Review

A Review of Blockchain Technology Applications in Ambient Assisted Living

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Abstract: The adoption of remote assisted care was accelerated by the COVID-19 pandemic. This type of system acquires data from various sensors, runs analytics to understand people's activities, behavior, and living problems, and disseminates information with healthcare stakeholders to support timely follow-up and intervention. Blockchain technology may offer good technical solutions for tackling Internet of Things monitoring, data management, interventions, and privacy concerns in ambient assisted living applications. Even though the integration of blockchain technology with assisted care is still at the beginning, it has the potential to change the health and care processes through a secure transfer of patient data, better integration of care services, or by increasing coordination and awareness across the continuum of care. The motivation of this paper is to systematically review and organize these elements according to the main problems addressed. To the best of our knowledge, there are no studies conducted that address the solutions for integrating blockchain technology with ambient assisted living systems. To conduct the review, we have followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology with clear criteria for including and excluding papers, allowing the reader to effortlessly gain insights into the current state-of-the-art research in the field. The results highlight the advantages and open issues that would require increased attention from the research community in the coming years. As for directions for further research, we have identified data sharing and integration of care paths with blockchain, storage, and transactional costs, personalization of data disclosure paths, interoperability with legacy care systems, legal issues, and digital rights management.

Keywords: ambient assisted living; blockchain; security and privacy; IoT blockchain integration; decentralization

1. Introduction

Ambient assisted living (AAL) is a research field that aims to bring smartness to our everyday environments by acquiring data from various sensors, understanding people's activities, behavior, and living problems, and deciding on proactive interventions to support the management of identified issues (see Figure 1) [1]. With the advance in sensing technologies and the prevalence of miniaturized, affordable Internet of Things (IoT) sensor applications have been developed to improve the beneficiary's quality of life and support personalized care [2]. A wider range of proof of concept applications for various use scenarios along with associated technologies can be found in the literature, such as fall detection systems [3], cognitive decline management [4], personalized care [5], remote follow-up [6], nutrition management [7], medication review [8] and well-being management [9].

Having more IoT devices and sensors associated with living environments leads to collecting patient data that must be shared among multiple parties on different sides [10]: validators, processors, healthcare stakeholders, etc. Nowadays, the ambient assisted living systems move the data collected in cloud systems (see Figure 1), where the potentially unlimited computation resources help in dealing with analytics and decision making [11].

Using decentralized distributed ledger solutions will allow multiple nodes to host the same set of encrypted data in multiple care systems that are hosted in different places and kept up to date with the actual state and data of the system [12]. Additionally, most of the collected data are rather sensitive and personal data of vulnerable people; thus, security and privacy have always been issues to deal with [13]. They constitute a barrier between vulnerable people and assistive technologies and prevent the adoption and good use of existing software solutions in the field [14]. People may become digitally vulnerable as data theft, fraud, and the unauthorized use of personal, medical, and financial information are often not even known by the victims [15].
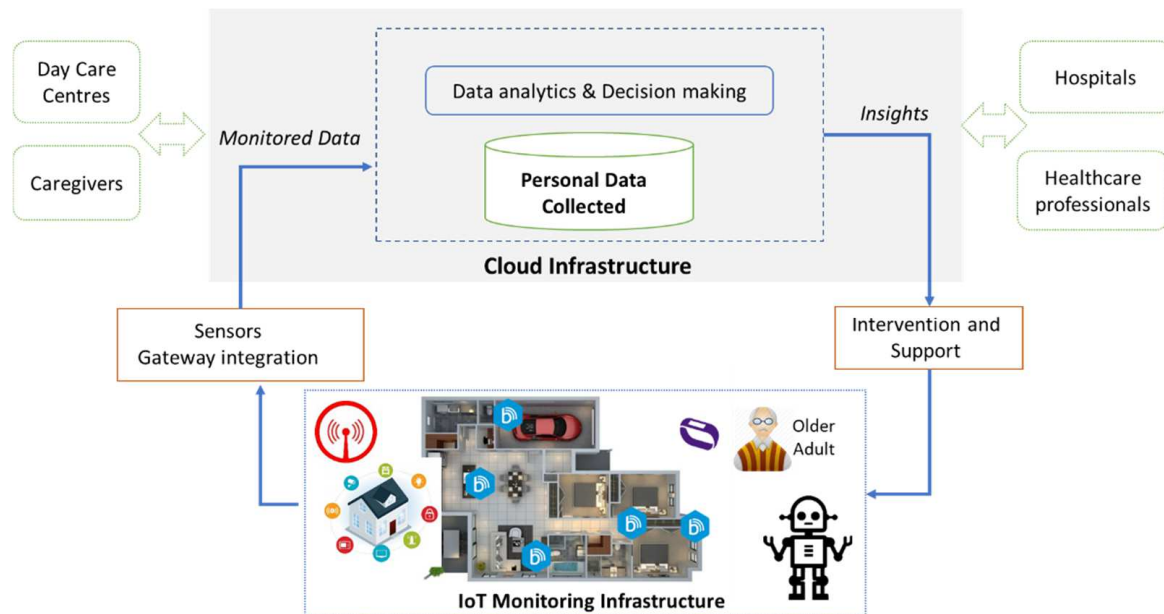

Figure 1. Conceptual architecture of a cloud-based AAL system.

The privacy and security problems are critical for data-driven assisted living applications and IoT networks such as the Internet of Medical Things [14]. Data ownership and elimination of potential breaches are objectives for keeping the data, and the system secured [16]. However, because of the lack of precise specifications, even ordinary procedures might result in security breaches [17]. There is a strong need to make such applications transparent, immutable, and distributed [18]. In general, in the discussions concerning privacy and security, how consumers understand privacy is key [19]. People are more inclined to value decentralized solutions for their capacity to safeguard their privacy goals [20]. On top of technical privacy issues, lately, personal details (i.e., used to identify a person) have become one of the most valuable commodities [21]. This information might be as basic as a name or identification number, or it can be more sensitive, such as medical or behavioral data [22]. As the world becomes more digitized, internet activity is increasingly recorded, often without the user's knowledge or agreement, constituting a barrier to ambient technologies adoption.

Blockchain technology is seen as a good solution for tackling IoT monitoring, data management, interventions, and privacy concerns [23] in ambient assisted living applications [24]. Stakeholders from the ambient assisted and care fields are interested in integrating blockchain technologies into their systems to benefit from improved security, privacy, and data ownership (see Figure 2) [24]. Conventional ambient assisted living solutions use centralized cloud-based models focused on structuring data rather than privacy, ownership, and decentralization. The adoption of blockchain technology can change this landscape [25]. In a blockchain-driven assistive living application, the users will join a blockchain network, and asymmetric encryption solutions will enforce the security of data sharing [26]. The IoT devices deployed in the user environment can be joined with

smart contracts to automatically generate and sign transactions and forward them to the blockchain to be stored immutably [27]. The generated transactions are aggregated in blocks disseminated in the network and will be mined in the future blocks. To change a value in a block, the entire history of previously linked blocks needs to be rehashed, requiring a lot of computational power not being feasible these days [28]. To prove the ownership of the data, the IoT device provides a signature of the transaction, which is also useful for authentication and validation [29]. The updates are stored in chained blocks, taking advantage of the technology's properties such as reliability, availability, immutability, and consensus [30]. The blockchain enforces the provenance of data by a linked list of nodes; thus, data can be traced back by iteration of the chain [31]. In addition, securely storing the sensor's data and respecting the personal data regulations is difficult considering the perspective of the domain [32]. So, using a decentralized, user-centric approach regarding data privacy can address security and data ownership problems in developing ambient assisted living applications.
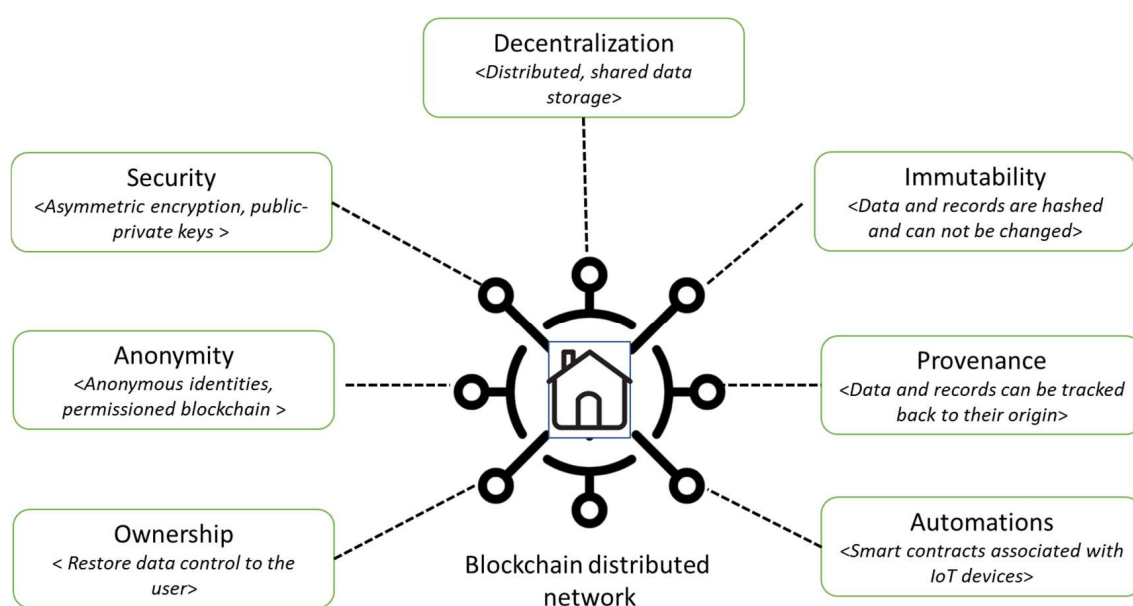

Figure 2. Features of blockchain technology desired for an ambient assisted living system.

Even though the research field is still at the beginning, relevant studies in the literature can be found. The motivation of this paper is to systematically review and organize them according to the research problems they address. To the best of our knowledge, there are no reviews conducted on solutions for integrating blockchain technology with ambient assisted living systems. To conduct this review, we have defined a search methodology with clear criteria for including or excluding papers, set up a reference interval, and focused on current important databases. We have included in the survey 87 papers on blockchain and ambient assisted living systems that were reviewed and organized. Thus, a reader would effortlessly gain insights into the current state-of-the-art research in the field. Nevertheless, there are still many gaps and open issues that would require increased attention from the research community in the coming years, such as data sharing and integration of care paths with blockchain, storage, and transactional costs, personalization of data disclosure paths, interoperability with legacy systems, legal issues, digital rights management, etc.

The remainder of the article is organized following the Introduction, Methods, Results, and Discussion (IMRAD) structure: Section 2 presents the methodology and methods used in conducting the literature review; Section 3 illustrates the results by describing and organizing the most relevant research works; Section 4 presents a discussion on the survey findings, and Section 5 draws the conclusions.

2. Materials and Methods

In carrying out our study, we have used the PRISMA methodology that defines the guidelines for conducting systematic reviews, which is widely accepted by most Web of Science (WoS) journals for organizing review-type articles [33]. More specifically, we have selected the "PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only" variant that features four main phases: articles identification, screening, eligibility, and inclusion. The goal of our systematic study is to create an overview of the domain of blockchain and IoT applications for ambient assisted living and to construct a snapshot of the state-of-the-art works for general or specific topics in this domain. This approach will also allow identifying current hot trends, future research directions, and research gaps.

The first step in our research study was to clearly define search strategy in terms of research questions, keywords, or key phrases to cover the study targeted topic of blockchain, IoT, and AAL applications. The following research questions have been selected for our study:

- Identify use-cases for blockchain and IoT applications in AAL;
- Identify applications, techniques, and tools developed for this domain;
- Highlight the challenges and limitations of blockchain and IoT in AAL;
- Find what are the main open research directions to be tackled

This led to the definition of the following main search keywords to be used in the next stage of the study:

- Blockchain IoT healthcare;
- Blockchain and Ambient Assisted Living;
- Blockchain and Active Assisted Living;
- Blockchain and Ambient Intelligence
- Blockchain and remote care;
- Blockchain data ownership in health care;
- Blockchain data sharing and analytics in health care;
- Blockchain and IoT security and privacy in health care

Using the above, the second step of applying the PRISMA methodology was to select the scientific databases for the search process. In this context, we have selected Web of Science as the main database for our study since it is the most comprehensive scientific database widely recognized for including high-quality conference and journal articles from the most important publishers (MDPI, IEEE, Elsevier, ACM, Springer, Wiley, etc.). Using the WoS database allowed us to focus our search on a single platform while receiving results from articles from multiple publishers. To conduct the search, we have used the Clarivate WoS web platform [34]. As a search method in this platform, we have selected the Topic type because it covers the key information from the WoS indexed research articles: title, abstract, author, keywords, and Keywords Plus. The search keywords have been transformed into search strings in the platform, e.g., "blockchain" AND "ambient intelligence".

Figure 3 illustrates the PRISMA 2020 flow diagram used to identify the articles that were included in the review. In the PRISMA identification phase, after aggregating the search results, we have identified 491 articles matching our search criteria. We have refined this set of articles and removed duplicate records (19 items), resulting in 472 records to be included in the Screening phase. In this phase, we have defined specific inclusion criteria for our study to further filter the results, thus, removing 312 records. Similarly, to further narrow the set of records in the Eligibility phase, we defined several exclusion criteria that helped us drop another 73 records. Both criteria are presented in Table 1.

Finally, in the inclusion phase, we obtained 48 records to be considered in the study for an in-depth analysis of the presented work, concepts, approaches, and solutions for blockchain in AAL.
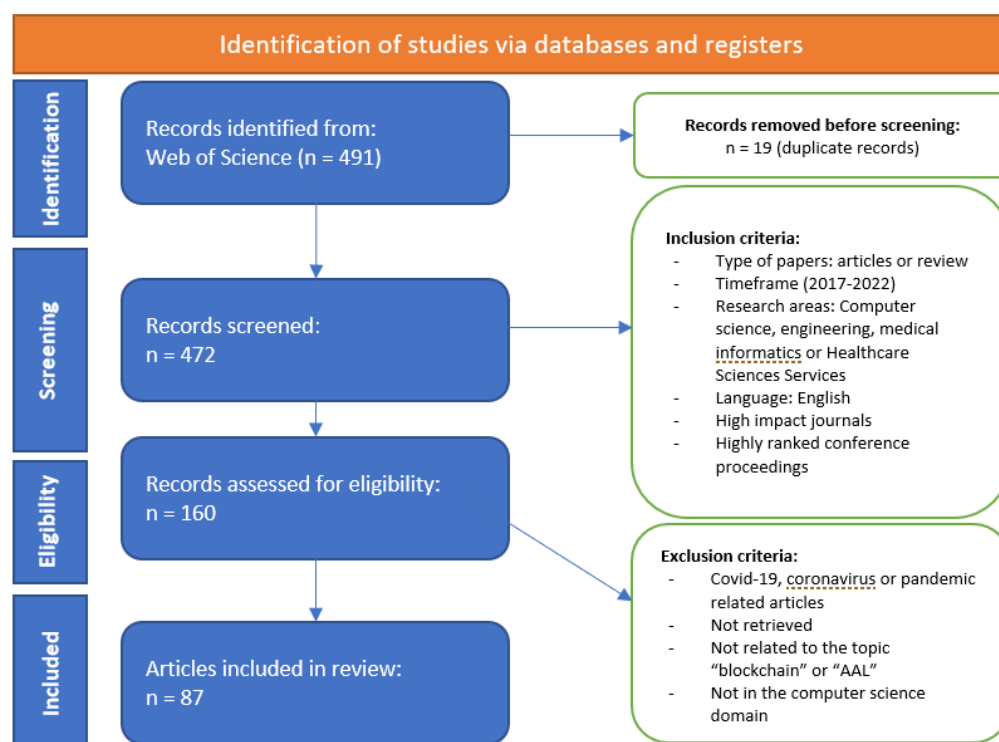
Figure 3. PRISMA 2020 flow diagram for the current study.

Table 1. Criteria for including and excluding articles in the study.

Screening Phase Inclusion Criteria	Eligibility Phase Exclusion Criteria
Type of papers: articles or review	Not retrieved
Timeframe (2017–2022)	Not related to the topics: blockchain, IoT, and AAL
Research areas: Computer science, engineering, medical informatics, or Healthcare Sciences Services	COVID-19, coronavirus, or pandemic-related articles
Language: English	Not in the computer science domain
High impact journals	
Highly ranked conference proceedings	

Figure 4 presents the included papers distribution per publishing year. It can be noticed that most of the research around the studied topics has been accelerated from 2020 onwards.
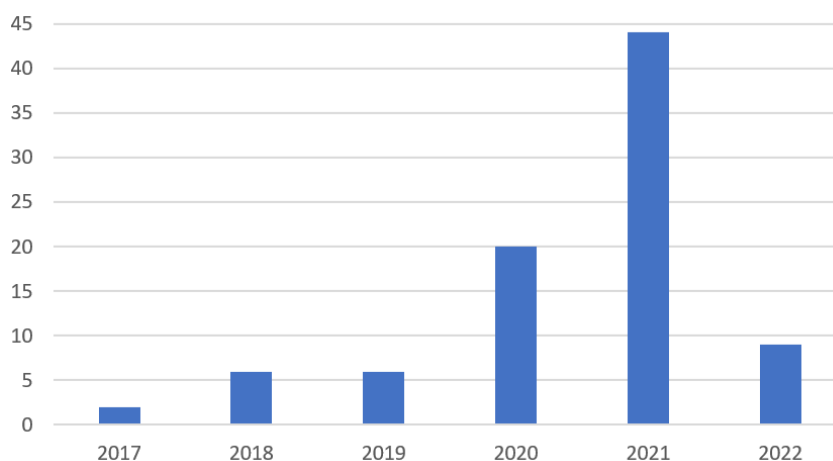

Figure 4. Results distribution by year.

Figure 5 shows the distribution of the selected articles using the journal/conference publisher as criteria. As it can be seen in the figure, all major highly rated publishers (Elsevier, IEEE, MDPI, and Springer) have shown interest in the blockchain and AAL research direction, 80% of the selected papers being published under one of the four.
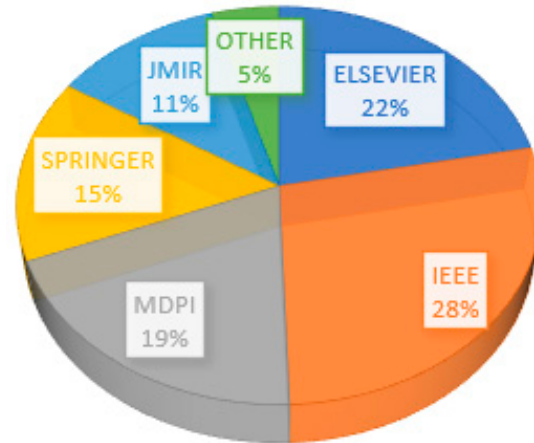
Figure 5. Results distribution by publisher.

As per the types of papers included in the study, in Figure 6, we illustrate the main categories of the analyzed papers, with an emphasis on article types.

Figure 6. Selected paper types.

Figure 7 shows the distribution of the included papers per journal and conference proceeding highlighting that more research related to the study domain has been published in IEEE Access and Sensors MDPI journals.

Figure 7. Journal and conference proceedings comparison.

Table 2 summarizes the query results as the number of records together with the number of items included in the study per each category.

Table 2. Results overview.

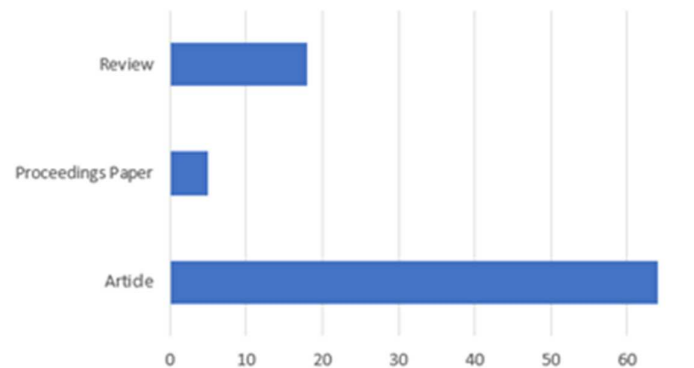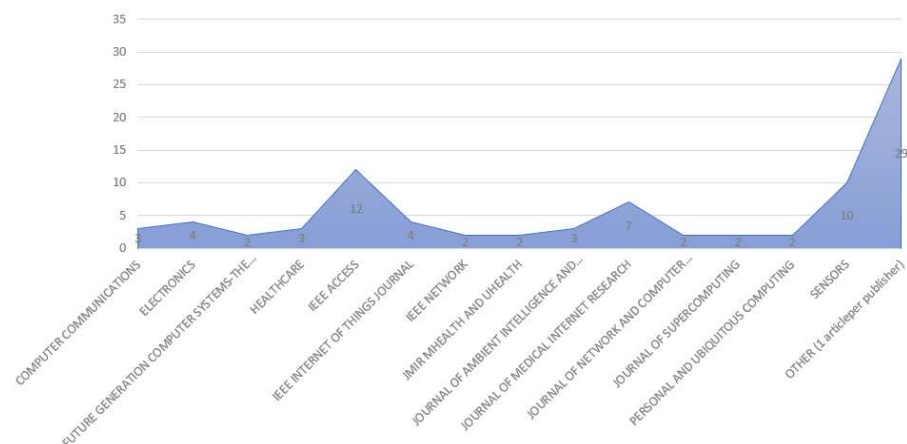| Search Keywords/Query Phrase	Identified Records	Selected Items (after Removing Duplicates)	Articles References
Blockchain and IoT	342	38	[13–15,17–22,24–32,35–54]
Blockchain and Ambient Assisted Living	15	5	[55–59]
Blockchain and Active Assisted Living	2	1	[60]
Blockchain and Ambient Intelligence	7	1	[61]
Blockchain and remote care	39	22	[62–83]
Blockchain data ownership in healthcare	15	6	[84–89]
Blockchain data sharing and analytics in healthcare	16	7	[10,16,90–94]
Blockchain and IoT security and privacy in healthcare	55	7	[95–101]

3. Results

After identifying and selecting the relevant papers using the defined criteria, we have conducted a qualitative analysis to identify blockchain applications and use cases in ambient assisted living systems and the associated challenges and limitations. Most of the literature on blockchain application in healthcare focuses on the health aspects, such as the management of electronic health records, and only a few relevant papers were found on addressing aspects of patient care at home using ambient assisted living systems. Nevertheless, most of the identified papers are very recent, mostly beyond 2020, showing that blockchain technology usage in ambient assisted living is a fast-emerging field of research that will gain a lot of attention in the near future.

We have organized the reviewed papers on the basis of the most important aspects of ambient assisted living reported in the literature to which blockchain may bring significant improvements: (1) monitoring, timely follow-up, and intervention of patients or older adults living at home using IoT devices; (2) decentralized data storage to avoid single point of failure, data manipulation issues, and mistrust; and (3) privacy and security aspects of cross-continuum of care.

3.1. Patient Monitoring and Intervention

Integrating IoT with blockchain technology is used to develop decentralized ambient monitoring and intervention infrastructures using IoT devices (see Table 3). The data provided by the IoT devices can be stored on the blockchain as transactions and replicated in all the nodes of the network. The blockchain can offer an efficient environment for disseminating IoT-acquired patient data in a secure way to all relevant healthcare stakeholders [63]. Blockchain can reinforce trust and address problems related to limited access to healthcare [67].

Table 3. Blockchain usage benefits of IoT monitoring in AAL systems.

Ambient Assisted Living Use Case	Blockchain Usage	References
IoT-based monitoring and intervention	Reinforce trust, provenance tracking	[63,67,72]
	Remote monitoring and telemedicine	[63,65,67–69,94]
	Patient data-efficient dissemination and interoperability	[17,18,57,64,71,84]
	Personalized care services	[17,65,70,94]
	Automation using smart contracts	[17,28,66,75]

The integration of IoT with blockchain may contribute to the relief of pressure on sanitary systems while simultaneously providing tailored care services to enhance people's quality of life [65,94]. The growing geriatric population with chronic medical conditions increased the adoption of IoT devices for remote at-home monitoring [68] and telemedicine [69]. These have become even more evident during the COVID-19 pandemic [63,67]. An IoT taxonomy relevant for ambient assisted living systems is provided in [16,47]. Five categories have been identified: sensor-based, resource-based, communication-based, software-based, and security-based methods. Blockchain has promising features for developing data-flow architectures that integrate the monitoring devices and assure patient data-efficient dissemination to relevant healthcare stakeholders [57,64]. The marriage of blockchain with Internet of Things technology supports the paradigm shift towards preventive and personalized care systems [17,70]. Although blockchain and IoT adoption in ambient assisted living systems is still in its early stages, it can address flaws in the care processes [18] and close some communication gaps, assuring better interoperability [71,84]. An investigation into the development of smart ambulances is presented in [19]. The blockchain can be used to increase interoperability and efficiency of information exchanges with the hospital for timely intervention in an emergency department [72].

Blockchain is a good choice for establishing a decentralized, self-contained IoT system deployed in older adults' homes [75]. In [28], the authors propose an IoT based on blockchain integration architecture, a rich–thin client IoT technique for addressing the challenges associated with the restricted IoT capacities when adopting blockchain in remote monitoring and healthcare processes. In this context, the smart contracts can assure a seamless and automatic solution platform connecting a range of IoT devices relevant for remote follow-up [66]. Smart contracts are a crucial feature of blockchain technology that enables it to be used in a variety of ambient assisted living systems [14,85]. However, the smart contract concept, its operation, and how it can be used in ambient assisted living are still poorly understood [48].

Nevertheless, the main barrier to integrating IoT monitoring devices with blockchain in the context of ambient assisted living systems is scalability [62]. The researchers of [24] provide an overview of blockchain technology and explore prominent consensus methods utilized in the healthcare processes. However, as the authors pointed out in [36], there are issues to be solved, including scalability and standardization. Research has been conducted to improve the scalability of IoT to blockchain integration [73]. This is a relevant aspect of ambient monitoring and assistive services [37]. In [44], the authors propose a blockchain framework that is described as more accurate, precise, and efficient than other popular methods of storing and accessing patient records among personnel, medical stakeholders, and facilities. In [18], the authors discuss the evolution of healthcare, identifying the research gaps such as the relocation of care from hospital to home and ambient assisted care [5] that we consider to be a relevant use case for joining Wireless Body Area Networks with blockchain [74]. Improved scalability of a permissioned blockchain framework has been described in [51] using Hyperledger Fabric as an infrastructure for the blockchain network. The authors of [31] investigated a composite scalability concept which can be seen differently depending on the grade of innovation we want to achieve. The notion of blockchain scalability is discussed, including techniques and ideas for increasing core blockchain functionality and blockchain-based applications in domains such as remote care [76,81]. Blockchain and fog computing is being used in care IoT to provide safe and trustworthy transactions [95]. An Extended Signature-Based Encryption technique is proposed for healthcare IoT device authentication, as well as authorization [52]. The authors claim the suggested architecture and algorithm may offer safe transaction and transmission. Finally, [54] looks at blockchain to IoT systems and how to make them more scalable. On-chain and off-chain methodologies are contrasted, and suggestions are made to help designers create scalable blockchain-based IoT medical systems.

3.2. Decentralized Data Management

As healthcare processes become more digitalized, issues concerning safe storage, ownership, and sharing of patient personal health records and related medical data have arisen [10], and they can be addressed by using blockchain technology (Table 4). To address some of the issues mentioned above, patient data can be stored in the cloud [59], and security policies can be applied via smart contracts [86]. Increasing the amount of time that vulnerable persons can spend at home alone and how data acquisition systems can efficiently share data using blockchain are presented in [87]. Removing some of the barriers to adopting electronic patient records in management platforms through a blockchain is presented in [88]. The data collected from IoT devices can be stored in an Interplanetary File System (IPFS) storage while data access and interactions are managed through smart contracts executed on a blockchain [96]. In [12], the authors identify four possible research directions for blockchain technology in the healthcare domain: scalability, privacy and security, digital currency management, and cross-chain technology.

Table 4. Blockchain usage benefits data management in AAL systems.

Ambient Assisted Living Use Case	Blockchain Usage	References
Decentralized patient data management	Safe, decentralized storage of data Data sharing and smart contracts Data ownership Health and care processes integration Data analytics	[42,59,77,82,91] [25,38,39,87,88] [12,14,25,26,49,83] [89,90] [40,42,43,46]

A blockchain-based architecture is presented in [38] to enable a distributed patient data sharing and smart-contract-based web service automation while not compromising the security and privacy of the system. To tackle the limitations of cloud-based systems, such as single point of failure, the use of decentralized data storage systems is proposed [42]. An essential insight into the possibilities of blockchain technology, particularly in the health sector, is provided in [25]. The authors discuss the reasons for using smart contract technology in healthcare and the prospects of using smart contracts in health records and sharing processes, medical testing, pharmaceutical manufacturers, big data, machine learning, security, and privacy, among other areas. The significant barriers to the use of blockchain technologies, along with scalability and storage conditions, are interoperability with legacy systems [49].

In [39], a data-sharing strategy based on the IPFS was developed, which not only increases the availability of data but also decreases data redundancy among the many stakeholders of the care ecosystem. In [14], the use of blockchain technology is discussed regarding the use of IoT in the remote monitoring of patients. Blockchain is seen as a good technology for facilitating the implementation of the internet of medical things, which refers to the interconnectedness of devices and sensors in the healthcare domain that collects real-time data [89]. The challenge with this data is that it is typically stored in a centralized location, which creates a single point of failure and raises privacy and security concerns [90], and a consortium blockchain network with smart contracts and interplanetary file systems can provide secure storage and transmission of data [77]. Important research directions in joining blockchain and ambient assisted living services are scalability, response time, blockchains interoperability, privacy, and ownership of data [83].

Big data, artificial intelligence, and distributed ledger technology, among other technologies, are blurring the barriers between the physical and digital worlds. Blockchain is a new technology and needs the development of more efficient and scalable strategies for incorporating it into the existing healthcare processes [43]. An innovative blockchain-based business model for health and care systems is described in [40]. It places the patient at the heart of the paradigm and may be used in any business situation with a set of user incentive criteria. As indicated in [42], blockchain technology may be utilized to enhance

IoT-driven care systems and tackle different difficulties. It offers a two-stage architectural solution for integrating IoT with blockchain using dew and cloudlet computing. In [46], a blockchain framework is proposed that allows data owners to create preferred access controls for electronic patient records. A two-chain architecture is used to store access controls as well as data transactions and employs a clustering strategy to handle the real growth difficulties associated with distributed ledgers.

Even though, as listed above, blockchain technology brings potential benefits for data management applications to ambient assisted living systems, there are challenges that limit its adoption [30,37]. Services built on fuzzy systems and blockchain technology are proposed in [49] to provide a behavior-driven intuitive security measure for healthcare IoT environments and networks based on blockchain. In [85], the authors explore different methods for assisting in medication usage. Blockchain can be used to store and disseminate information concerning adverse responses to prescription pharmaceuticals [97]. In [26], various scenarios are presented in the form of an analysis that verifies the key aspects of establishing, verifying, and changing people's identities. It presents various blockchain identity verification solutions available on the market built on top of public or private blockchains. Finally, a significant amount of time might be saved if patient characteristics are disseminated among all relevant stakeholders across the care continuum [91], illustrating how distributed ledgers and blockchain technology might be used for AAL systems to support decentralized data management [82].

3.3. Security and Privacy

Blockchain technology usage in ambient assisted living systems brings benefits (see Table 5) for addressing flaws and vulnerabilities, such as security flaws in smart IoT devices [41], trust and security, as well as the interoperability of such systems with legacy applications [20]. It may also circumvent the restrictions of client/server architectures in cloud-based ambient assisted living applications because of its scattered peer-to-peer nature [13].

Table 5. Blockchain usage benefits for the security and privacy of AAL systems.

Ambient Assisted Living Use Case	Blockchain Usage	References
AAL system security and privacy	GDPR compliant applications	[32,35,78,79]
	Informed consent management	[14,21,27,35,50,56,58,60,99–101]
	Data privacy and identity management	[13,15,29,45,50]
	Security and confidentiality	[20,22,27,30,50,80,93]

A thorough literature review of GDPR-compliant blockchains was conducted in [32]. The essential GDPR for blockchains can be broken down into six categories that include data removal and modification, security by design, data controller and data processor obligations, consent management [35], data processing norms and lawfulness, and geographical reach. In [79], new research paths are proposed, such as the adoption of private blockchains to support the implementation of ambient assisted living systems. The authors of [41] examined recent breakthroughs in IoT-based healthcare procedures identifying critical challenges for systems development such as security, privacy, and authentication. In [43], blockchain technology was utilized to address such challenges to build a more efficient and dependable care system. Additionally, blockchain provides relevant features for ambient assisted living systems, such as data tampering and service failures [78]. Utilizing a distributed ledger, data might be visible to all users and, therefore, would allow for data integrity and provenance tracking verification [92].

In [35], a thorough assessment of the implementation of blockchain technology in the sphere of consent is presented, as well as privacy and data management. The consent of the patient is an important topic in the field of ambient assisted living systems [50]. In [60], a

study was conducted on better techniques to manage informed consent so that data access is not abused and personal data protection regulations are respected. A good platform for obtaining informed consent from both a patient and a proxy (in the case of patients who have no discernment or cannot make decisions for themselves) is the Hyperledger fabric network blockchain [27] with smart contracts. Blockchain platforms may combine several roles and stakeholders in the care system, such as institutions that regulate access to personal data, data consumers, research institutions such as universities, and devices and technologies that acquire data [98]. A consent management framework that incorporates Distributed Ledger Technologies is presented in [21]. The platform offers an onion-layered secure way of transmitting sensitive data and a better way of accessing management methods. IPFS can be used for sharing files in a safe, transparent, and decentralized way in ambient assisted living systems [14]. Similar solutions based on another type of blockchains can be found in the literature [99], but they are not focused directly on consent, even if they can be interpreted as access to data itself [100].

Lately, differential privacy has emerged as perhaps the most successful privacy guarding solution for IoT medical and care infrastructure [13]. Some experimental findings and confidentiality proofs that demonstrate a particular suggested protocol that has a reasonable computational cost, as well as security safeguards for digital healthcare transactions, are presented in [45]. For decentralized and trustworthy healthcare data interactions, smart contracts and Elliptic Curve Encryption can be employed. One goal of ambient assisted living data protection protocol is to be resistant to a variety of threats and to have reasonable operating and computing capabilities [15]. A blockchain solution using a zero-knowledge-based authentication architecture to tackle privacy issues is presented in [29]. The architecture authenticates devices without revealing any information about the identity of the user. The paper also introduces the ZKNimble cipher, which is suitable to be used by devices that do not benefit from a good processing power.

According to [27], the ambient assisted living and care systems should deliver and share patient data through a secure transfer to ensure the confidentiality of data [93]. This was made feasible using a blockchain-based approach to the system's architectural design [55], while work still needs to be carried out on interoperability. It is explained in [20] how many IoT applications in healthcare are no different from those in any other area, and the research should concentrate on the industry's unique requirements, such as good levels of privacy and security. In this context, the number of blockchain-based applications in healthcare has increased lately, but the domain highly demands interdisciplinary studies [30]. A blockchain classification for IoT applications is provided in [47]. The authors explore the most prevalent blockchain systems for healthcare.

In [50], a blockchain-based solution is proposed for managing private data using Hyperledger Fabric and Caliper and can be used in various domains such as healthcare. The core benefits of blockchain technology for such systems are immutability, traceability, and transparency [80]. In [22], a decentralized and scalable architecture is presented supporting device access, authentication, as well as data security. A novel authentication protocol has been devised and constructed on Physical Unclonable Functions cryptographic primitives. This makes it practically difficult to predict the key values of the protocol because of the randomness provided by the physical architecture of the protocol. The system suggested in [53] enables medical officials to authenticate data received by a common wearable device with a verification error of less than 1% and a price compared with fewer as being much cheaper for one hour of observing the activity. A decentralized specific ring-based authorization method, as well as an authentication scheme and patient's records anonymity algorithms, are provided to increase the proposed system's security [58]. It allows for decentralized automated identity management, privacy, and security [61]. Finally, in [15], the authors use blockchain to protect patients' anonymity and privacy from several potential threats while enabling important institutions to interact with one another. Only authorized users have access to the genuine identities, addresses, as well as medical data of patients

in the proposed system [101]. Authorities should use blockchain to tackle the issue of cyber-attacks tampering with sensor data [56].

4. Discussion

As the population of the world is aging, societal challenges will need to be faced, especially about the delivery of care, which needs to be improved, and new care system paths need to be designed. At the same time, the development of IoT sensors and technology such as blockchain can ease this process by the implementation of ambient assisted living services which aim at moving the care from hospitals and care centers to home. The integration of sensors in older adults or patients' homes to enable remote follow-up and care is seen as key in delaying.

The ambient assisted living systems address many of the concerns of patients in this transition towards remote care and personalized interventions, such as (1) time-consuming process for healthcare professionals caused by the lack of accurate monitoring and follow-up support, (2) patient data-sharing gaps across the care continuum, (3) not having a proper care support network in place to reduce patient anxiety or worries; (4) patients and family caregivers lacking sufficient knowledge and skills to optimize self-care; (5) patient difficulties in adherence to postdischarge instructions, e.g., medication usage or behavioral changes.

Despite advantages brought to the care process, the ambient assisted living solutions have a rather limited adoption mostly because of the problems related to IoT sensors integration, data sharing, trust, ethical considerations, data confidentiality, privacy, etc. (see Table 6). As shown by the qualitative review conducted, blockchain technology can play a significant role in addressing some of the concerns related to the ambient assisted living services adoption, but at the same time, several technological barriers require further investigation.

Table 6. Assisted living issues and blockchain solutions.

Ambient Assisted Living Open Issues		Blockchain Solutions	Future Research Directions
Monitoring and Interoperability	IoT sensors integration scalability	Smart contracts for a device to chain integration,	Improve scalability and decrease transactional costs
		transactions based on monitored data	
		Edge off-chain data vs. on-chain transactions	
	Interoperability	single source of truth	Blockchain networks integration, care system legacy application integration
		No data segregation	
Data Management	Data Storage	Decentralized	Decrease storage costs
		Encrypted data	
		Replicated blocks	
		Tamper proof	
	Data sharing	Sharding based on healthcare rules and care paths	Create new care and data-sharing paths for the transition from hospital to home
Security and privacy	Privacy and ethical considerations	safe environment for sharing patient data	Common concept of the data confidentiality, personalization of data disclosure paths
		Informed consent management	
		Creation of a patient's digital identity	

Blockchain scalability is important for integrating the technology into ambient assisted living systems. The monitoring data related to the patient's state and well-being, captured

using IoT sensors, must be disseminated through the blockchain network. However, nowadays, the scalability of blockchain networks is low for handling an increasing number of transactions as more people will utilize the platform. The quantity of data to be saved on the blockchain will increase in tandem with the number of transactions on the network. It may cause problems related to the network speed and high costs. It is difficult to assess blockchain performance concerning the integration of IoT monitoring devices in living environments and the storage and dissemination of patient data for remote follow-up. Because the technology is decentralized, there is no benchmark against which to compare performance. However, there are a few methods for assessing performance. One method is to look at how many transactions a blockchain network processes in a particular amount of time. Another technique to assess performance is to look at a blockchain network's average transaction time.

As scalability is a significant issue of the blockchain, managing a high number of transactions is important to gain broad acceptance in ambient assisted living systems. However, there are several solutions for improving scalability. Sharding is one potential solution in which the blockchain is split into several shards, each of which may execute transactions concurrently and can be correlated with the organization and data-sharing procedures in healthcare. It would enable the network to handle a considerably higher volume of transactions without compromising speed or efficiency. Another option is off-chain scaling, which entails shifting part of the data off-chain, and this can be a relevant option even to relieve some of the privacy concerns as the patient monitoring data will be stored at the edge.

In the blockchain, there is a lot of room for privacy. This is relevant for ambient assisted living systems where private data and informed consent must be carefully handled. With blockchain, we may construct a safe and private transactional environment to share patient health records and data. Blockchain, if properly used, has the potential to eliminate fraud and improve transparency. However, ensuring privacy needs further research and development. One of the difficulties is that all parties must have a common concept of the data confidentiality, and new care and data-sharing paths need to be created in the healthcare systems. The creation of a digital identity is another way that blockchain may aid in the enforcement of privacy. This would allow us to choose which personal information is shared and with whom. In an ambient assisted living system, we may, for example, select to share the data partially with our family and not at all with our insurance company. A digital identity would offer us complete control over our personal information, allowing us to guarantee that it is shared only with the people we choose.

Another issue of ambient assisted living systems is the possibility of data leaks and modification. Unauthorized parties may have access to monitoring data if they is not protected adequately. Therefore, data may be encrypted using blockchain. This makes it extremely difficult for anyone who is not allowed to read it and modify it. A decentralized network is what defines a blockchain. It implies that our data are not stored in a single area, making it extremely difficult to be modified. Smart contracts can be created using blockchain technology. Integrated into ambient assisted living systems, they may automatize the IoT devices integration as well as the data processing jobs. As a result, we may designate how and by whom our data can be utilized. If someone tries to use our data in a way we have not approved, the smart contract will prohibit them immediately. The data stay private and safe by utilizing blockchain to encrypt data, build a decentralized network, and construct smart contracts.

Finally, the ability of various systems to communicate and interoperate is important for care and support systems that need to integrate stakeholders across the whole continuum of care. The capacity to exchange currency and data between various blockchain networks is one of the advantages of blockchain interoperability. It may contribute to developing a more integrated and efficient care ecosystem. Another advantage of blockchain interoperability is that it might reduce fragmentation risks. It can assist in guaranteeing that there is a single source of truth and that information is not segregated by allowing multiple blockchain

networks to collaborate. Interoperability on the blockchain can let consumers have a more efficient experience. Users may hopefully avoid dealing with numerous distinct care applications by allowing blockchains to interact and integrate. Interoperability across blockchains can also assist in enforcing security. It is possible to uncover potential risks and weaknesses by allowing multiple blockchain networks to share data and information. Interoperability on the blockchain can also assist in cutting expenses. It is possible to prevent duplication of effort and resources.

5. Conclusions

In this paper, we have used the PRISMA methodology to identify, study, and report the relevant state-of-the-art literature around blockchain and its applicability in ambient active living. We have defined inclusion and exclusion criteria, have set several international databases for pooling articles, and finally selected 87 research papers in the qualitative study. As many of the desirable features of ambient assisted living systems may be assured by integrating and using the blockchain technology, we have organized the review to reflect the solutions in relation to the IoT monitoring and integration of environmental sensors, managing and sharing of data, and security and privacy aspects.

The outcome of the study shows that the integration of blockchain with ambient assisted living systems is a hot topic in many of the papers published after 2020. The adoption of remote assistive care was accelerated by the COVID-19 pandemic, and as shown by the qualitative review conducted, blockchain technology can play a significant role in addressing some of the concerns related to ambient assisted living services adoption. Although blockchain technology has the potential to revolutionize the care and ambient assisted living industry, more research is needed to fully understand its implications and applications. Future research includes expanding and replicating existing frameworks, performance, scalability, privacy, and interoperability of blockchain systems in IoT healthcare applications. More studies are needed on the adoption of blockchain in the health and care ecosystem, concentrating on topics such as scalability, costs, creation of new care and data-sharing paths for care transition from hospital to home, governance, and interoperability.

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