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THE SMART CITY BLOCKCHAIN GOVERNANCE: A LITERATURE REVIEW

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Abstract

A smart city is a relatively new socio-technical notion related to sustainable and intelligent urban life. During the past decade, numerous smart city initiatives have been implemented around the world as a test bench for sustainable economy. However, as big data grows in smart economies, there is a great concern about security along a sense of trustiness for the controlling authorities of these data depositories. Blockchain is a sharing economy technology that reshapes the smart cities terrain having immune records, public consensus, and security mechanisms that decentralize control to all citizens and government organizations. This work provides a systematic literature review of blockchain based applications across the governance of smart cities. The paper discusses and organizes use cases from seventy-nine selected papers into smart city governance using a component-based analysis to classify the use for blockchain smart city platform and distributed applications in smart governance.
Keywords: sharing economy; blockchain; smart city governance; smart contracts; Security threats

1. Introduction

Smart Cities transform the urban context to meet the modern urbanization challenges by integrating sustainability, social technology, and quality of living. According to a McKinsey report (McKinsey, 2020), the number of Smart Cities will reach 600 worldwide by 2021. In the last decade, various smart city frameworks have been introduced that have derived mainly from the research departments of large technological corporations. These technology leaders compete, invest, and strive to gain a dominant position in the smart cities' platform market. IBM in Santander, Microsoft in Buenos Aires, Oracle in New York, Sysco in Amsterdam, Siemens in Masdar (Santana et al., 2016; Brutti et al., 2019) are identified as a few of the smart city platform vendors that implement the connected city vison through the Internet of Things (IoT) and other modern technologies (Aldairi, 2017). Also, open-source platforms like FIWARE, protect cities to avoid vendor lock-in and provide a loyalty-free infrastructure to connect IoT devices with smart city applicability (Cirillo et al., 2019).

Smart city applications not only collect a wide range of sensitive personal data, but also control the city's cyber-physical infrastructure related to areas, such as energy and transport. The massive number of connected devices along with the lack of cryptographic features imposes security threats (Abosaq, 2019; Zhang et al., 2017) on infrastructure, and vulnerabilities among citizens over sensitive private data (Yang and Xu, 2018). Moreover, smart city platforms follow a centralized server approach to control all city data fragmented in various smart city vendor's servers. The centralized control of smart data from private corporations or governmental organizations increases the risk of single point failure from cyber-attacks (Aldairi, 2017; Zhang

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et al., 2017).

A blockchain is a peer-to-peer, shared, immutable, and distributed ledger (the chain) that records transaction data and tracks assets (the block). The blockchain is shared among all its members (the nodes). Assets could be physical, such as a property, or digital, as a certificate. When a transaction is initiated, represented as a block, it is broadcast to all member nodes of the blockchain. When a consensus is met between all nodes and the new block becomes valid, it is added to the blockchain (Nakamoto, 2009; Patil and Puranik, 2019; Mselmi, 2020). The fact that a blockchain is not owned or controlled by any single organization, and the ledger is shared in real time, increases the level of trust among citizens (Kundu and Kundu, 2019). The sense of trust is also enhanced by the immutability of blocks, where all transaction data are stored permanently and they remain reputed (Christidis and Devetsikiotis, 2016; Al-Imamy and Zygiaris, 2022). Confidentiality is maintained through cryptographic techniques preserving anonymity in both the transactions and the transacting parties. A blockchain is also suitable when traceable transactions or operations are needed or when operations require enhanced security and privacy (Zyskind et al., 2015). Users may also retain self-sovereignty by identifying themselves and controlling their personal data. Disintermediation, as the removal of third-party auditors in blockchains, is another characteristic of blockchains, where the nodes can validate the transactions using consensus algorithms (Patil and Puranik, 2019, Christidis and Devetsikiotis, 2016; Marsal-Llacuna, 2018). The main objective of this work is to leverage and classify the existing use cases of blockchain technology as layered components on a smart city governance framework.

2. Background

A blockchain platform lies at the centre of a blockchain smart city, which is shared between individuals, communities, and the city government. The platform must provide tools to generate and distribute ledgers and applications. Hyperledger fabric is an open-source platform developing a suite of stable frameworks, tools libraries for enterprise-grade blockchain deployments and creation of blockchain applications. It is the main "blockchain application generator" for the various use cases of a smart city. Hyperledger fabric (Dhillon et al., 2017) is a community-based platform and cannot be controlled by a single entity that naturally fits into a smart city ecosystem (Zhang et al., 2018). Other blockchain platforms that can be used as open source are Corda and Ethereum.

There are complementarities between theses platforms as blockchain engines, but instead of choosing a specific platform, the smart city blockchain infrastructure should provide a plurality of choices in order to cover the variety of demands for smart city blockchain applications (Saraf and Sabadra, 2018). Stellar and XPR are distributed ledger platforms built to facilitate cross-platform asset transfer. These innovative blockchain platforms allow institutions to make transactions directly from smart contracts. The smart city platform should support crypto currency payments with Bitcoin (Antonopoulos, 2014) and Litecoin (Haferkornm and Quintana, 2015) as the two representative payment systems (Jonker, 2019). The list of available blockchain platform at the city level can be extended to support the demanded requirements of new applications.

Blockchains can be permissioned/private or permissionless/public based on the level of access

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the participants are granted. Cryptocurrency blockchain platforms like Bitcoin, Ethereum (Haferkorn and Quintana, 2015) are permissionless and they are self-sustained reducing drastically operational overheads. Public blockchains in smart energy or intelligent transport blockchain should be permissionless with the open participation of city residents. Permissionless blockchain are completely open to fully extend to all participants. They enforce anonymity and transparency to all participants as all transactions are recorded in public and they are immutable (Zheng et al., 2018). Permissionless blockchains imply trust and transparency due to the crowd-controlling characteristic at the cost of speed. The algorithms for control and consensus are exercised to a large number of participants like in peer-to-peer energy trading.

In a permissioned blockchain, each participant has a unique identity, which enables the use of policies to constrain network participation and access to transaction details (Mingxiao et al., 2017). Private Blockchains in a way are controlled by a smaller group of nodes; they do not require anonymity and can be used for restricted access like a voting system or medical records system (Mitani and Otsuka, 2020). The system is controlled by a group of peers that are assigned the role of trusted validators. An example of a trusted validator is the city government. Hyperledger and Multichain (Greenspan, 2015) are examples of platforms that could deploy private blockchains on a smart city. A hybrid combination of public and private blockchains like Cardano (Zheng et al., 2018) mainly belongs to the federated blockchain platforms, where a leader node is assigned to provide permission to other nodes. Since some smart city applications are for autonomous vehicles requiring permissionless access, and voting applications having restricted/permissioned access, the least set of blockchain platforms for a smart city operation is Ethereum (permissionless) and Hyperledger Fabric (permissioned). Consensus algorithms are used in blockchains to reach a decision about the validity of a data block. Every blockchain application is dedicated to a specific consensus type, and platforms are based on a specific consensus mechanism (Mingxiao et al., 2017). For example, Bitcoin and Ethereum are based on Proof-of-Work (PoW) consensus and are the most adopted consensus mechanisms (Antonopoulos, 2014) represented in at least half of the cases we studied.

The consensus in PoW is achieved through the cryptographic complex task of the miners (Dannen, 2017). The majority (34) of our use cases are using Proof-of-Work consensus mechanisms. The PoW consensus algorithm makes sure that at least 51% of the peers agree the hash provided by a miner is a valid proof of work (Viriyasitavat and Hoonsopon, 2019). The Proof of Stake (PoS) consensus mechanism is used by one use case, but the number will most probably increase because Ethereum is transforming into PoS mechanisms (Pilkington et. al, 2017). It is an alternative of PoW, where the miners, instead of competing are assigned by an algorithm according to their stakes based on the amount of coins that a miner possesses, reducing the lengthy validation process. Byzantine Fault Tolerance (BFT) consensus is used by Hyperledger and Multichain platforms (Castro and Liskov, 2002; Zheng et al., 2018). The basic assumption for consensus is two thirds of the peers must be reliable nodes in order to avoid failure of the system.

In a smart contract, the terms of the agreement between two parties are defined internally and executed automatically. Smart contracts are important elements in the blockchain smart city. They are generated when a transaction occurs in the blockchain (Hu et al., 2019; Christidis and Devetsikiotis, 2016). Smart contracts are used to generate immutable records, for example, in

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administrative use cases, land administration, real estate (Stefanovic et al., 2018), IoT, and e-voting (Sheikh, 2019). Smart contracts in the smart city blockchain platform can be implemented from the Ethereum and the Hyperledger Fabric platforms. Ethereum runs the Smart Contracts for applications that are for mass consumption. On the other hand, Hyperledger leverages blockchain technology for delivering high degrees of confidentiality, resilience, and scalability (Chen et al., 2017; Shen and Pena-Mora, 2018).

The IoT system includes short-range wireless devices such as smart meters, ZigBee, RFID, and location-based technologies. The huge number of connections of sensors and transmitters positioned in a centralized, client-server-based model in IoT is raising communication and scalability issues (Samaniego and Deters, 2016; Novo, 2018; Zhang and Wen, 2017). Blockchain is a valid technology to protect IoT devices such as security cameras, traffic lights, or sensors, from possible attacks enabling devices to make their own security decisions without a central controller (Rotună et al., 2019).

The reduced traffic transfer of data to cloud also diminishes the risk for security threats. In a smart city, road, artefacts, cars, and doors may communicate with other things increasing tremendously the lines of communication with a centralized server that can be exposed to hacking by malicious activities, such as, Distributed Denial-of-Service, if an IoT server or a server leveraged on the cloud environment is compromised (Chaudhry et al., 2018; Boncea et al., 2019). Such centralized architecture suffers from Single Point of Failure (SPF) increasing vulnerability (Sharma et al., 2017; Li and Zhang, 2017; Sakakibara et al., 2017). A complementing fusion of blockchain and IoT technologies may benefit from each other in a reciprocal manner (Miraz and Ali, 2018).

In blockchain, IoT Implementing an effective consensus with communication overhead among IoT devices with limited computation resource and preserving the anonymity of the nodes is a challenging research target. As a response to this issue, cryptocurrency like IoT, Byteball, and IOTA provide a customized blockchain for IoT changing the consensus process from a linear blockchain to tangle using Direct Acrylic Graphs (Sultan et al., 2018). Worner and Bomhard (2014) described a use case where sensor transfer data was employed in exchange of bitcoin using the same node addressing as the Bitcoin network. A client and a node can exchange data addressing the public key of the sensor and the client (Jovovic et al., 2019). The execution of the data transfer is processed through smart contracts. The IoT combined with the blockchain technology will generate huge application prospects and provide solutions to many existing challenges in IoT (Hui et al., 2019). The notion of pluggable consensus where users may be able to plug the requested consensus in the platform may be a possible research area in the future.

Biswas and Muthukkumarasamy (2016) proposed a blockchain based security framework to enable secure data communication that integrates the blockchain technology with smart devices to provide a fault tolerance and secure communication platform in a smart city. Under central access, massive surveillance programs must assure security (Restuccia et al., 2018). Presumably, blockchains address all of the security concerns for IoT taking under consideration its anonymity, decentralization, and non-repudiation (Miraz and Ali, 2018). Sultan et al. (2018) argues in favour of a blockchain enabled enhanced IoT Ecosystem Security to be complementary technologies to each other. Unlike personal computers or workstations, sensors have limited computational

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power to perform this operation. The delay of the consensus mechanisms to signal transmission in sensors is a serious drawback of applying blockchain in IoT (Miraz, 2019; Dorri et al., 2017).

One of the key challenges of the IoT is to enable and control autonomous and self-organized Machine-to-Machine (M2M) communications. IoT communications are based on real time processing with enormous requirements on speed and bandwidth. The response to the security threats risen by scalability issues is to reduce communication overload by clustering (Dorri et al., 2017). When a smart device is added to the smart city ecosystem, a new block is inserted to the blockchain. A smart device, in this system, can store the data either on local storage or on a cloud storage. Another blockchain IoT solution is using a communication hub on a cluster of sensors (Restuccia et al., 2018; Alphand et al., 2018). Blockchain algorithms for consensus assume high delays that do not complement the real time processing requirements (Alphand et al., 2018). For example, PoW algorithms consider that the consensus mechanism should take place by each node locally.

Smart governance contributes to the reduction of corruption, the improvement of administrative efficiency of and the upgrade of integrity in administrative processing (Kshetri and Voas, 2018). Under the smart governance notion, decision making requires the reengineering of administrative decision making by leveraging blockchain-off data, decentralizing control, and auditing and automating the processes (Jun, 2018).

The blockchain technology uptakes the digital governance notion to the level of “blockchain governance” (Jun, 2018; Allessie et al., 2018) mainly affecting the distributed document processing in automated processes. The blockchain use cases highlight the importance of time stamp in document processing (Beris and Koubarakis, 2018), the digital identification (Mehmet and Serkan, 2019) using cryptography and hashing, digital signature and Self-Sovereign Identity (SSI) in which any entity comprehensively owns and controls their own data. Wang et al. (2017) design and implement a blockchain-based administration process, which is decentralized, to make the document sharing between government agencies more efficient (Carter and Ubacht, 2018).

All information sharing requests are recorded on the blockchain as a robust, trusted, shared link. Services such as handling of legal documents, attestation, and family status certificates are considered as use cases with the smart governance (Swan, 2015). On a larger scale, the world citizen blockchain application is used as a passport service to identify citizens from all countries. Smart governance in the blockchain context is an entrusted mechanism for managing and holding official records of both citizens and communities (Bakre, et al, 2017; Jaffe et al., 2017).

City certificates as birth certificates can be falsified in their digital or paper form. Certificates issued via a blockchain are secured. Since certificates issued on the blockchain can be automatically verified by the blockchain, there is no need for a centralized notary service nor does the recipient have to contact the issuer to receive verification (Datta, 2019; Huynh et al., 2018). Other uses cases are document verification, e-residency approaches (Sullivan and Burger, 2017) as public notary blockchain (Hou, 2017). The Dubai Government announced the documents blockchain management system to be enacted by 2020 and the digital passport by 2027. The State of Illinois has launched a blockchain pilot to digitize birth certificates (Ojo and Adebayo, 2017; Alexopoulos et al., 2019).

Blockchain digital identification allows the automatic authentication providing access of an entity to a system. Blockchains use Self-Sovereign Identity (SSI), that allows the user to control every aspect of their credentials (Chalaemwongwan and Kurutach, 2018) and store them in their own devices (Rivera et al., 2017), without the central control of any authority (Muhle et al., 2018). The identified entity is assigned to a self-generated identification number derived from the combination of the public key and the corresponding private key (Smolenski, 2016).

SSI relies on a public-private key pair to record user information including biometrics on a shared and decentralized ledger (Wang and De Filippi, 2020), although SSI is relatively new technology, and comprises financial and social inclusion of vulnerable populations (Blasted and Allen, 2018; Reijers et al., 2016). Users may identify themselves using any mobile application including personal data like national cards, driving license, or certificates (Rotună et al., 2019). A successful use case is the Estonian e-Residency program that allows expatriations to receive national identification and set up a business (Nasulea and Mic, 2018). The Dubai government announced the implementation of the blockchain electronic ID management system. The city of Zug in Switzerland offers blockchain-based digital identity to their residents (Salha at al., 2019).

Moving state land archives to an open distributed ledger as in the case of Georgia land registry has stored one million land titles on a blockchain, where land titles are recorded via Bitcoin blockchain or by using smart contracts. The city of Pelotas in Brazil and The Dubai Land Department (DLD) use blockchain technology to store real estate transactions. The system combines real estate including tenant information and visa status (Müller and Seifert, 2019). The city of Andhra Pradesh in India has developed a blockchain-based land registry. Georgia has begun to include state land in the registry in a blockchain to avoid corruption (Kombe et al, 2017). Blockchain could be a solution for problems with trust in some developing countries, where there is no trust system between all the partners involved in land administration processes, where blockchain would be a "shared single source of trust" (Vos et al., 2017, Lemmen and Beentjes, 2017). Due to the limited scripting abilities of the Bitcoin blockchain, smart contracts along with IoT and GPS technology are introduced to facilitate real estate transactions and exchange of titles. Sweden's real estate blockchain provides secure architecture to store land transactions with the use of cryptographic protocol (Kaczorowska, 2019) and an automatic registrar machine (Bhatia et al., 2019). Blockchain in land administration can be to avoid ubiquity of land titles using the immutable characteristic. Automated blockchain notifications of ownership changes or changes in the land registry results in an enhanced transparency level through the consensus mechanism (Lemieux, 2017; Leible et al., 2019).

A distributed blockchain voting system does not assume a trusted authority to validate the results and the integrity of the voting is enforced by the voters themselves (Moura and Gomes, 2017). Riemann and Grumbach (2017) have highlighted the need for a distributed voting protocol using a cryptographic algorithm that could limit the power of authorities in online voting protocols (Tarasov and Tewari, 2017). So far, only few distributed online voting protocols have been proposed and even less are fully distributed (Noizat, 2015; Kubjas, 2017). Most blockchain solutions request to attain external verifiability of the voting results, for example, a tamper proof blockchain ledger to the validated and authorized nodes of auditing group (Shaheed, et al., 2017). A distributing e-voting system incorporates many verification stages as voter registration, voting, and ballot opening (Shaheen et al., 2017). A significant use case for truly distributed e-voting

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system using cryptographic data to create trust and transparency in e-voting is illustrated in the work of several use cases (Johnson et al., 2017; Nair et al., 2015; Hsiao et al., 2017). Schulz and Schafer, (2017) have proposed distributing e-voting systems that support: eligibility ensuring that only voters with legal voting qualifications can vote, non-repeatability ensuring that each voter is limited to one vote and anonymity. In several cities, Ukraine has already begun to use e-vox, a distributed registry based on Ethereum e-voting (Boucher, 2016).

3. Quality Assessment Criteria

We performed a quality analysis for assessing the quality of primary study. This challenging task was evaluating the quality of qualitative studies. Quantitative studies are evaluated based on their validity reliability. Some researchers contend that all research are subjective to the same quality criteria while other research use different criteria for qualitative research. This research is considering the suggestions given by Wen et al. (2012). Table 1 represents a total of 12 quality assessment questions. Each question was answered based on the articles in this study.

TABLE 1: QUESTIONS FOR QUALITY ANALYSIS

#	Questions	Yes	Pertly	No
1	Is the objective of the study clear?	79(100.0%)	00(00.00%)	00(00.00%)
2	Is the dataset size sufficient for this type of studies?	65(82.28%)	14(17.72%)	0(00.00%)
3	Is the data collection procedure clearly defined?	65(82.28%)	12(15.18%)	02(2.54%)
4	Does the author provide sufficient detail about the experiment?	71(89.87%)	03(03.79%)	5(06.32%)
5	Are the threats to validity given?	11(13.92%)	12(15.18%)	56(70.88%)
6	Are the limitations of the study given?	52(65.82%)	27(34.17%)	00(00.00%)
7	Does the study clearly define the performance parameters used?	51(64.55%)	12(34.17%)	1(01.26%)
8	Are the learning techniques clearly defined?	20(25.31%)	42(53.16%)	17(21.51%)
9	Are the results clearly stated?	70(88.60%)	09(11.40%)	00(00.00%)
10	Is there a comparison among techniques?	68(86.07%)	04(02.06%)	07(09.86%)
11	Does the study add value to the existing literature?	76(96.20%)	3(03.79%)	00(00.00%)
12	Does the study provide any tool or source code online?	02(02.53%)	00(00.25%)	77(97.46%)

The research agenda has shifted into blockchain smart cities, since they advocate features that support the notion of decentralized connectivity. In the year 2014 three research papers were published reflecting the digital money and smart cities. In the year 2017 thirty-three (33) research papers were published on the topics. We have noticed the trend line increasing from the 2014 to 2020 as shown in Figure 1. The figure also shows the disparate distribution of articles according to the years. In 2014, we found the first and only one research article on sensors that can be deployed in smart cities. Since then several research articles were published on the topic.

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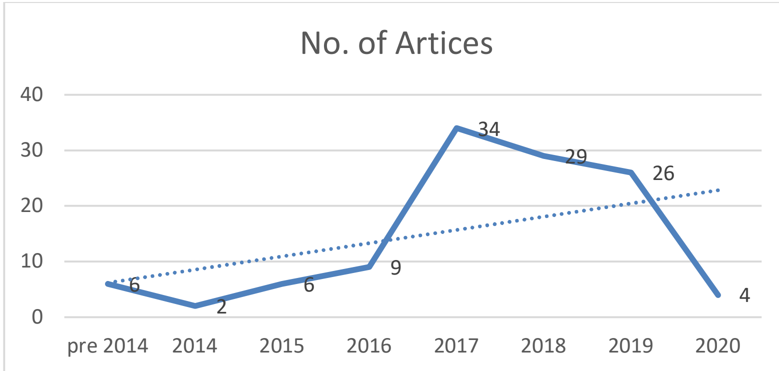

Fig. 1: Number of articles

The previous works in the area of blockchains in smart cities have focused heavily on specific application areas like energy, IoT, or transport (Munsing et al., 2017, Zhang and Wen, 2017, Kanza and Safra, 2018). The research of a modular framework or a platform (Nasulea and Mic, 2018) for blockchain smart cities has been concentrated mainly on sectoral or functional classifications for blockchains. Sun et al. (2016) proposed a conceptual framework with human, technological, and organizational typology of blockchains, from a sharing economy perspective, as a design concept. Karale and Ranaware (2019) proposed a classification of blockchain based on sectoral applications in smart cities, while Shen and Pena-Mora (2018) classify use cases into sectors with focus on sustainable cities. Tapscott and Tapscott (2018) have researched the blockchain role on redefining trust in smart communities. Ibba et al. (2017) and Rebrisoreanu et al. (2018) have contributed to the smart city platform reference as the basis for implementing blockchain applications.

Salha et al. (2019) investigate how blockchain technology could increase the value of a smart city. Pieroni et al. (2018) argue that the integration of different platforms is the most challenging task to overcome in smart city implementation. While the above-mentioned research efforts cover fragments or various typologies of blockchain smart city applications, blockchain-enabled applications under a smart city governance have not been covered to the full extensibility yet.

4. Results and Discussions

Blockchain technology offers advantages that are related to key communications technologies for smart cities. It is a form of social technology defined as ways people communicate, cooperate, compromise, and make consensus (Jun, 2018). The refinement of smart cities under the blockchain prospectus is the main task of this research. This paper uses existing smart city frameworks as a reference to analyse the effect of blockchain on smart cities. In order to create a meaningful analysis, the smart city reference model, which is widely acceptable, is used (Anthopoulos et al., 2016; Lazaroiu and Roscia, 2012; Zygiaris, 2012), which uses layers as a taxonomy mechanism. The layers that the analysis concentrates on are the smart city platform and the city's governance, (Shen and Pena-Mora, 2018; Ibba et al. 2017). The research employs a literature review analysis in academic journals related to blockchain use cases that illustrate extensive analytical coverage. A component-based analysis (Stirewalt and Dillon, 2001) is used to decompose individual layers into individual blockchain use cases as communication interfaces in the smart cities' environment. The component-based analysis could identify the extent of existing uses in each of the smart city layers related to governance. Within the smart city reference model, the following research question is generated: What are the blockchain use cases researched by the academic community, and what taxonomies exist in relation to the smart city governance framework?

The database sources for literature review are ResearchGate, ACM, ScienceDirect, Scopus, ASCE, IEEE, Springer, Web of Science searching academic papers, and conference proceedings (Rhoades and Ellen, 2011; Denney and Tewksbury, 2013). The initial search using a combination of keywords "Blockchain smart cities", produced limited results. Only 75 papers were identified, while broadening the search to a generic blockchain keyword, 3246 papers were identified. The initial screening in these papers shows many papers that were indirectly related to blockchains, but they have a clause, section, or keyword that misled the research direction. The next search attempt was made using thematic keywords along with blockchain keywords, such as "smart city blockchain consensus". This searching type created useful results that were more focused in blockchain smart city governance. In the next screen, all metadata of the papers screened using the title, abstract, and keywords metadata are listed. In this stage, 253 papers were selected for detailed screening. After the metadata screening process, each paper was classified as generic (178 papers) or use case (75 papers). Generic theoretical framework papers were excluded from the current research. Only explicitly defined papers that illustrate use cases are considered in the current research. The screening process resulted in 75 use cases over blockchain smart city governance papers. The final results of the searching and screening process are presented in Table 2.

TABLE 2: USE CASES IN BLOCKCHAIN SMART CITY GOVERNANCE

Components	Intellectual Contributors
Blockchain smart city platform: Metadata Searching: 103 Final Screening: 32	Biswas and Muthukkumarasamy (2016); Dhillon et al., 2017; Zhang et al., 2018; Saraf and Sabadra, 2018; Jonker, 2019; Antonopoulos, 2014; Haferkornm and Quintana, 2015; Zheng et al., 2018; Greenspan, 2015; Mingxiao et al., 2017; Mitani and Otsuka, 2020; Viriyasitavat and Hoonsopon, 2019; Dannen, 2017; Castro and Liskov, 2002; Pilkington et. al, 2017; Sheikh, 2019; Chen et al., 2017; Samaniego and Deters, 2016; Novo, 2018; Zhang and Wen, 2017; Li and Zhang, 2017; Sharma et al., 2017; Chaudhry et al., 2018; Rotună et al., 2019; Worner and Bomhard 2014; Jovovic et al., 2019; Sakakibara et al., 2017; Hui et al., 2019; Miraz and Ali, 2018; Boncea et al., 2019; Dorri et al., 2017; Alphand et al., 2018
City Government Metadata Searching: 48 Screening: 15	Kshetri and Voas, 2018; Jun, 2018; Beris and Koubarakis, 2018; Allessie et al., 2018; Carter and Ubacht, 2018; Wang et al. 2017; Hou, 2017; Ojo and Adebayo, 2017; Datta, 2019; Swan, 2015; Jaffe et al., 2017; Sullivan and Burger, 2017; Alexopoulos et al., 2019; Huynh et al., 2018; Brutti et al., 2019
Digital Identification Metadata Searching: 32	Muhle et al., 2018; Leible et al., 2019; Smolensky, 2016; Rotună et al., 2019; Reijers et al., 2016; Wang and De Filippi, 2020; Rivera et al, 2017; Bakre, et al, 2017; Chalaemwongwan and Kurutach, 2018

Screening: 9	
Land Administration Metadata Searching: 35 Screening: 8	Kaczorowska, 2019; Vos et al., 2017; Bhatia et al., 2019; Müller and Seifert, 2018; Stefanovic et al., 2018; Lemieux, 2017; Leible et al, 2019; Kombe et al, 2017
e-voting Metadata Searching: 35 Screening: 11	Riemann and Grumbach, 2017; Shaheen et al., 2017; Noizat, 2015; Moura and Gomes, 2017; Kubjas, 2017; Schulz and Schafer, 2017; Boucher, 2016; Johnson et al., 2017; Nair et al., 2015; Hsiao et al., 2017; Tarasov and Tewari, 2017

Smart cities use different technologies and infrastructure transparency for public administration by using blockchain that acts as a tool for decentralized and distributed applications (Dapps). The smart city blockchain governance relates to a collective infrastructure that supports multiple blockchain platforms, Hyperledger fabric, and Multichain for permissioned Dapps running on smart contracts. Hyperledger Iroha is utilized for generation permissioned networks for identity. The Bitcoin platform is for payments and Litecoin for micropayments. Moreover, Ethereum may be used for permissionless smart contract blockchain Dapps running smart contracts. XPR and Stellar may be used for transfer of assets. This is generic indicative list of the platforms needed at the governance level. As the blockchain Dapps for smart cities extends in context, more platforms must be included in the reference model. Blockchain applications must be generated in platforms that support a specific access model, permissioned or permissionless. In the reference model, all governance applications are permissioned. Moreover, if a city accepts fee payment with cryptocurrencies, then also a permissionless platform is required.

The selected platform also predefines the consensus algorithm, for example, PoW for Ethereum. The Dapps at the governance level can be implemented with PoW, PoS, and VFT consensus mechanisms. More mechanisms can be included in the reference as the extent of applications grows in diverse areas. While Pow is still the dominant consensus algorithm, PoS and VFT are also considered in validating small contracts, especially when city administrators may play the role of validators. Smart contracts can be the results of blockchain transactions among citizens, communities, and public authorities' administrators for services. To establish the necessary security level to reduce fraud attempts, smart contracts should be stored on the blockchain without an outward linkage with external databases. The platform should encompass an IoT ledger from all transmitter records in the city. The IoT ledger along with blockchain security services should safeguard the blockchain smart city platform. The current research has investigated the use cases that relate to blockchain applications in the smart city governance concluding four areas that use cases and maturing pilot applications have started in the context of smart cities.

These are administrative processes: land administration, e-voting, and self-sovereign identity.

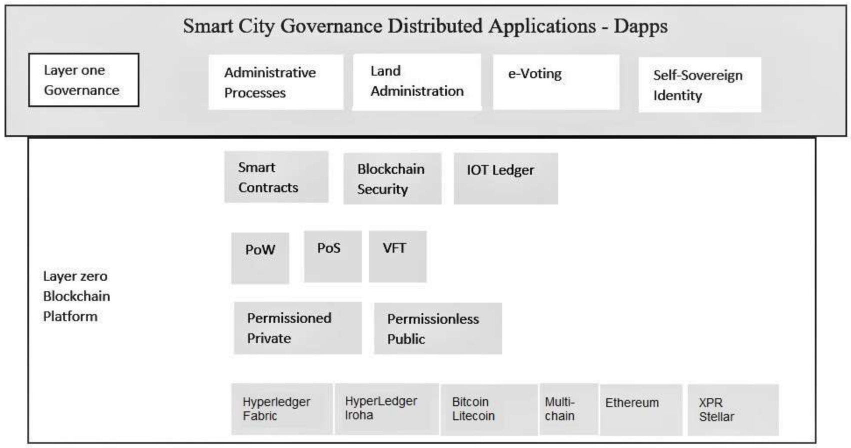

FIG. 2: SMART CITY GOVERNANCE BLOCKCHAIN TYPOLOGY

Many more use cases investigate indirectly or partially issues related to smart cities.

There are significant research clusters that take place formulating the next layers of blockchain smart cities dealing mainly with environmental issues. There is significant research agglomeration in water and energy management. Blockchain technology for a decentralized immutable public environmental transactions ledger may be used as peer-to-peer trading in sharing an economy mode for water (Lin et al., 2018; Dogo et al., 2019) and energy in the microgrid (Tanaka et al., 2017; Thomas et. al 2017). Another area that has gained research significance on the smart grid is charging electric vehicles (Knirsch et al., 2018; Cebe et al., 2018). Intelligent transportation systems are gaining ground in blockchain, as a secured and trusted environment for sharing economy Dapps, like ridesharing (Kanza and Safra, 2018, Khanji and Assaf, 2019). These fragmented research clusters have not been overviewed under the prism of the smart city prospective.

5. Conclusions

This article presents the findings of a systematic literature review on uses cases in the domain of smart city governance. The research is based mainly on existing uses cases. Ninety-seven percent of the use cases used in this research are derived on theoretical background between the years 2017-2019. Blockchain smart cities is an emerging research area that receives great attention, but more empirical studies using advanced research conventions to spread the maturity of this field are needed. The findings of this paper are a starting position to discuss standards and a reference architecture for a blockchain smart city model. Most of the use cases in smart cities are scattered and fragmented as significant pieces of a puzzle that have not been attempted to be put together. The paper capitalized on the work of a secure and scalable infrastructure for blockchain smart cities as a preparatory test field for large-scale adoption of distributed smart city applications.

This research can be expanded in relation to the secure connection of a blockchain platform with external databases without compromising the security aspects of blockchain technology. Once empirical research data are developed, the reference model can receive additional layers such as environment, transportation, and health. The limitation of this study is that it is based on theoretical use cases with limited availability to empirical data. The empirical work in the area has just started with tens of blockchain projects created to transform to smart government. The blockchain smart city reference model could be adopted by future research as new technological developments take place. This study offers a useful starting point for future research for the development of blockchain-based smart city governance for researchers.

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