Neural Computing and Applications
https://doi.org/10.1007/s00521-021-05800-6

S.I. : MACHINE LEARNING APPLICATIONS FOR SECURITY

A conceptual framework for blockchain smart contract adoption to manage real estate deals in smart cities

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Received: 16 October 2020 / Accepted: 5 February 2021

Abstract

Blockchains-based smart contracts are disrupting the smart real estate sector of the smart cities. The current study explores the literature focused on blockchain smart contracts in smart real estate and proposes a conceptual framework for its adoption in smart cities. Based on a systematic review method, the literature published between 2000 and 2020 is explored and analyzed. From the literature, ten key aspects of the blockchain smart contracts are highlighted that are grouped into six layers for adopting the smart contracts in smart real estate. The decentralized application and its interactions with Ethereum Virtual Machine (EVM) are presented to show the development of a smart contract that can be used for blockchain smart contracts in real estate. Further, a detailed design and interaction mechanism are highlighted for the real estate owners and users as parties to a smart contract. A list of functions for initiating, creating, modifying, or terminating a smart contract is presented along with a stepwise procedure for establishing and terminating smart contracts. The current study can help the users enjoy a more immersive, user-friendly, and visualized contracting process, whereas the owners, property technologies (Proptech) companies, and real estate agents can enjoy more business and sales. This can help disrupt traditional real estate and transform it into smart real estate in line with industry 4.0 requirements.

Keywords Blockchain · Smart contracts · Smart real estate management · Smart cities · Smart contract implementation · Smart contract design

1 Introduction and background

Smart cities are characterized by their focus on people, communities, and advanced technology usage [1–3]. This concept of technologies has been widely discussed, leading to smart cities being explored as a digital city, intelligent city, ubiquitous city, wired city, hybrid city, information city, and many more [4]. Big9 technologies are a recent concept where the adoption of nine such key technologies is explored and recommended to be adopted in the smart city. These include drones, the Internet of Things (IoT), clouds, software as a service (SaaS), big data, 3D scanning, wearable technologies, virtual and augmented realities (VR and AR), and artificial intelligence (AI) and robotics [5–7]. Researchers have explored these technologies over time, and their adoption frameworks presented for smart cities. These include the technology acceptance models for smart real estate management [5, 7–9], cloud computing model for smart city logistics [10], smart city reference model to build smart city innovation ecosystems [11], citizen-centric technology acceptance model for urban technologies [12] and unified smart city model for smart city conceptualization and benchmarking. In addition to these technologies, new avenues in using technology in smart cities have emerged, such as blockchain technology in the mining of cryptocurrencies in ‘bitcoin housing’ [8, 9, 13].

A cryptocurrency is a digital or virtual currency that is secured by cryptography [14]. Such security makes it nearly impossible to counterfeit or double-spend. The word “cryptocurrency” is derived from the encryption techniques that secure the network. A cryptocurrency is a medium of exchange for currency such as the Australian

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dollar [15]. However, it is digital and uses encryption techniques to control monetary units' creation and verify funds' transfer. These cryptocurrencies are based on decentralized networks that use blockchain technology. A distinguishing feature of cryptocurrencies is that they are generally not issued by any central authority [16]. Thus, these are theoretically immune to government interference or manipulation. Bitcoin is one of the best-known and novel cryptocurrency for which blockchain technology was invented [15]. Other types of cryptocurrencies include the altcoins, Litecoin, Peercoin, Namecoin, BitShares, Dash, Dogecoin, Ripple, Ethereum, Cardano, and EOS [16–18]. These cryptocurrencies rely on the same or similar blockchain technology as the bitcoin, either complementing or improving specific bitcoin characteristics. For example, Litecoin saves the computing power required for coin mining. Peercoin enhances the efficiency of mining and the security of the currency. Dash facilitates faster processing of transactions with enhanced privacy protection. Bitshares and Ethereum provide digital platforms and graphical user interfaces to run smart contracts [17]. Recently, bitcoin houses are getting attention in smart cities. Such houses can generate bitcoins that can be used to reduce the energy bills and, in some instances, generate money for the owners. Bitcoins and blockchains have been investigated in smart cities for various purposes ranging from designing smart cities [19] to its real estate relational value [20], real estate and land registration [21], creating and securing digital twins [22], low carbon emission and green environment [23], and smart contracts [24].

Blockchain is a state-of-the-art novel disruptive technology based on cryptography that can be widely used to support and manage digital currency transfers and deals. Leiding et al. [25] defined blockchain as a technical combination of an unlimited number of chained blocks in chronological order. Global blockchain is valued at more than $ 4.1 billion and is growing rapidly [26]. Zīle, Strazdiņa [27] defined it as a distributed ledger created by chains of cryptographically connected blocks where data are shared between all nodes in the network. Figure 1 is developed based on the data available at statista.com by the authors, and it shows that the current size of blockchains is around 248000 Mb as of the third quarter of 2019. Further, from 2016 to 2020, about 54.27 million users of the blockchain-based bitcoin wallet have been identified. Similarly, in terms of global spending on blockchain bitcoins, a total of approximately $17.9 billion are expected to be spent on blockchain solutions. These blockchains bitcoins were first conceptualized in 2008 by Satoshi Nakamoto, who used a Hashcash-like method for timestamping blocks, which were not required to be signed by a trusted party. Further, a difficulty parameter was introduced to the block to stabilize the rate at which blocks are added to the chain [28].

Blockchain provides a distributed database solution and maintains a constantly growing catalog of data records confirmed by the participating nodes. The associated data are recorded in a public ledger that includes every transaction ever completed through the blockchain [29]. An advantage of the blockchain is that it is a decentralized solution that does not require any third-party organization as the middleman. The information-sharing of every transaction in blockchain with all nodes makes the system more transparent than centralized transactions involving a third party. Further, the anonymization of the nodes in blockchain makes it more secure for other nodes to confirm the transactions [30]. The end-to-end encryption in the blockchains relies on using two keys: public and private [31, 32]. In public-key cryptography, every public key matches only one private key. Together, these two keys are used to encrypt and decrypt the relevant messages. If you encode a message using a person's public key, they can only decode it using their matching private key. The public keys are more like the business address on the public sphere, and anyone can look at or share it. These are used to encrypt messages before sending them to a recipient [32]. This public key is paired with a unique private key, like a key to the front door. Only the recipient with a private key can open the door or, in this case, decrypt the message [31]. Together these keys ensure that the exchanged data are secured.

Bitcoin is the first practical application of the blockchain technology that has created a decentralized environment for cryptocurrency, enabling the participants to buy and exchange goods through digital money [29, 33]. However, just like their nascent technological counterparts, blockchains face technical challenges and limitations such as throughput, latency, size and bandwidth, security, resource wastage, limited usability, versioning, hard forks, multiple chains, and others [29]. Nevertheless, blockchains have been used in various fields such as supply chain, engineering management, finance, business, healthcare, IoT-enabled industries, privacy, and information and data management [33]. In smart cities and specifically smart real estate management through blockchain transactions, concepts of smart contracts are being explored by the latest research [24, 34–37].

Smart real estate management is a newer concept introduced to manage the real estate business and smart city transactions. Ullah et al. [5] defined smart real estate as an urban area that utilizes user-centered, sustainable, and innovative technologies for its resources efficiently and sharing critical information with real estate users, managers, and agents. Similarly, smart real estate management is the administration of smart real estate process through computers and networked technologies for enhancing the quality of life of its users. Thus, it is a technology-

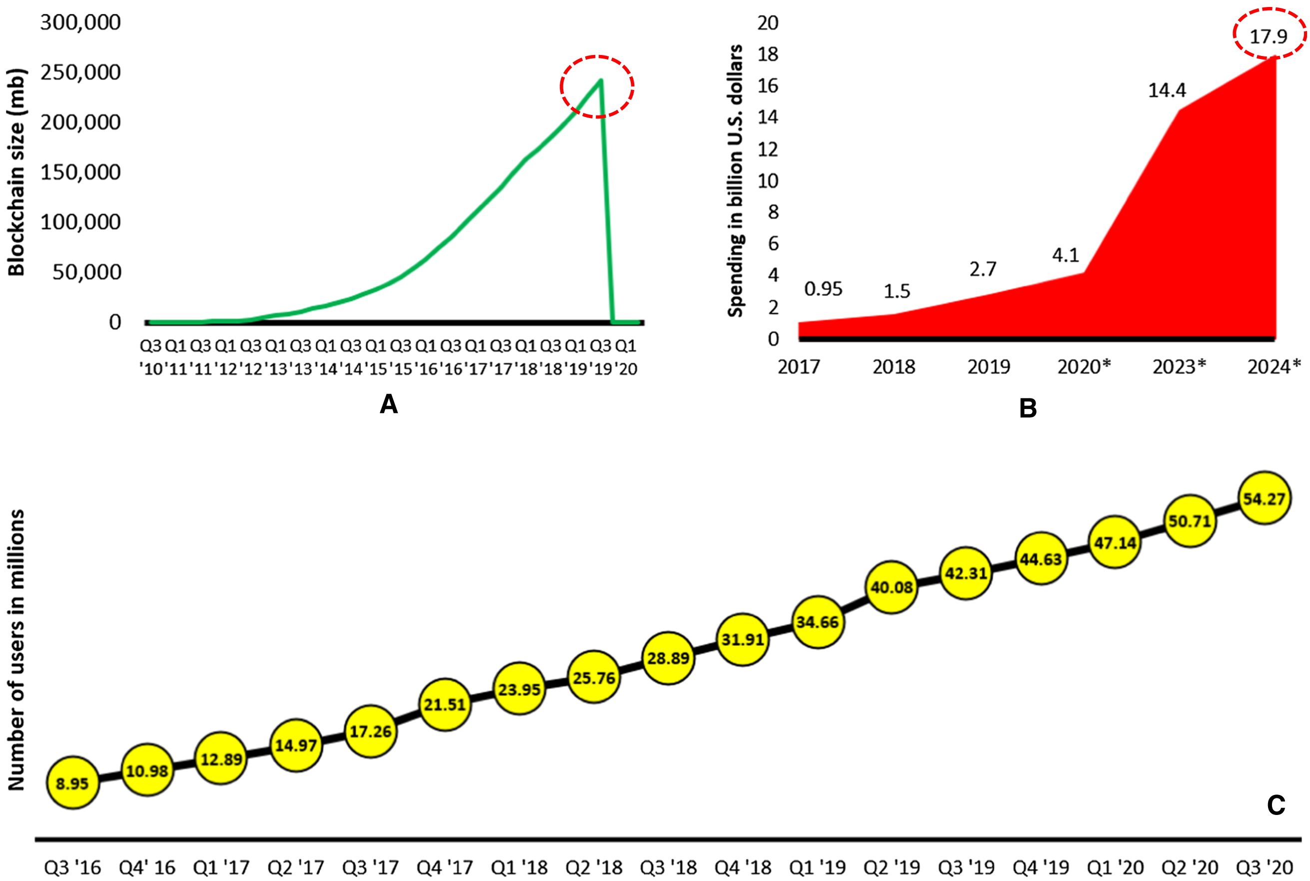

Fig. 1 Blockchain statistics **a** Size of the Bitcoin blockchain from 2010 to 2020, **b** Worldwide spending on blockchain solutions from 2017 to 2024, **c** Number of blockchain wallet users worldwide from third quarter 2016 to third quarter 2020

dependent domain characterized by three key aspects: sustainability, innovation, and user centredness. The concept of smart real estate started with the introduction of smart homes and smart offices and has since been evolving [38, 39]. Accordingly, various technologies have been explored for smart real estate management in smart cities. These include disruptive Big9 technologies, and more recently, the use of blockchains [5, 8]. Further, the blockchains have been used for relational value calculations [20], land registration [21], enhancing trust in a viable real estate economy [40], digital rebuilding [41], logistics resources sharing [42], and smart contracts [24, 30] in real estate. Blockchain investments are among the top 10 PropTech investments globally, as shown in Fig. 2, developed based on the data retrieved from statistita.com [43].

Blockchains are a good candidate for establishing secured smart contracts in real estate deals [24, 30]. A smart contract is a set of digital agreements and protocols within which the parties perform their jobs [44]. The term "smart contracts" was first proposed by Nick Szabo in 1994, who referred to smart contracts as a computer system enforcing a contract's conditions. It is a general-purpose computational mechanism provided through the Ethereum Virtual Machine (EVM) and uses Ethereum blockchain concepts. Ethereum is a widely used cryptocurrency platform along with bitcoin. Ethereum was introduced in 2014 and launched in 2015 by an early bitcoin developer Vitalik Buterin [34]. It raised \$16m in token sales in 2014. It is a decentralized open-source blockchain that provides smart contract functionality. These blockchains are used to encode or execute smart contracts between parties, such as cryptocurrency, to be transferred to a party. These contracts provide new ways to establish blockchain-based multiparty relationships that can aid the smart real estate management process [34, 45].

Smart contracts have been focused on the recent literature, and their various aspects and applications have been explored in detail. These include laws of order exploitation [46], de-anonymizing Ethereum blockchain [30], hybrid architectures with On and Off–blockchain [47], permission and permissionless blockchain [35], blockchain-based accountability [22], knowing the customers [48], sustainable blockchain-enabled services [37], on sharding open blockchains [49] and others. Among the critics of smart contracts, its legal issues are widely discussed. As

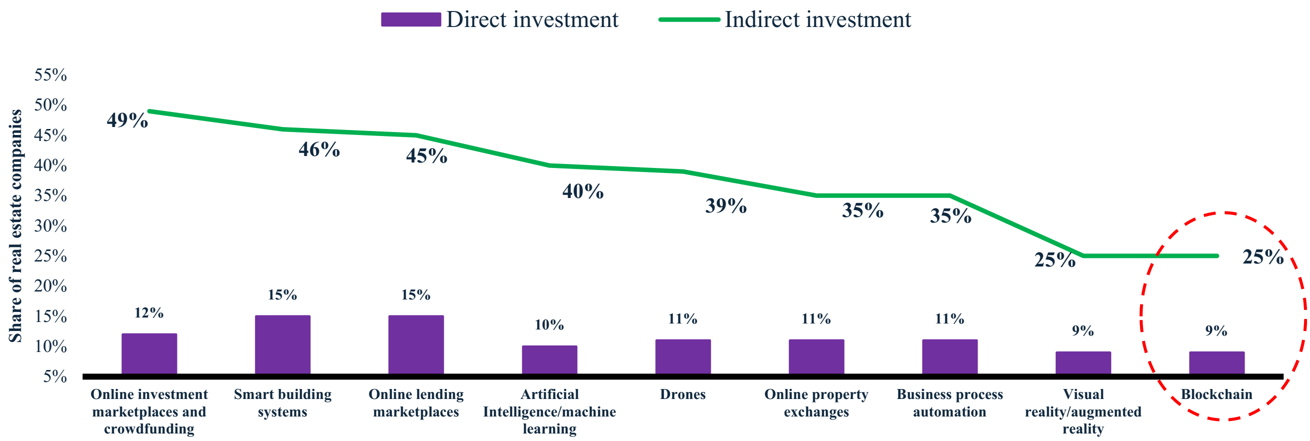

Fig. 2 Direct and indirect investments in Proptech firms by global real estate companies in 2019 (data source statista.com)

Hoffmann [44] discussed in legal systems, a contract consists of an offer and acceptance that provides sufficient information about the parties to the contract, an object of the agreement, modes of performance, etc. However, the smart contract is simply a software-based log of actions that may have legal significance but is challenging due to its self-execution.

Other concerns include the nascency of these smart contracts and its language's programming complexity, such as Solidity. Similarly, off-chain reliability is another concern for smart contracts. The rule of garbage in–garbage out stands true if the parties to a smart contract do not have the expertise to upload useful data to the affiliated blockchain. Further, while in web 2.0, hackers could access all the data, in web 3.0, both data and money can be accessed, thus making smart contracts more critical. Nevertheless, these contracts have been widely adopted in many fields; however, their applications and explorations in smart real estate management are limited. Among the few available studies focused on smart contracts for smart real estate management, securing p2p real estate transactions [50], blockchain smart contracts design [24], and smart city transactions [19] are reported. Overall, there is a serious dearth of literature regarding smart contract applications for smart real estate management. Therefore, the current study targets this gap and explores the concepts of blockchain smart contracts for smart real estate management in smart cities and proposes a conceptual framework for aiding real estate transactions through blockchain smart contracts. Accordingly, a systematic review of literature is conducted, and a conceptual framework is presented for incorporating blockchain smart contracts in real estate deals.

In the rest of the paper, a comprehensive method is presented based on which the literature is retrieved. This is analyzed, and the results are drawn accordingly. Based on the retrieved literature, results, and comprehensive review of the literature, a conceptual framework is presented for incorporating smart contracts to aid smart real estate management in smart cities. It is expected that the proposed framework will open new avenues of research and practical adoption of blockchain smart contracts in real estate that can help it move toward smart real estate in the industry 4.0 era.

2 Method and materials

This study follows a three-stepped method, as shown in Fig. 3. A systematic literature review process is conducted in which keywords and search strings are formulated in the first step. These keywords and strings are searched for on two literature retrieval search engines of Web of Science and Scopus. Along with it, Google Search trends are investigated for the formulated keywords. In the second step, the results of search trends and literature retrieval are listed and analyzed. Accordingly, the content and keyword analyses of the retrieved literature are conducted and discussed. The yearly publication trends, affiliated authors, their organizations, articles' focus, the associated methods discussed in these articles, and key aspects of smart contracts addressed in these articles are listed and discussed. Based on the reviewed literature, the layers involved in the blockchains and their decentralized app structure and layers are discussed in the last step. A conceptual design is presented for the smart contract. Further, its implementation and termination procedures and frameworks are also presented and discussed, and the study is concluded.

The use of WoS and Scopus for retrieving academic literature is not new and has been implemented in many review studies [5, 9, 13, 51, 52]. These two sources are considered as the highest value sources for retrieving high-quality academic literature as discussed by Mongeon, Paul-Hus [53], Archambault et al. [54], and Aghaei Chadegani

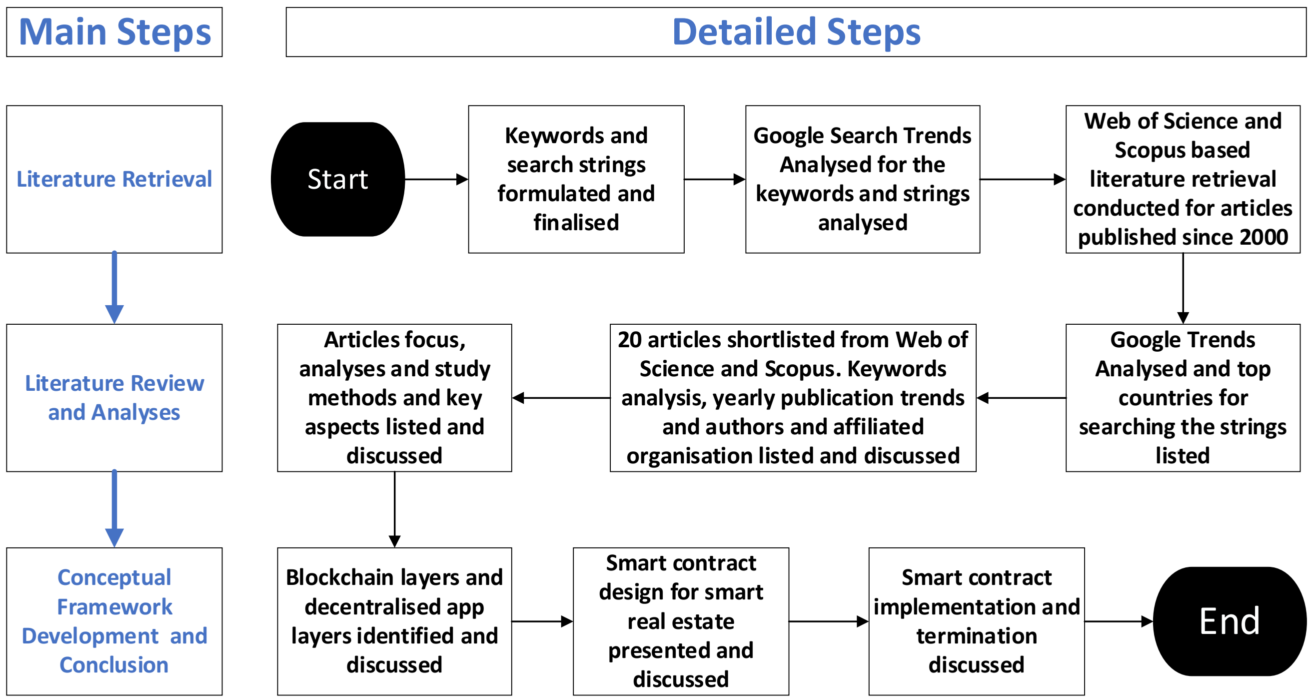

Fig. 3 Methodology of the paper

et al. [55]. Accordingly, these have been used for retrieving academic articles in various fields of knowledge. Azeem et al. [51] used Scopus to retrieve articles related to the competitiveness in the construction industry. They retrieved factors related to the contractor's perspective on barriers to improving the construction industry performance. Ullah et al. [52] used WoS and Scopus to retrieve articles related to students' performance in a construction management course. They used these factors to examine the impact of students' attendance, sketching, visualization, and tutors' experience on their performance. In real estate, Ullah et al. [5] used WoS and Scopus to review the drivers of, and barriers to, the use of disruptive digital technologies and online platforms for promoting smart real estate technology. Munawar et al. [13] used these repositories for conducting a systematic analysis of big data and its applications in smart real estate and disaster management. Similarly, Ullah, Sepasgozar [9] used it to highlight the key factors influencing purchase or rent decisions in smart real estate investments. Taking motivations from these relevant studies, the current study uses WoS and Scopus search repositories for retrieving literature related to blockchain smart contracts in smart cities.

In the first step of the method, a systematic literature retrieval process is conducted. The keywords related to blockchain in smart cities, smart real estate, and smart contracts are investigated. Accordingly, the formulated keywords and strings consist of "Blockchain Real Estate," "Blockchain Smart Contract," "Blockchain smart city," "Blockchain transactions Real Estate," "Blockchain transactions" and "Blockchain smart home." The keywords and strings are joined by the Boolean operators of "AND" and "OR" as shown in Table 1.

These keywords are searched for in the title, abstract, keywords of the search engines' articles, and affirming articles are retrieved. Multiple levels of screening are performed to highlight the most relevant articles only. These screens consist of restricting the articles to post 2000 only since the terms are introduced after 2000. It is impractical to expect articles on it before 2000. Further, this helps in keeping a recent focus and highlights relevant articles to blockchain and smart contracts. The next screen restricts the article types to articles, conference papers, and book chapters only. This eliminates retrieval of irrelevant publications such as editorials, discussions, periodicals, posters, catalogs, closures, and others as per the current study's scope. Afterward, the articles are restricted only to English language articles, and all others are excluded. In the final screening, the remaining articles are thoroughly studied to exclude articles with an irrelevant focus, such as articles focused on biology, nature, climate, and manufacturing. No matter how strong the strings are designed, the search engines' computer algorithms retrieve some irrelevant articles. Therefore, in all literature-based studies, human involvement and double-check are required to retrieve and finalize only relevant articles. Thus, in the current study, following this approach, all articles were double-checked, and only articles focused on real estate,

Table 1 Literature search engines, search strings, steps, and results

Search engine	Search strings	Synthesis step	Results
Scopus	(TITLE-ABS-KEY ("Blockchain Real Estate") OR TITLE-ABS-KEY ("Blockchain Smart Contract") OR TITLE-ABS-KEY ("Blockchain smart city") OR TITLE-ABS-KEY ("Blockchain transactions Real Estate") OR TITLE-ABS-KEY ("Blockchain transactions") OR TITLE-ABS-KEY ("Blockchain smart home")) AND PUBYEAR > 1999	Basic search	**171**
		Time limit	**171**
		Article limit	**57**
		Real estate or smart city only	**19**
Web of science Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.	("Blockchain Real Estate") OR ALL FIELDS: ("Blockchain Smart Contract") OR ALL FIELDS: ("Blockchain smart city") OR ALL FIELDS: ("Blockchain transactions Real Estate") OR ALL FIELDS: ("Blockchain transactions") OR ALL FIELDS: ("Blockchain smart home") Basic search	**82**	
		Time limit	**82**
		Article limit	**31**
		Real estate or smart city only	**14**
Total retrieved	**33**		
Duplicates	**13**		
Final shortlist	**20**		

smart cities, and affiliated smart contracts are shortlisted. Based on these screenings, 33 articles are retrieved: 19 from Scopus and 14 from Web of Science. Scopus and Web of science have been used in the recent literature retrieval studies and are thought of as highly relevant and useful sources for retrieving the academic literature [5, 13, 51]. These retrieved articles are cross-checked to remove duplications; thus, 13 articles are reduced as these were included in both sources. This reduced the total articles included in the current study to 20 articles, which validates the absence of literature in this novel area, as shown in Table 1.

2.1 Systematic literature review process

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed in the current study for conducting the systematic literature review, as shown in Fig. 4 [56]. PRISMA guidelines provide 12 points for conducting the systematic review process incorporated in the current study, as explained below.

1. The review is based on the keywords-based articles retrieved from WOS and Scopus repositories published in the last 20 years, as presented in Table 1.
2. The keywords must be present in their title, abstract, or keywords sections of the articles to be eligible for inclusion in the current study.
3. WoS and Scopus repositories are the information sources that can be accessed at webofknowledge.com and scopus.com/search/form.uri?display=basic.
4. Search strings are used for conducting the literature search process, as listed in Table 1.
5. The study selection process consisted of keyword searching, screening, removing duplicates, qualitative analysis in the form of reading abstracts and keywords, and subsequent risk extraction and quantitative analysis for risk scoring.
6. The retrieved articles from Scopus and WOS repositories were analyzed through VOSviewer, read in detail, the keywords matched, and blockchain and smart contracts-relevant information extracted for the data collection or extraction process.
7. The data items consisted of Google Trends analysis, country-wise trends analysis, year-wise publication trends, and classification of the key factors and themes into computer aspects, transaction aspects, relational aspects, technological aspects, legal aspects, hierarchical aspects, compliance aspects, organizational aspects, storage aspects, and information aspects.
8. The risk of bias in individual studies did not affect the review process as the risks' stress levels are not considered in the current study. A more straightforward approach of the count is used that is not biased.
9. The summary measures consist of distributing the themes and groups into six layers: Network layer, Transaction layer, Blockchain layer, Trust layer, Application layer, and Security and Management layer.

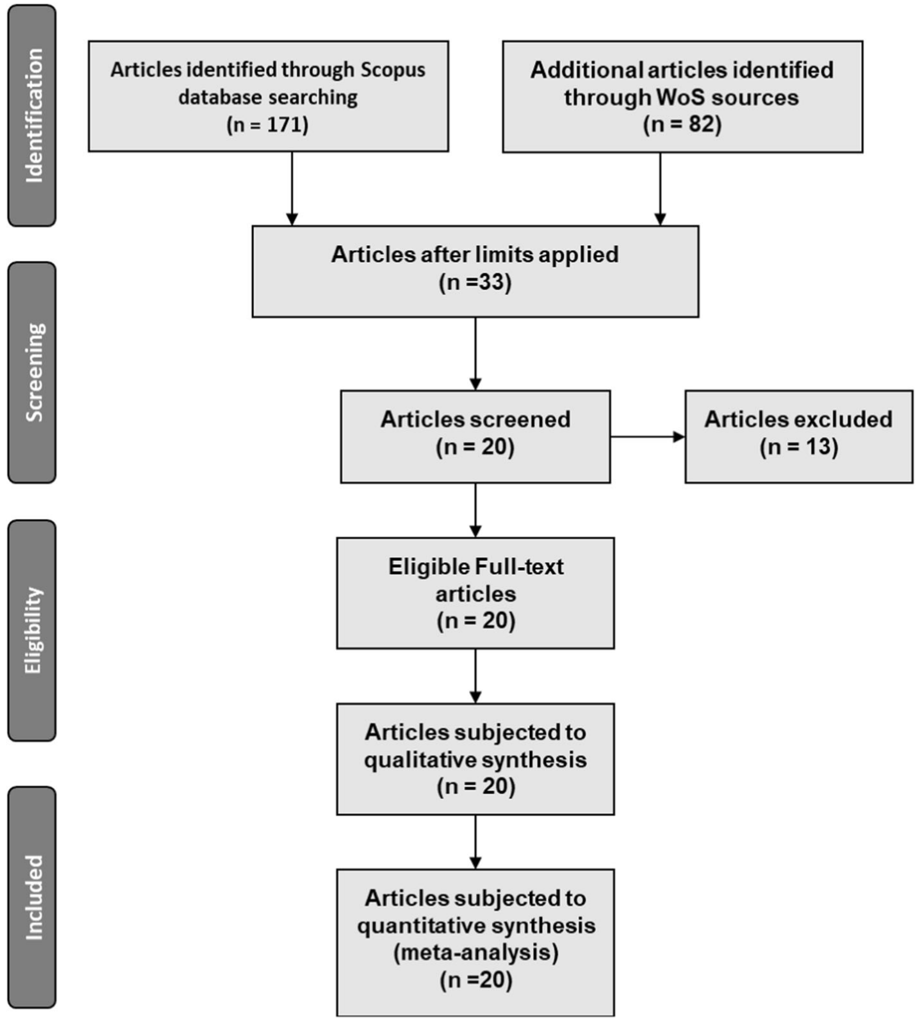

Fig. 4 PRISMA's systematic review flow diagram for the current study

10. For the synthesis of the results, these are compared with other studies to check consistencies.
11. For handling the risk of bias across studies, all studies were subjected to the same rules. However, all published articles may not be retrieved due to the specific selection criteria and article retrieval process based on keywords.
12. The additional analyses comprise linking the factors and themes to blockchain smart contracts and proposing a practical smart contract model.

3 Results and discussion

3.1 Literature review results and discussions

As discussed in the method section, global web search trends are observed for the search keywords and strings using the Google Trends plugin provided by Google. Figure 5 shows the global web search trends from 2010 to 2020 for the keywords and strings used in the current study.

The trend line shows a flat trend from 2010 to 2016; however, there is an abrupt increase in the global search trends around later 2017 and early 2018. This is the time when blockchains, transactions, and smart contracts were focused. Afterward, a steadier trend shows a focus on these trends and equal attention to these terms. Among the compared strings, blockchain transactions are the topmost focused search term going head to head with blockchain contracts except for a severe uprise to blockchain transactions in later 2017–early 2018. This is followed by blockchain real estate, whereas blockchain smart homes and blockchain smart cities are the least searched terms. The trend analysis is further extended to highlight the top countries searching for the keywords. The results in Fig. 6 show the top five countries where the search is originating. These include Australia, Canada, India, the USA, and the UK. For Australia, the trend is 33 percent search for real estate blockchain and 67 percent for blockchain transactions. The USA and Canada have a more balanced distribution of the searches. The USA shows 29, 31, and 40 percent distributions for real estate blockchain, blockchain contracts, and blockchain transactions, respectively. For Canada, the percentages are 30, 31, and 39, respectively. Similarly, the UK has a distribution of 19, 38, and 43, whereas India follows a trend of 11, 48, and 41 percent distributions. The remaining search categories are too low to display.

After analyzing the keywords' global and country-specific search trends, the focus is shifted toward the retrieved literature. Among the total 20 articles, 11 identified as conference papers, followed by eight journal articles, and one book chapter. A scientometric analysis of the retrieved articles was conducted accordingly. Figure 7 shows the scientometric analysis and mapping of the Web of Science retrieved literature. The mapping is performed using the VosViewer ® tool, a widely adopted tool for bibliographic and scientometric analyses [5, 13, 51]. The results in Fig. 7a–g show seven key clusters of linked factors through blockchains and smart contracts. Based on this clustering, the keywords associated with Web of Science retrieved articles can be divided into seven broad categories falling under two groups: blockchains and smart contracts. These categories are as follows:

- Category A (Fig. 7a): The computer aspects that include keywords such as Solidity, Ethereum, decentralization, proof of concept, and blockchains.
- Category B (Fig. 7b): The transaction aspects that include keywords such as real estate transactions, usage of artificial intelligence, sustainable development goals, and others.
- Category C (Fig. 7c): The relational aspects that include keywords such as trust, relational values, and certifications
- Category D (Fig. 7d): The technological aspects that include keywords such as technology influence, exploration, and blockchain land registration.

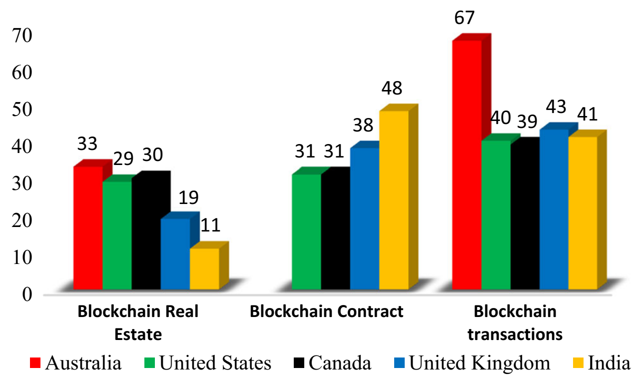

Fig. 6 Country-wise trends for the search of the keywords and strings from 2010 to 2020

- Category E (Fig. 7e): The legal aspects that include keywords such as law, avoidance, and declaration of intent.
- Category F (Fig. 7f): The network aspects that include keywords such as multifaceted scaling solution, hierarchical encryption, hierarchical conditionality, common secret, and others.
- Category G (Fig. 7g): The compliance aspects that include keywords such as contract compliance, contract enforcement, contractual rights and obligations, and others.

  Similarly, the same process of scientometric analyses is repeated for Scopus retrieved articles. Figure 7 (a–e) shows five key categories of the keywords linked mainly by the keyword "blockchain." The categories are discussed as follows:
- Category A (Fig. 8a): The organizational aspects that include keywords such as enterprise blockchain, knowing the customer, business intelligence, user data protection, sales, time efficiencies, and others.
- Category B (Fig. 8b): The technological aspects that include keywords such as technology influence, exploration, and blockchain land registration. This is the

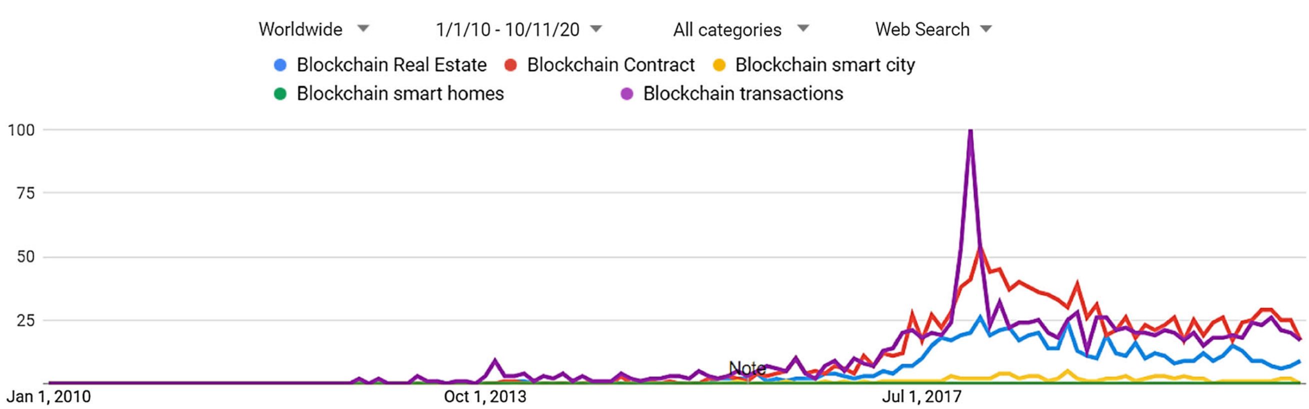

Fig. 5 Google Trends for global search of the keywords and strings from 2010 to 2020

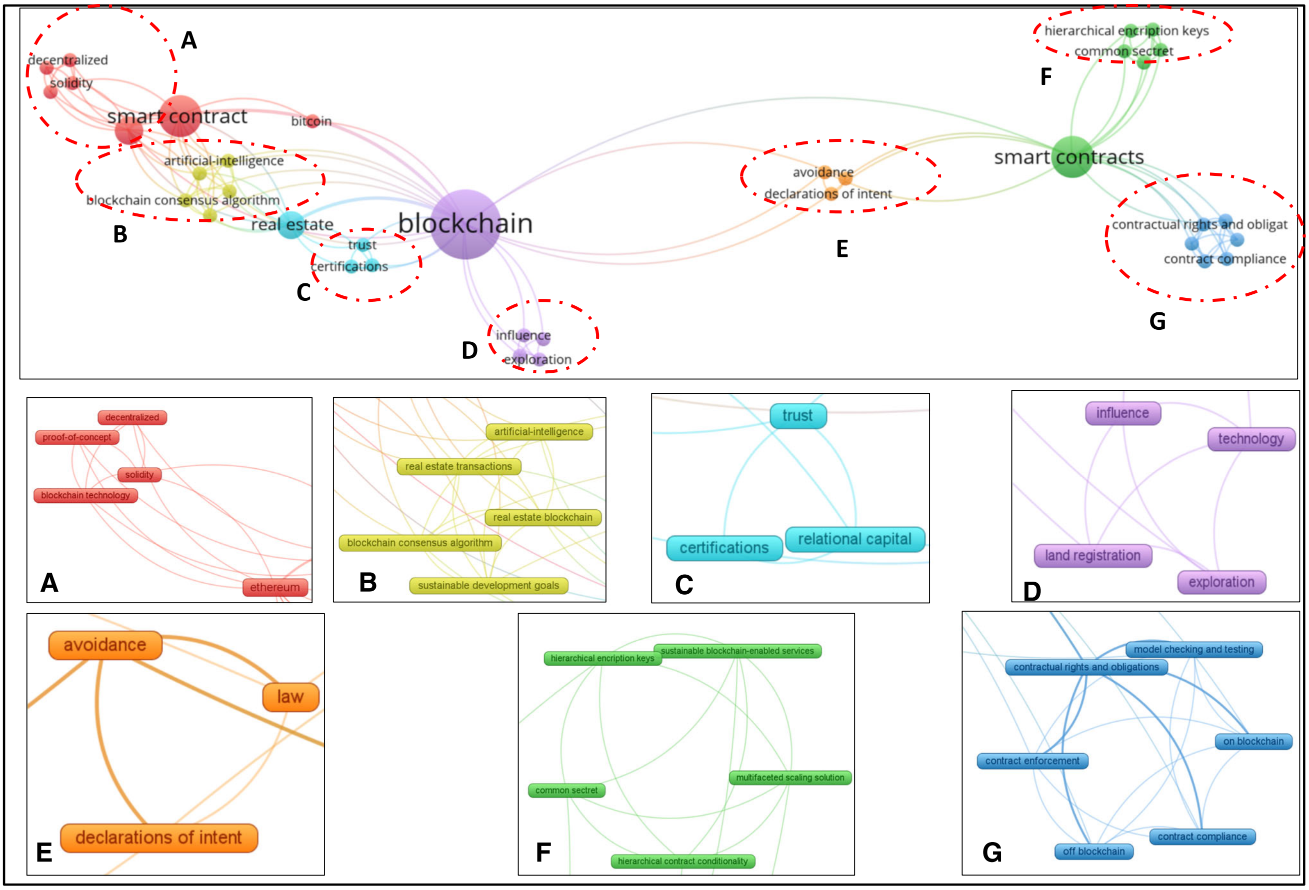

Fig. 7 Web of science retrieved keywords, **a** computer aspects, **b** transaction aspects, **c** relational aspects, **d** technological aspects, **e** legal aspects, **f** hierarchical aspects, **g** compliance aspects.

same as category D of the Web of Science retrieved articles.

- Category C (Fig. 8c): The computer aspects that include keywords such as Solidity, Ethereum, decentralization, proof of concept, transactions, and blockchain algorithms. This is a mix of categories A and B of the Web of Science retrieved articles.
- Category D (Fig. 8 d): The storage aspects that include keywords such as data storage, digital storage, storage verification, signature verification, automation, and others.
- Category E (Fig. 8e): The information aspects that include keywords such as information management, infrastructure for information, information dissemination, information resource, government departments, and others.

Overall, by combining the categories extracted from both the search engines, ten categories can be highlighted for the blockchain smart contracts. These categories are focused on the computer aspects, transaction aspects, relational aspects, technological aspects, legal aspects, network aspects, compliance aspects, organizational aspects, storage aspects, information aspects. These aspects can be explored in the futuristic studies focused on blockchain smart contacts.

Along with the keyword analysis, in the systematic literature review and categorization, a year-wise publication trend was investigated for the retrieved articles, as shown in Fig. 9. Accordingly, it can be seen that no article was retrieved from 2000 to 2014. Overall, an increasing trend is observed, and the highest number of papers (09) are recorded for 2020, which shows the recent and current focus on this topic. Further, most of the retrieved articles are published in the last three years.

After the year-wise publication trends are observed, the author of the articles and corresponding citations, as mentioned at the retrieval source and Google Scholar, are listed in Appendix A. A minimum of two citations at the original source is based on the inclusion of articles in Appendix A. Seven out of the nine articles are conference papers, followed by only two journal articles. Further, Google Scholar captures more citations than the two sources utilized in the current study. This is because Web

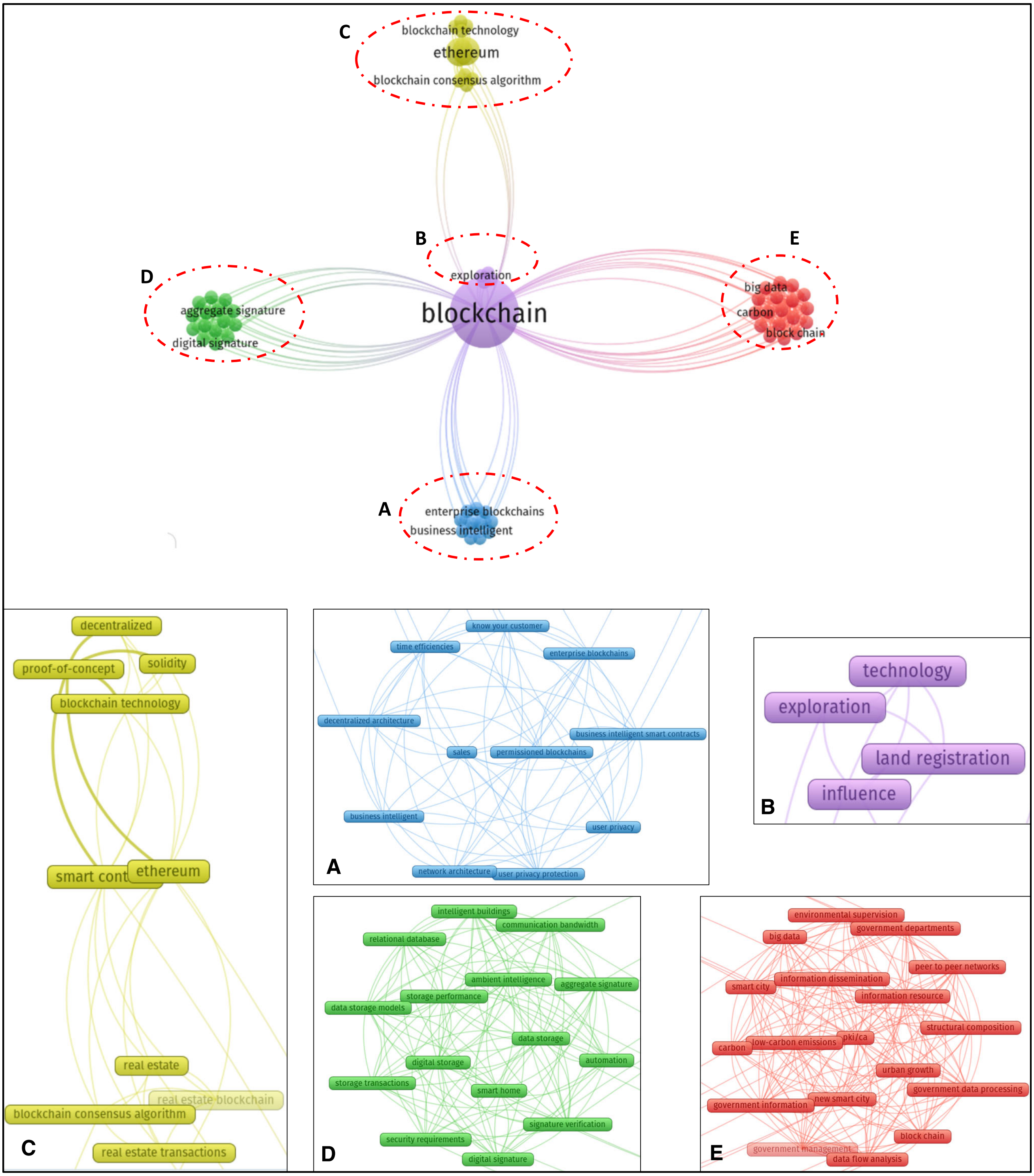

Fig. 8 Scopus retrieved keywords, **a** organizational aspects, **b** technological aspects, **c** computer aspects, **d** storage aspects, **e** information aspects.

of Science or Scopus, by default, considers only indexed sources as citations to the articles. In contrast, Google Scholar is more open and considers thesis, non-indexed articles, and other sources citing the articles. Thus, only high-quality scientific articles are considered and indexed by the Web of Science and Scopus that augments the quality of articles considered in the current study.

In the next step of the systematic literature analysis, the retrieved articles' affiliated organizations are investigated. A minimum of 10 citations and at least one document

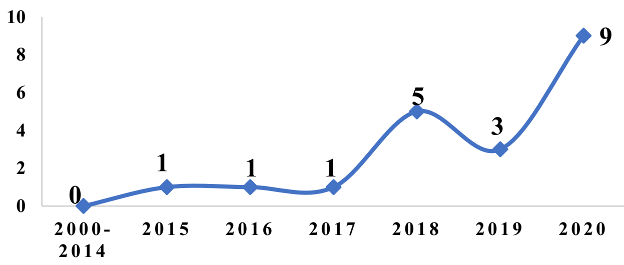

Fig. 9 Year-wise publication trend of the retrieved articles

associated with the organization are considered the inclusion criteria. Appendix B lists the organizations, their locations, total papers mentioning these, and the citations to date, as mentioned at the retrieval source. Nchain, a UK-based organization, is reported as an affiliated organization in two documents attracting 17 citations. It is comprised of 94 people and managing 7.8 billion worth of bitcoins through blockchains. This is followed by the Japan-based Muroran institute of technology and NTT service evolution laboratories, mentioned in one article attracting more than 100 citations. Next in line are Data61 (CSIRO) at the University of New South Wales Australia and Ens Paris-Saclay, Université France with, one document and 64 citations.

A detailed investigation of the retrieved articles is conducted to highlight the originating themes, the articles' focus, the methods used to investigate the problems, and the key aspects or topics discussed in these articles, as shown in Table 2. Two themes emerged from this analysis: generic blockchains and blockchains smart contracts. These are in line with the scientometric mapping performed automatically through VosViewer. Among the study methods, the literature review and conceptual protocol design are the top utilized methods in the retrieved articles. The current study is in line with this. It uses a mixed-method where the literature is utilized to formulate a conceptual framework for adopting smart real estate smart contracts. Among the key aspects discussed, smart contracts, data, user security, financial management, and overall city management are focused.

3.2 A conceptual framework for blockchain adoption in the smart real estate buy/rent process

Based on the ten aspects identified in the literature review section, a six-layered framework is proposed for the smart real estate rent or buy process, as shown in Fig. 10. The presented system's diagram links the aspects and keywords retrieved from the literature to the proposed layers in the blockchain smart contract framework for smart real estate management in smart cities. Accordingly, the ten aspects are merged and grouped into six layers. Some aspects, such as information and organization aspects, are merged into a single security and management layer. Some are directly linked to a single layer, such as the network aspects are linked to the network layer, whereas some aspects are linked to multiple layers, such as the legal aspects that can impact both trust and security and management layers. Accordingly, all the aspects, their selected keywords as per literature, and the proposed six layers are linked to the smart contract blockchain framework for smart real estate management.

3.3 Layers in the proposed framework

Figure 11 presents the layers involved in smart real estate blockchain smart contracts execution. The owners or sellers, the users, or buyers and the blockchain management team are the three main stakeholders involved in the smart contracting process. It follows a stratified approach in line with Dewan, Singh [19], and Karamitsos et al. [24]. The components of these layers are explained as follows.

1. *Network layer* This layer consists of the servers, the storage devices, the P2P network Ethereum or Hyperledger nodes, and the associated communication and verification mechanisms.
2. *Transaction layer* This layer consists of transaction initiation, validation, processing, and currency mining. This may be initiated by the users or directly by the smart contracts.
3. *Blockchain layer* This layer consists of the blocks containing all necessary smart contract information. It can be permitted or permissionless, depending on the type of smart contracts. Further, it includes the data blocks, timestamp, hash function, chain structure, encrypted layer, Merkle tree, and other key requirements of the blocks.
4. *Trust layer* This layer consists of the consensus development mechanism where using consensus algorithms, an agreement between the parties to a smart contract is reached. It is used for authenticating the transactions in the network. Proof of work, proof of state, fault tolerance, and distributed ledgers are used in this layer.
5. *Application layer* This layer consists of the front and back-end applications, the decentralized applications (DApps), and the smart contracts and their digital wallets. The users and owners can access and complete the smart contracts through this layer using their computers or cell phones.
6. *Security and Management layer* This layer runs throughout the process and aims to secure and manage the blockchain smart contracts. Since the blockchains

Table 2 Themes, focus, methods, and key aspects discussed in the retrieved articles

Theme	Focus	Study method	Key aspects discussed
Generic blockchain	Accountability in digital twins	Modeling	Smart contracts, tokenization of content, eliminating counterfeit products, supply chain improvement, digital twins, and end-to-end security
	Real estate relational value in web applications	Survey	Products certifications transparency, NEO blockchain, smart contract
	Real estate and land registration	Literature review	Land registry
	Smart homes cloud storage mechanism	Identity-based proxy aggregate signature (IBPAS) scheme	Data storage, resident security
Blockchain smart contracts	Laws of order	EthRacer tool	Bug detection, event tracing, Ethereum smart contracts
	Void declarations of intent	Literature review	Irreversibility of blockchain transactions, legal perspective
	Hybrid blockchain architectures	Contract validator tool	On and Off–blockchain components, quality of services, scalability, performance, transaction costs
	Know your customer	Conceptual centralized architecture	User privacy protection, optimal schema clarity
	Non-interactive smart contract	Conceptual Non-interactive smart contract protocol (NECTAR)	Privacy, correctness, and verifiability
	Contract validation	Conceptual game theory system	Smart contract validation
	Permissioned and permissionless contracts	Conceptual protocol (BlockME)	Permissionless blockchains, trust, integration issues,
	Sustainable blockchain-enabled services	Multiple conceptual systems	Functionality, complexity, and versatility of blockchain-enabled services,
	Smart city design	Conceptual protocol	Smart contracts, city design, city asset management
	Secure P2P real estate transactions	Conceptual neural algorithm blockchain	Financial management, transactions accuracy
	Real estate contracts	Case study	Smart contracts, development of paperless layer for all city transactions, city asset management
	Contract recording	Conceptual protocol	Contractors' consent
	Blockchain security for contract management	Conceptual hybrid blockchain	Proof-of-stake, credibility score, contracts management, digital rights management
	Ethereum De-anonymization	Stylometry techniques	Smart contracts, Feature selection, Heuristic refinement, Authorship attribution

are vulnerable to attacks such as eclipse, self-mining, and 51% attack, this layer provides the protection. Overall, it deals with data privacy, identity management, transactions and accounts security, and attack preventions.

3.4 Smart contract delivery through decentralized applications and Ethereum Virtual Machine (EVM)

Figure 12 shows the interactions between DApps and the EVM through which the smart contract is delivered to the users. A smart contract is developed in Ethereum using its programming code known as Solidity. This contract is passed on to the DApp for deployment through the blockchain network to the users and owners. GoEthereum (Geth) and PyEthereum (PyEth) apps can be used for deploying the smart contract, whereas the graphical user interface is provided through web browsers and cell phone applications for users to access this smart contract.

3.4.1 Decentralized applications (DApps)

Smart contracts are developed through the blockchain network using DApp. It provides a simple, easy-to-use, and

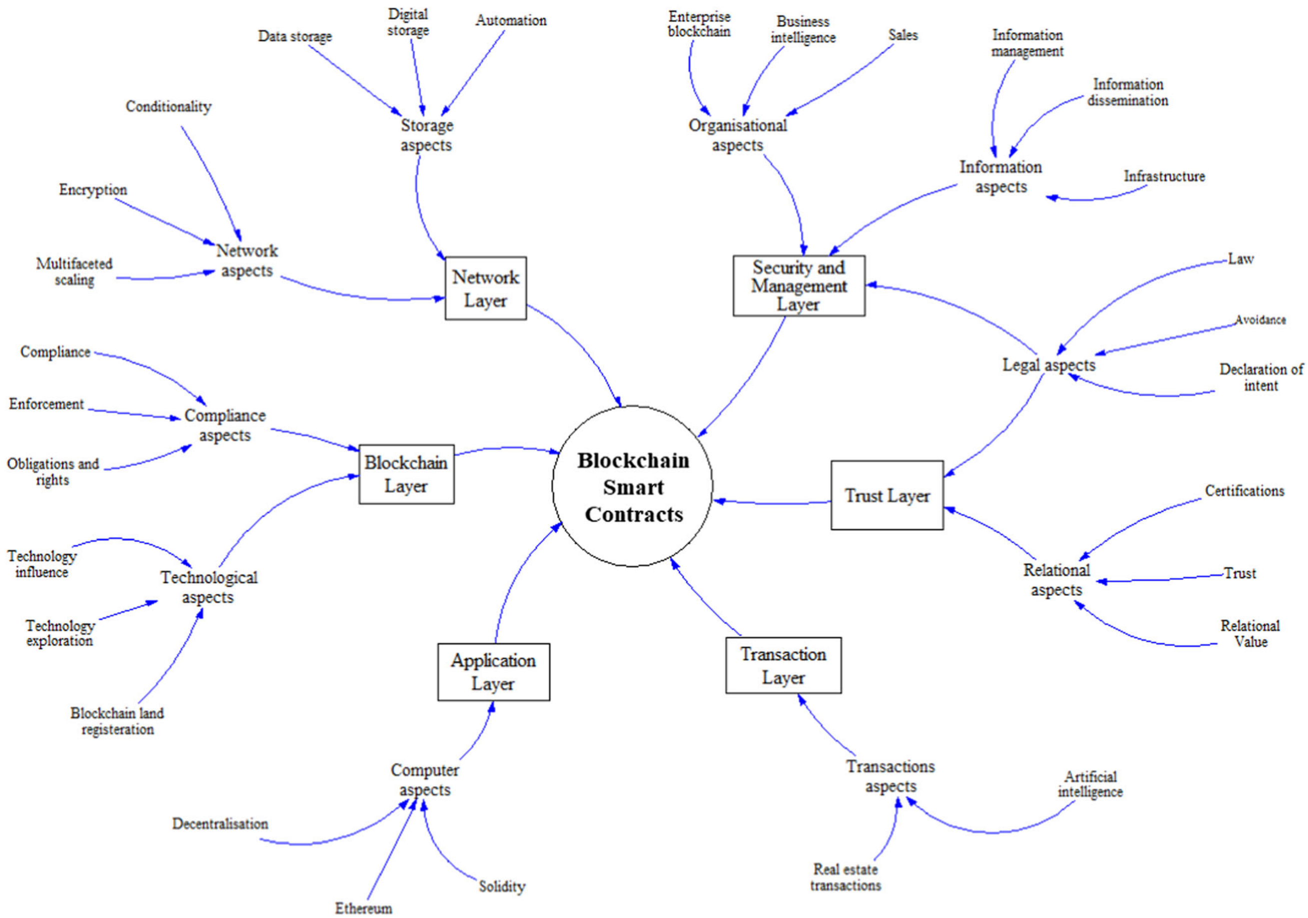

Fig. 10 Systems diagram showing the linkage between the layers, aspects, and keywords

user-friendly interface to the smart contracts whereby the nontechnical users and owners can use it with ease. It uses two interfaces: the front-end and back-end. The front-end interface consists of web browsers and cell phone applications composed using HTML, CSS, and web browsers. The back-end interface is developed using HTML, CSS, java, web3.js, and others. Multiple blockchain users and owners can interact with the DApps using its user-friendly front-end interface. This DApp interacts with an EVM. This interaction is done through the remote protocol call (RPC), which is used by DApp to interact with the EVM.

3.4.2 Ethereum virtual machine

An EVM is a powerful, sandboxed virtual stack embedded within each full Ethereum node. It is responsible for executing a contract bytecode written in higher-level languages, like Solidity, and compiled to bytecode. This machine is completely isolated from the network, filesystem, or host computer processes, making it a powerful tool. It can perform any logical step of a computational function through its Turing completeness, written in JavaScript that powers the World Wide Web. Various programming languages, including C++, Java, JavaScript, Python, Ruby, and many others, can be used in the EVM. Anyone in the system can execute its function in a trustless ecosystem, hence generating a smart contract. It consists of a sync client such as a parity client, a transaction pool, a miner, and multiple blocks. The application programming interface (API) to the system can be provided through java development kits or other software development kits such as web.js or Nethereum. The machine is further connected to multiple other nodes and mining pools. The smart contract generated in the EVM is deployed through the DApps that can be signed and interacted with by the users through the front-end GUIs.

3.5 Designing and interacting with the smart contract for smart real estate management

Figure 13 shows the design and interactions of key stakeholders with smart real estate management's smart contract. The overall process is that an owner can access their account to add details, addresses, keys, balances, and other

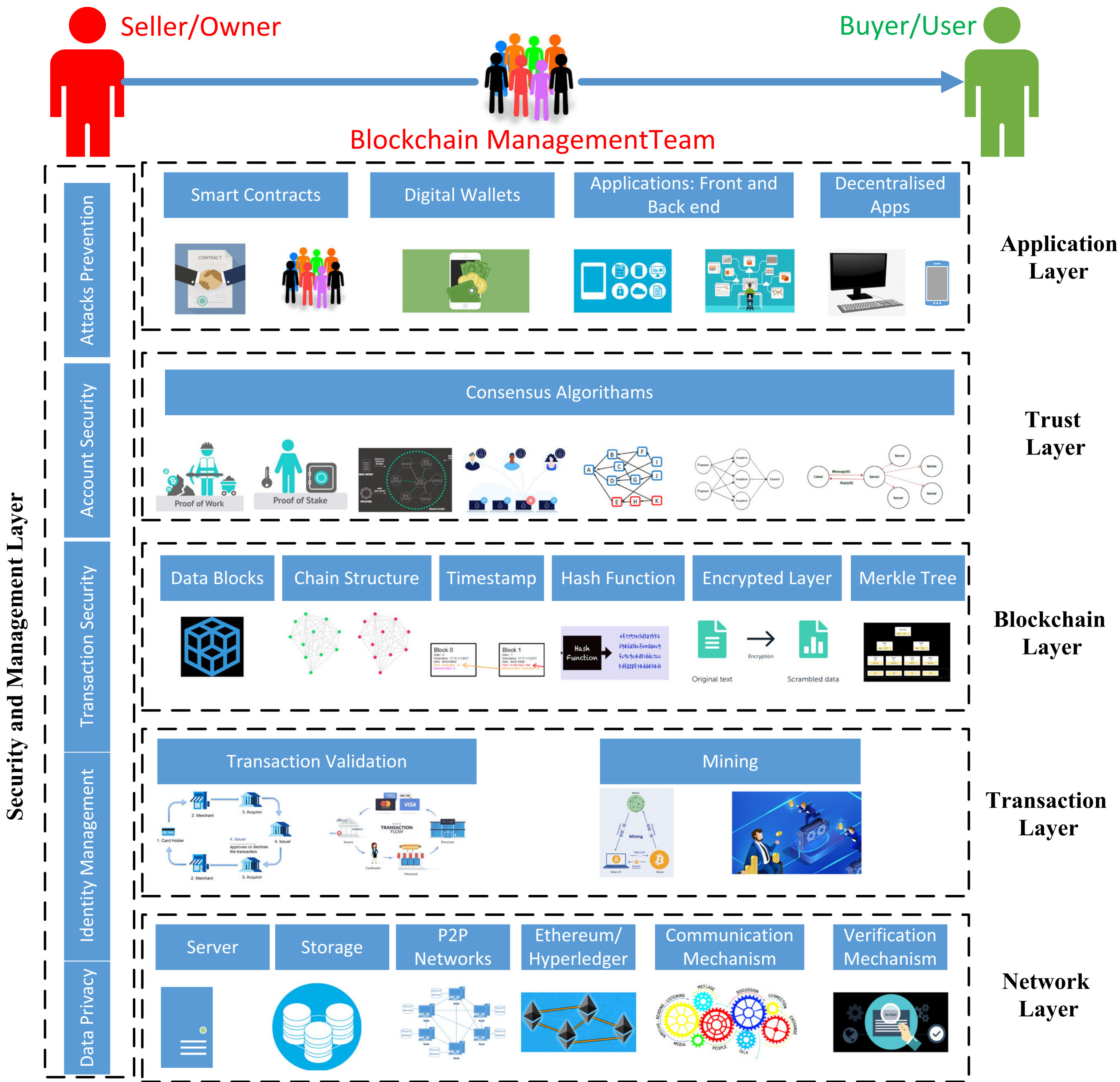

Fig. 11 Blockchain layers in smart real estate deals and transactions

information related to the property's transactions and sales. They can authorize the transactions or calls for three functions: create a contract, terminate a contract, or withdraw a contract. Key functions of the smart contract are called accordingly. Similarly, the user accesses their accounts to authorize transactions related to purchase or rent payments. The smart contract functions are called where the parties' details are exchanged, and a smart contract is formulated. The blockchain smart contract management team manages this process.

Different key variables, functions, contract modifiers, and key events are called during the smart contract execution. Initially, "create" and "start" functions can be used to create and start smart contracts. These can be modified and eventually terminated using the "modify" and "terminate" functions. The key variables, functions, modifiers, events, calls, and aims are presented in Table 3.

3.6 Implementing and terminating the smart contract

Figure 14 shows the implementation and termination steps involved in the smart contracts' adoption of smart real estate. The implementation and termination steps are

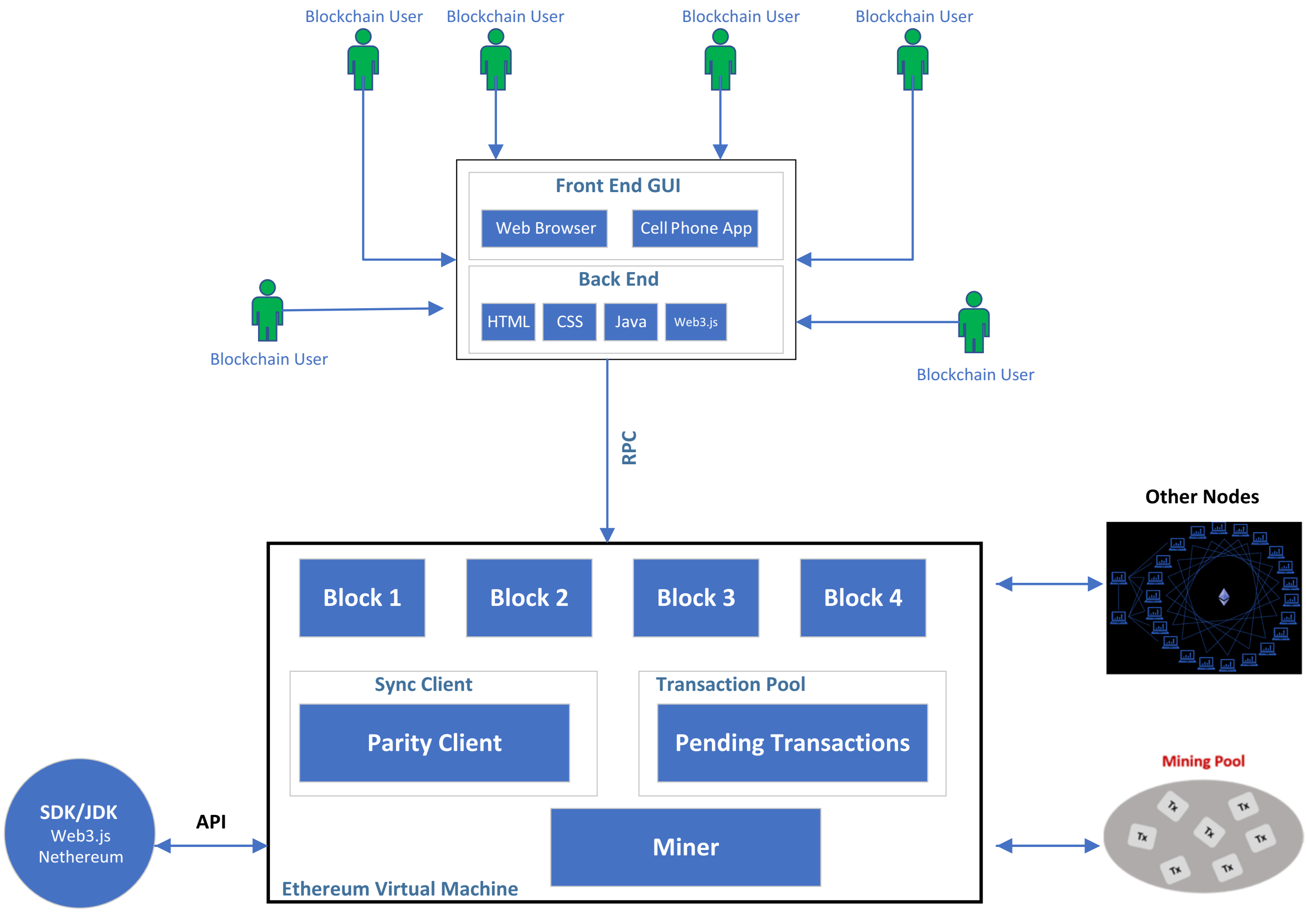

Fig. 12 The decentralized application and its interactions with Ethereum Virtual Machine

explained subsequently. It is worth mentioning here that the proposed system is not aimed at eliminating the real estate agents; instead, it can augment the process. Currently, online portals are used for data entry and printing purposes only. However, the proposed system can digitalize the process and move toward greater sustainability.

Further, multiple portals are used, such as in the Australian Fairtrade portal, for paying bonds; this information must be separately shared with the agents who then contact the owners. The agents have their own system in place where the payments are paid. Much going back and forth is involved in the process, with both the owners and potential renters going through multiple systems. The proposed system can streamline the process and provide a single point of contact or contract where all parties are automatically linked through the smart contracts.

3.6.1 Smart contract implementation

Assuming that the smart contract format and templates have been finalized as per the layers, design, and codes previously mentioned, the following steps are involved in implanting smart contracts in smart real estate:

1. The owner opens the portal or launches a web interface through their browsers or cell phone applications.
2. The owner enters their contact details, property details, email address, encrypted keys, and other details.
3. The owner provides the details of the agent or any third party managing the contract.
4. The renter or buyer accesses the portal's web interface through their browsers or cell phone applications.
5. The renter or buyer enters their contact details, email address, and other details.
6. The web platform accesses the smart contract template, and key information based on the above data is prefilled.
7. The contract is ready to be signed by both parties and is digitally signed.
8. The renter or buyer authorizes the payments of bonds or installments or lump sum money received by the owner.
9. The management team's charges, agents, and blockchain managers are deducted, and the

Table 3 The description, function calls, and aims of the functions in the smart contracts

Description	Function call	Aims and results
Key variables	Owner address	Displays owners address
	map(address=>prop) owner	Captures address of the owner
	map(address=>prop) renter	Captures address of the renter
	map(address=>prop) buyer	Captures address of the buyer
	prop_id_purchase;	Displays the purchase id of the property
	prop_purchase_value;	Displays the purchase value of the property
	prop_id_rent;	Displays the rent id of the property
	prop_rent_value;	Displays the rent value of the property
Key functions	buy_agreement()	Launches the buying agreement template
	rent_agreement()	Launches the renting agreement template
	get_prop()	Return and display the property details
	get_prop_owner()	Return and display the owner details
	get_prop_renter()	Return and display the renter details
	get_contract()	Return and display the agreement details
	pay_rent()	Launches the rent payment portal
	pay_purchase()	Launches the purchase payment portal
	terminate_contract	Launches the contract termination sequence
	withdraw_contract	Launches the contract withdrawal sequence
	kill()	Sends a signal to end the process
Contract modifiers	.onlyContractOwner()	Displays the modification portal for the owner
	onlyRenter()	Displays the modification portal for the renter
	onlyBuyer()	Displays the modification portal for the buyer
	inState	Returns true if the corresponding state is at the specified state.
Key events	paidRent(address_from,prop_amount)	Displays the event of rent paid with payers' address and the amount
	paidPurchase(address_from,prop_amount)	Displays the event of payment with payers' address and the amount
	contractTerminated(address_to)	Terminates the contract and addresses it to the other party

remaining amount is transferred to the owners' nominated account. The deduction information is shared with the owner.

10. The owner acknowledges the payments, confirmed by the system, and the contract is over with ownership rights transferred to the buyer in case of property purchase.
11. For rent cases, after step 9, the renter keeps paying the regular rent amount either through manual means or direct debit from their nominated account, and the system keeps generating messages for both parties to inform them about the transaction status.
12. The process continues until the contract term is over.

3.6.2 Smart contract termination

To terminate the smart contract, a contract must exist in the first place. Hence, the steps 1 to 9 of smart contracts implementation are performed accordingly. This can only occur in a rental arrangement as the selling arrangement is usually not terminated. Instead, the contract is withdrawn before a deal is finalized. Nevertheless, for rental agreement termination, once a contract is established, the following steps are followed:

1. If the owner wants to terminate the contract, the blockchain management team or agents are informed who send the contract termination notice to the renter.
2. A notice period is given to the renter, and arrangements are made for their bond release after inspecting the property.
3. The renter evacuates the property before the notice period's expiry, and the bond money is released to their accounts.
4. For renters and owners happy to keep the contract ongoing and not terminate it after its initial contract period is over, the implantation process continues till it is deemed necessary to terminate the contract.

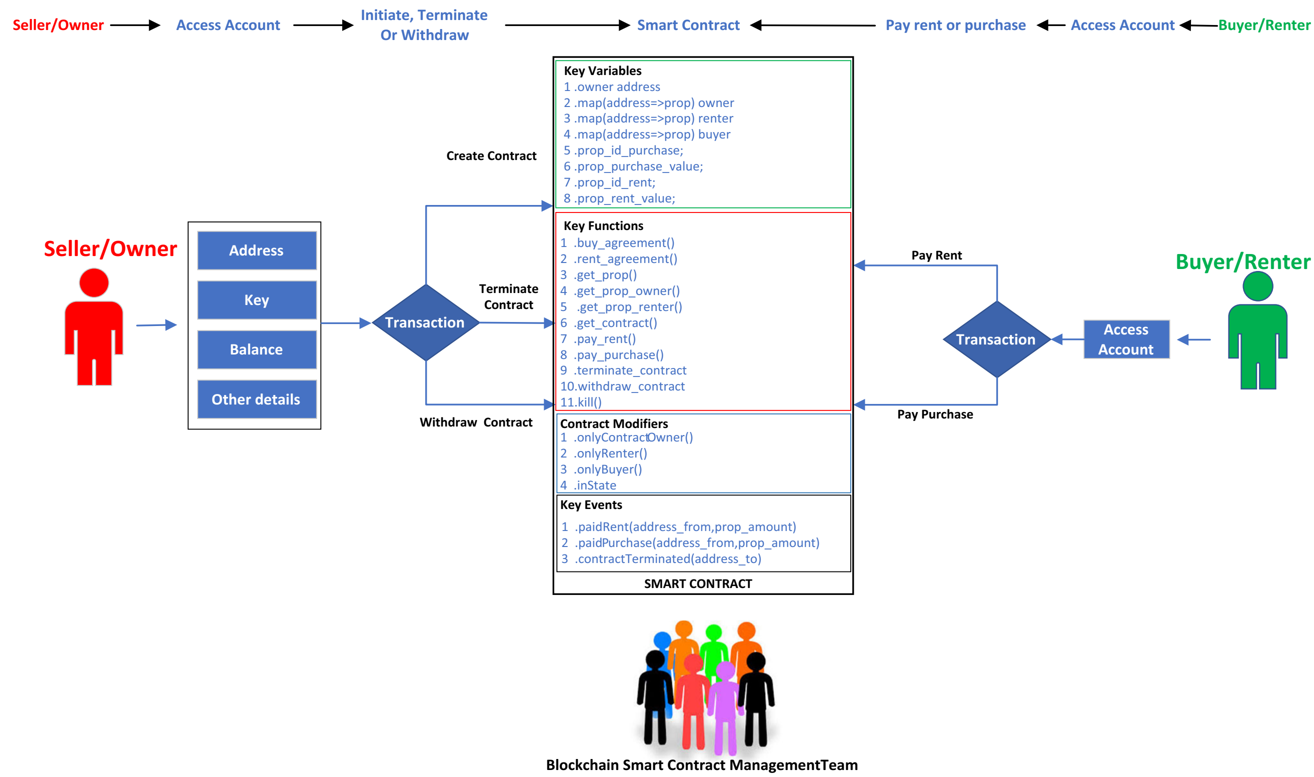

Fig. 13 Smart contract stakeholders' interactions in smart real estate

For validating the proposed framework, a two-step procedure was adopted. Firstly, it was discussed with a panel of ten experts comprising two professors, four Ph.D. students, and four real estate and property developers to discuss its applicability and relevance to the real estate sector. All the panel members were working in the fields of real estate, IT, and construction management. These panel members were asked to comment on the framework regarding its logical relations, components, structure, and applicability. Based on their comments and propositions, logical changes were made to the framework. In the next step, the proposed framework was compared with similar studies. Any significant deviations were noted and discussed both in-house and with the panel to remove chances of any abnormalities. As such, the study is comparable to the works of Karamitsos et al. [24], Dewan, Singh [19], and Huh, Kim [50]. Karamitsos et al. [24] and Dewan, Singh [19] have used the same layers as the current study, thus validating these layers' presence and usage for blockchains in smart cities. Karamitsos et al. [24] have used these layers in real estate, and Dewan, Singh [19] utilized them for smart cities. The current study has the same layers but more factors and themes than these studies, thus building upon their knowledge.

Similarly, Huh, Kim [50] presented the user interface for blockchain transactions in real estate. Considering these relevant studies and expert opinions, the proposed framework can be adopted and applied to smart cities' smart real estate deals. In terms of applicability, the proposed framework applies to smart contracts deals in real estate, blockchain transactions, smart contracts in construction, smart cities, and other technology-oriented fields. It can be adopted by construction managers, city managers, Proptech developers, real estate and property agents, managers, and developers and help transform these traditional sectors into smart sectors in line with industry 4.0 goals.

4 Conclusions

The current study targeted a novel area of blockchain smart contract implementation for smart real estate management in smart cities. A comprehensive literature review of systematically retrieved literature was conducted to highlight ten key aspects of the blockchain smart contracts applicable to smart real estate management. These include the computer aspects, transaction aspects, relational aspects, technological aspects, legal aspects, network aspects, compliance aspects, organizational aspects, storage aspects, information aspects. Further, the review highlighted Australia, the UK, the USA, India, and Canada as the top five countries searching for blockchains, transactions, smart homes, and smart contracts. The top two search

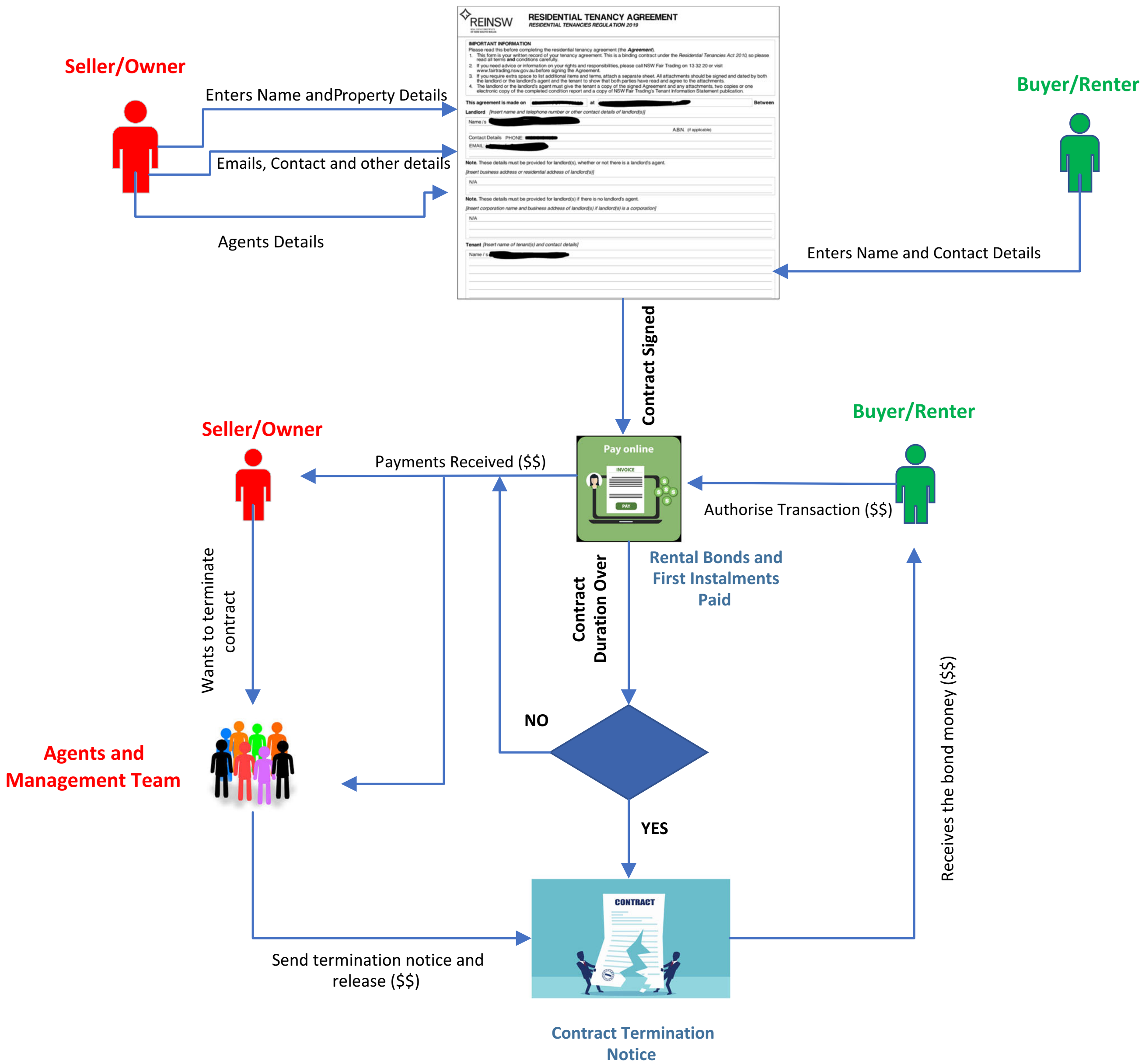

Fig. 14 Implementation and termination of the smart contracts in smart real estate deals

terms are blockchain transactions and blockchain contracts. Regarding the paper's yearly publication count, most of the articles are published in 2020, highlighting the researchers' recent and updated focus on the current study's keywords. Further, the review is summarized into two themes: generic blockchains and blockchain smart contracts.

A conceptual framework is presented for adopting blockchain smart contracts for smart real estate management in smart cities based on the systematic, comprehensive literature review. For this purpose, the ten identified aspects are linked to and presented as six layers of blockchain for managing smart real estate deals and transactions. These are the network layer, transaction layer, blockchain layer, trust layer, application layer, and security and management layer. A DApps and its interactions with EVM have been presented that show how a smart contract is developed and shared with the key stakeholders: users and owners. A detailed design and interaction mechanism is highlighted for the real estate owners/sellers with smart contracts buyers/users. A list of functions outlining different commands for starting, creating, modifying, or terminating a smart contract is presented. Lastly, a detailed stepwise procedure for establishing and terminating smart contracts between smart real estate buyers/renters and owners is presented that outlines how a smart contract can be established or terminated.

The current study is a valuable yet humble edition to the body of knowledge and state of practice. In terms of its research implications, the current study provides a multi-layer, blockchain smart contract adoption framework. Each layer of this framework can be further investigated and strengthened through academic scrutiny for unearthing the associated factors. Accordingly, layer-by-layer holistic frameworks can be developed and coded to provide easy-to-use and friendly user interfaces for adopting blockchain smart contracts in smart cities. These sub-frameworks can be integrated into the city-wide frameworks for large-scale adoption and implementation of blockchain smart contracts in real estate deals. Further, the legal aspects can be investigated, and adoption rules and regulations devised for large-scale implementation. For the practical value of the framework, it has implications for key stakeholders of smart real estate. The users can enjoy a more immersive, visualized, and UpToDate contracting process that is more secure and user friendly, whereas the owners can enjoy more business and sales. This will create a win-win situation where the users have pleasant immersive experiences, and the agents and property dealers will have more business due to enhanced trusts. This will also eliminate the real estate users' regrets, as highlighted by Ullah, Sepasgozar [9]. Proptech companies, real estate agents, and blockchain managers can adopt smart contracts and enhance their businesses. The real estate agents and agencies can integrate these smart contracts into their systems to replace traditional contracts and empower them to make more informed decisions through more transparent contracts. Similarly, Proptech companies can investigate and invest in other technologies such as AI and machine learning and integrate them into the systems to implement these blockchain smart contracts. This can help disrupt the traditional real estate and transform it into smart real estate to materialize the smart city dreams in the industry 4.0 era. Overall, this framework applies to all levels of city management and governance. It is expected to attract wider readers and audiences such as real estate managers, real estate agents, property developers and valuers, property managers, contract managers, smart city management team, city governance team, legal authorities, and facility management teams.

The current study highlights the issues limiting the transformation of real estate and provides a mechanism for adopting smart real estate management smart contracts. The study is limited due to the scarcity of literature on the general blockchain smart contracts and its focus on smart real estate management. In the future, other aspects of blockchain, such as the ten aspects identified in the current study, can be explored in detail. Further, a practical framework in the form of a sophisticated website or app can be developed to visualize smart real estate's smart contract process. Lastly, from an adoption point of view, blockchain is above governments right now where they have little to interfere with. The transactions such as with bitcoin are untraceable, and the money moves beyond borders. Thus, in the case of smart contracts, the regulatory bodies need to devise plans and regulations to ensure that proper laws are being followed. Further, in contracts for real estate, every key stakeholder might need to know who the other parties are, how much they pay, the conditions, etc. The 'anonymity' of transactions can play here that can be investigated by future studies.

Appendix A

Authors, citations, year, and type of the retrieved articles.

Authors	Retrieved Citation	Google Scholar Citation	Publication Year	Type	Ref
Watanabe H., Fujimura S., Nakadaira A., Miyazaki Y., Akutsu A., Kishigami J	101	165	2016	Conference	[36]
Amani S., Bortin M., Bégel M., Staples M	64	125	2018	Conference	[34]
Wright C., Serguieva A	15	25	2017	Conference	[37]
Molina-Jimenez C., Sfyrakis I., Solaiman E., Ng I., Weng Wong M., Chun A., Crowcroft J	14	29	2018	Conference	[47]
Sun M., Zhang J	7	11	2020	Journal	[23]
Kolluri A., Nikolic I., Sergey I., Hobor A., Saxena P	6	32	2019	Conference	[46]
Dewan S., Singh L	2	2	2020	Journal	[19]
Falazi G., Hahn M., Breitenbucher U., Leymann F., Yussupov V	2	5	2019	Conference	[35]
Covaci A., Madeo S., Motylinski P., Vincent S	2	4	2018	Conference	[57]

Appendix B

Affiliated organizations, their locations, and citations of the retrieved articles.

Organization	Location	Documents	Citations
Nchain	London, UK	2	17
Muroran Institute of Technology, Muroran-city	Hokkaido, Japan	1	101
NTT service evolution laboratories, Yokosuka-city	Kanagawa, japan	1	101
Data61 (CSIRO), UNSW	NSW, Australia	1	64
Ens Paris-Saclay, Université Paris-Saclay	Paris, France	1	64
Codex, Stanford University	Stanford, US	1	14
Computer laboratory, University of Cambridge	Cambridge, UK	1	14
Hat community foundation	Cambridge, UK	1	14
School of Computing, Newcastle University	Newcastle, UK	1	14
Singapore Management University	Singapore	1	14

Acknowledgements The authors are grateful to Mr. Bilal Ayub (Ph.D. Scholar RMIT University) and Dr. Tayyab Ahmad UniMelbourne for their kind comments and advice on improving the paper while the authors were waiting for reviewers' comments. The academic community helps add substantial value to the body of knowledge, and we are grateful to have such people around. We are also thankful to Dr. Samad Sepasgozar and Dr. Jamaluddin Thaheem for their encouragement and guidance.

Funding The article received no funding from any private or government organization.

Data availability Data are available with the corresponding author and can be made available upon reasonable request

Code availability Codes are available with the corresponding author and can be made available upon reasonable request

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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