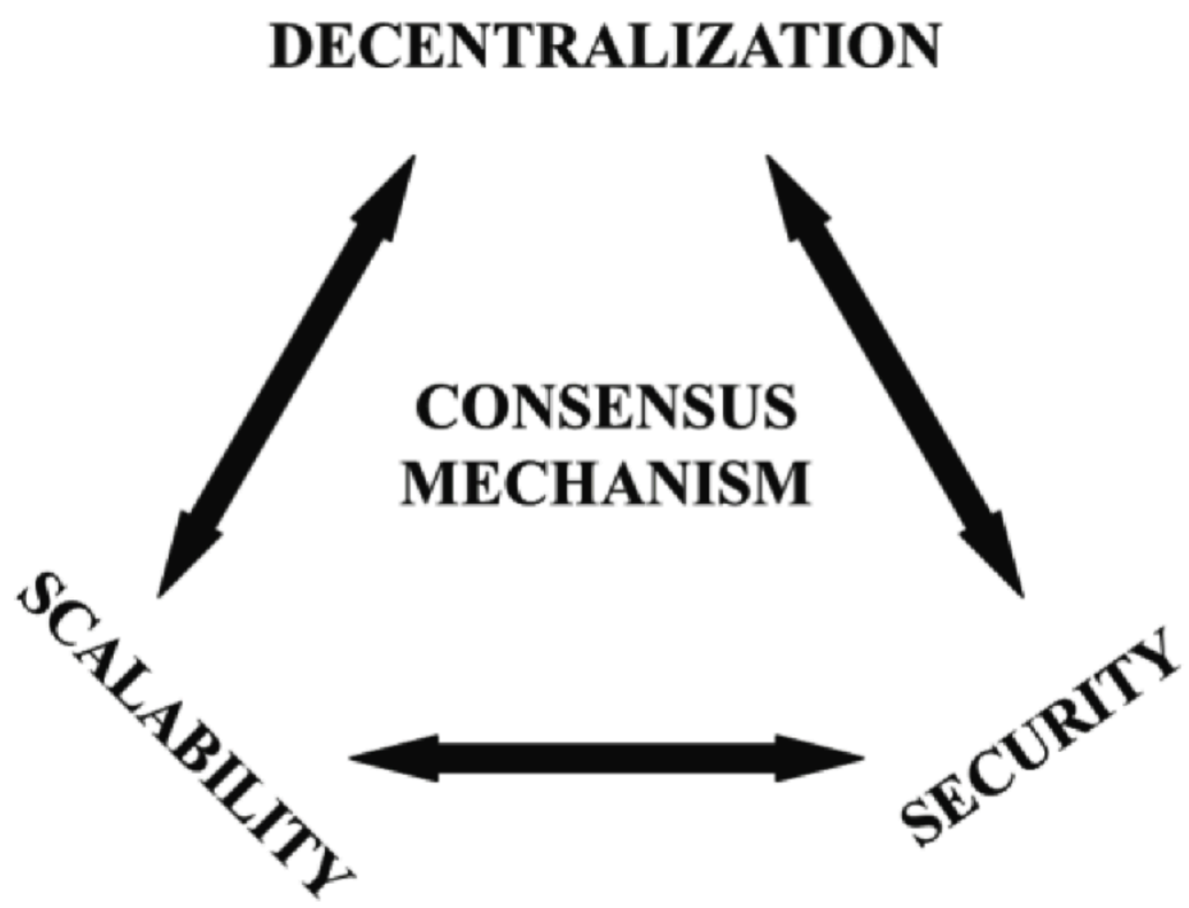

Figure 2. Blockchain's trilemma.

In this regard, the development of new blockchain architectures has significantly improved scalability without excessively sacrificing security or decentralization (Bano et al., 2017).

In the end blockchain could ensure the possibility of access to individual data without the interlocutor gaining access to the entire database. This capability has made the development of blockchain for structure management throughout its lifecycle.

Methodology

The work has focused on defining a potential architecture for implementing a framework that maximizes the benefits of IoT sensors, integrated into a digital twin benefiting from blockchain technology. This study stems from the authors' belief that a digital twin, to be considered as such, not only needs to provide an effective view of the studied infrastructure based on well-defined physical and environmental parameters but also must allow the implementation of functions for efficient facility management while ensuring data management, whether related to a physical-mechanical or economic parameter.

The work has been based on two specific questions:

How is the state of the art of blockchain technology and the level of application it has reached in the construction industry.

What possible architecture to adopt to perform optimally according to the needs presented by such infrastructures?

The work involved an extensive review of existing literature and a deep exploration of blockchain technology-related literature. This enabled an understanding of potential positive aspects while simultaneously identifying possible implementations to address some challenges in applying this technology.

In the Figure 3, you can observe the workflow followed by the team. It is evident how the requirements of these infrastructures have been connected with the characteristics expected of

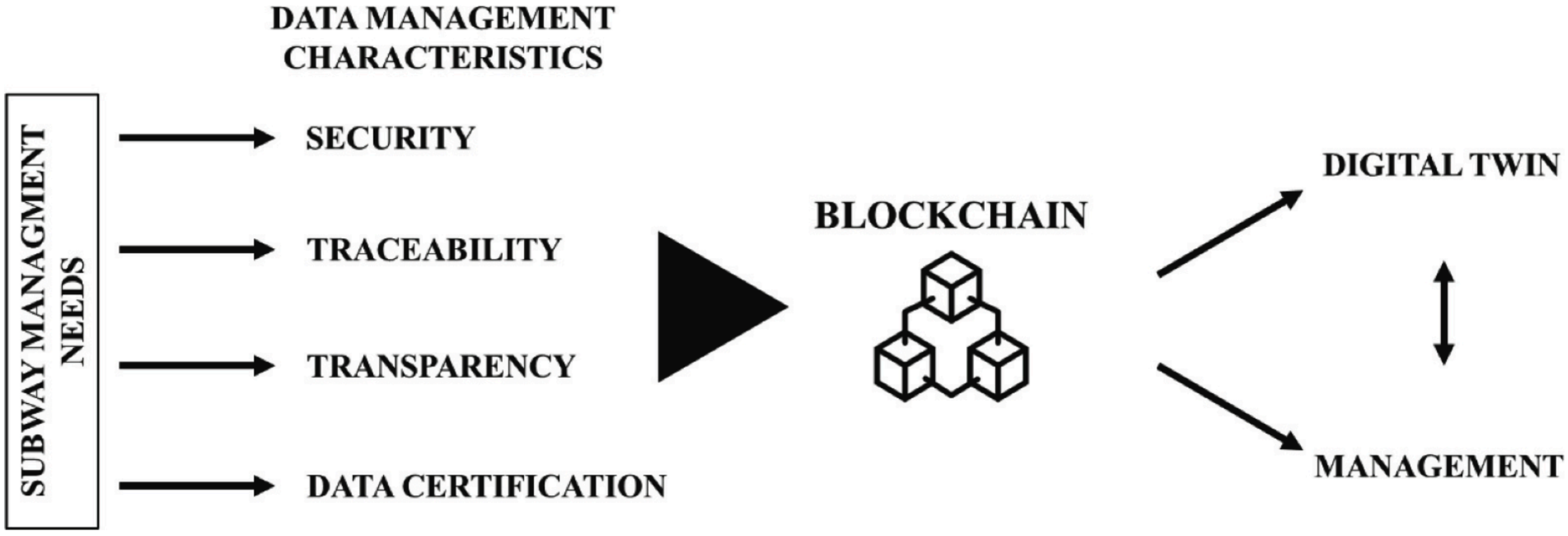

Figure 3. The correlation between the needs of a subway infrastructure and the utilization of blockchain for its management.

a system to be considered efficient from a data management perspective. Starting from data management, the application of blockchain technology has been initiated, with the ultimate focus being the potential implementation in digital twin and LCA systems.

3 APPLICATION

The application of Blockchain technology in the management of subway monitoring systems, as well as in the management and scheduling of maintenance procedures, and handling relationships with various suppliers, presents an innovative approach. The creation of a blockchain framework leveraging recent developments, such as technologies that do not require mining, is a significant step forward. Traditional mining procedures have been associated with substantial computational efforts, resulting in both economic and environmental burdens, particularly in early applications.

Recent advancements have given rise to blockchains like IOTA (Alshaikhli et al., 2022), specifically designed for managing and transmitting data from IoT sensors. The entire infrastructure could be equipped with structural or environmental sensors, collecting data on various parameters under investigation. In this scenario, the operator could decide between two strategies.

The first strategy involves acquiring data from sensors and certifying it. This can occur immediately or by setting a specific delta time to collect data packets that are then certified together.

The second strategy involves connecting, using technologies like 5G, to obtain a digital twin containing the collected data and certifying the final result only afterwards.

As shown in the diagram in Figure 4, the two strategies diverge on the subject of certification. The first proposed solution suggests certifying raw data, allowing not only for archiving but also for safeguarding them from potential tampering. On the other hand, the second strategy involves certifying the digital twin.

Certifying the model not only provides the ability to validate the current state of the infrastructure but also validates various post-processing operations to which the data are subjected.

Both strategies can be executed through manual or automated certification operations.

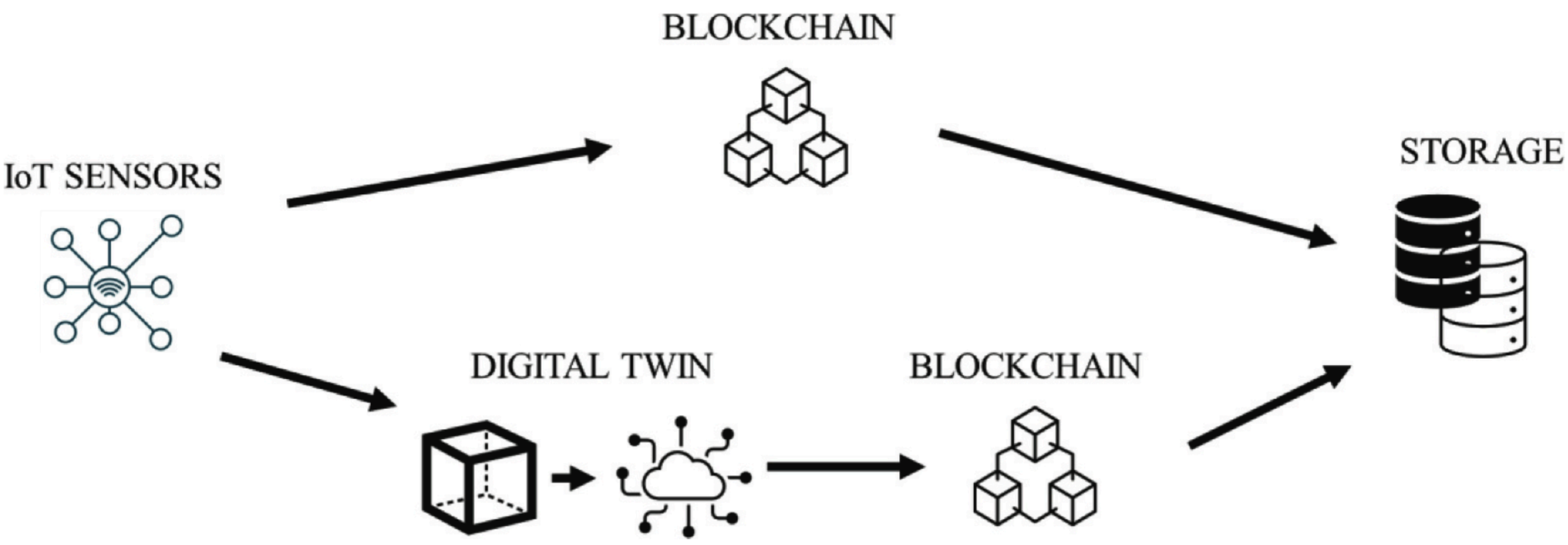

Figure 4. Two possible application of blockchain for data security.

Subsequently, the protected and certified data could be shared with all parties involved in various operations. The framework architecture allows data owners to share data with selected entities, ensuring data compartmentalization among individual users. This procedure ensures traceability and confidentiality levels among different users that the current BIM methodology may not completely guarantee.

Simultaneously, creating a blockchain linked to the structure enables the transmission of useful information for various processes. With a single cryptocurrency, it becomes possible to make payments for services and transmit technical instructions, materials, quantities, and more, all in one transaction, this possibility is provided by smart contracts. (Ghiani, 2021).

To create a smart contract the first step is the parties define the corresponding objectives for each party and agree on the expected outcomes.

In the next step all specifications and contract clauses are written in computer logic language and coded in a programmatic way.

All specifications and contract clauses are then written with computer logic and coded in a programmatic way. Then the smart contract will be sent to the Blockchain, that will be executed on its own when specific criteria are activated. When a consensus is achieved from the majority, the transaction will be added to the ledger, the smart contract will be executed, and the results will be registered (Cachin et al. 2017).

Through the consensus mechanism, it is possible to guarantee the transparency of operations, which is typical of blockchain technology. The application of this procedure allows administrations to establish economic and operational relationships based on a dedicated cryptocurrency. This cryptocurrency acts as a guarantor of a broader system involving operating companies, infrastructure managers, and technicians.

POSSIBILE SMART CONTRACT SCHEME	
Contract ID	XXXXXX
From	Client ID
To	Contractor ID
Time	gg/mm/aa - hh:mm:ss
INPUT	BIM File
	Work Size [mq, t, ecc…]
	Material
	Work of time
	Cost
	Notes
	Ecc.
Signature	

Figure 5. Example of smart contract.

In a way, the cryptocurrency takes on the role of a digital certification for adhering to specific technical, economic, and environmental characteristics. This ensures a quality system among the involved companies, allowing them to demonstrate compliance and adherence to established standards.

In the end with this solution it is possible obtain a system with different characteristics:

Strong security;

Data trust;

Traceability;

Transparency;
Quality control.

The diagram below (Figure6) illustrates the identified architecture intended for use in implementing a framework that can ensure multiple functionalities, proving to be both dynamic and efficient across different territorial and managerial contexts.

The diagram shows how the solutions involve using blockchain in two different time steps. This is because it is believed that the optimal solution should not only have the certification of pristine data, which could also be used in legal disputes, but also utilize the blockchain to certify and protect the digital twin. This solution allows for the creation of a data background and provides a mechanism to have an always updated and verified digital twin that can be used to track various events and interventions that the structure has undergone over the years.

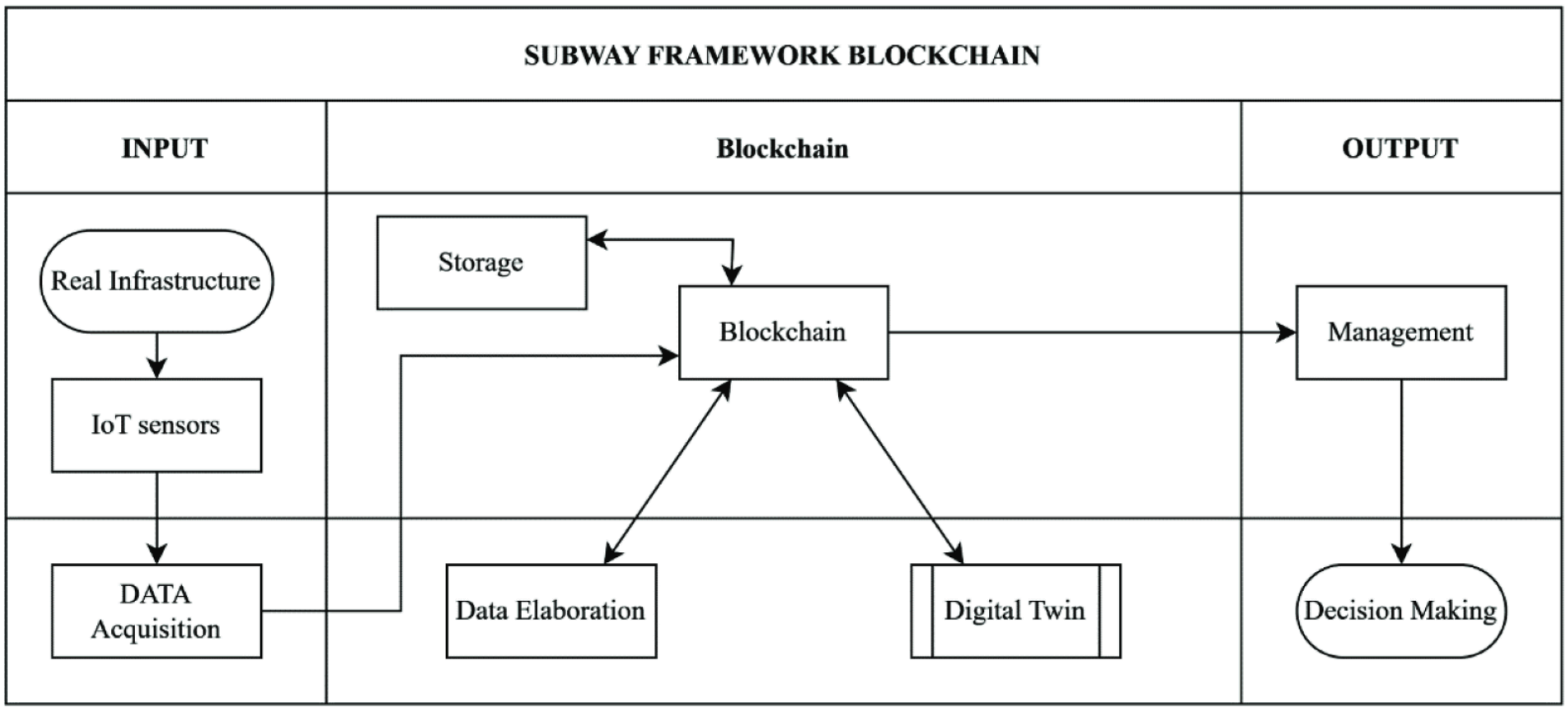

Figure 6. Framework's architecture to use blockchain for subway infrastructures.

The use of a certified model containing all the information, verified and transparent, related to the entire life of the structure is not to be underestimated. In this way, the life cycle analysis process could benefit from it, including the verification of any environmental criteria introduced in the years following the construction and commissioning of the subway.

4 CONCLUSION

This work has allowed for a clear definition of milestones and requirements necessary for the development of a framework aimed at the optimal combination of blockchain technologies with the capabilities of IoT. The obtained results and the defined architecture of the framework will lead to developments, through the use of an open-source ecosystem, resulting in a blockchain that is usable and adaptable to all the needs involved in the physical and economic management of infrastructures such as subways.

It is believed that the use of blockchain can maximize the utilization of existing tools, still underutilized to date, provided by the BIM methodology. Additionally, it serves as a valuable tool to ensure the security and transparency of all operations, both during the construction phase and management phase throughout the entire lifecycle.

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