Demystifying Blockchain: A Critical Analysis of Application Characteristics in Different Domains

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***Abstract*—Different vertical domains have gained popularity in integrating Blockchain technology with their existing applications, because of its numerous benefits like immutable, transparency, privacy, persistence, and security. Blockchain technology is used in various circumstances, allows the applications to achieve higher security, improved traceability, and transparency. This paper reviewed most of the applications related to the different domains and the number of criteria met by each application in each domain requirement. This paper examines the advantages, disadvantages, and limitations of implementing the Blockchain in various applications in different domains. Furthermore, this paper describes the prerequisites for deploying Blockchain across multiple application fields.**

***Keywords*—blockchain, application characteristics, vertical domains, security**

I. Introduction

The benefits of Blockchain are ddecentralization, immutable, privacy, transparency, availability, tamper-proof, audibility and security. The scope of Blockchain technology has expanded enormously due to its wide range of powerful features not only in financial areas such as crypto currency but also in academic, education, health care, food industry, voting, identity management, advertisement, agriculture and IoT [1, 2]. While there are other outstanding survey papers on Blockchain, we distinguish ourselves in this work by identifying the hurdles and discussing the prerequisites for effective Blockchain integration in industrial applications. For example, in one of the survey, Zheng *et al*. [3] mainly examined applications in banking, public and social services, reputation systems and IoT. They focused on the advancement on consenus algorithms and challenges.

Similarly, Gamage *et al*. [4] describes the fundamental principles of Blockchain, including its uses, challenges, and potential improvements. Finally, this study gives a standard categorization of different forms of Blockchain, and a detailed examination on future studies where researchers may obtain more information about Blockchain.

Maesa *et al*. [5] investigated numerous fascinating applications, such as electronic voting and access control systems, and analyzed the challenges that are encountered in many research and business applications.

Li *et al*. [6] address systematic study on various types of security threats and survey about the real attacks, vulnerabilities in a smart contract that exist in Blockchain technology, reviewed solutions and focused on future research directions on security. Monrat *et al*. [7] focused on comparative study of tradeoffs, consensus mechanisms, discussed taxonomy, architecture and different challenges raised in Blockchain Technology, and presented information on the technology's potential future applications. This paper explains the implementation of PEST analysis and analyzes food supply chain. Al-Jaroodi *et al.* [8] This article examines industrial application sectors and focuses on opportunities, advantages, and problems. It specifies the prerequisites that enable implementation and specific issues that must be addressed in the industrial sector. Chen *et al*. [9] surveyed different Blockchain applications like cryptocurrency, healthcare, advertising, insurance, copyright and explored the summary of individuals and organizations of Blockchain applications to motivate many more applications to be implemented.

There is an unexpected surge in the increasing implementation of DAOs and their applications in several fields. Detecting misbehaving nodes in such decentralized networks demands extra work. BBRP [10] protocols offer possible solutions to this problem, but several outstanding issues with BBRPs must be resolved. Creating sensitive information in a distributed manner in the absence of centralized authority is a difficult task. However, to improve the security and dependability of users, DAO management systems have the potential to replace centralized systems. However, it would have setbacks and difficulties until it reached maturity, like cutting-edge technology like Blockchain.

Even though Blockchain technology is decentralized and distributed, during the development of applications, there is a possibility of a centralized system. As a result, several cloud computing service providers, including

Manuscript received October 10, 2022; revised November 23, 2022, accepted December 9, 2022; published July 26, 2023.

Amazon AWS and currently, Microsoft Azure, are currently providing Blockchain as a service (BaaS) [11].

Since 2015, Blockchain research has been exponentially increasing [12]. But most of the issues related to Blockchain still needed to be resolved, pertained to different applications and domains, such as agriculture, smart cities, services, big data, and different services like smart grid, supply chain management, security, privacy, etc.

However, none of the surveys focused on the overall characteristics of the domains and their applications, nor did they examine the number of applications that met domain specifications.

We started by finding the most often used alternative words and synonyms in the research in order to fully utilize the scope of the searched literature in this effort. As a result, we used our suggested taxonomy and search criteria to perform our selection process. First, we divided the present research difficulties and issues in Blockchain into many groups such as characteristics, domains, applications, research articles and industry applications in Table I. We have gathered most of the industrial applications which have already implemented in Blockchain and analyzed different characteristics used in different applications. Blockchain is implemented in sectors like education, health care, public sector and agriculture which employ most of characteristics. Finally, we focused on future scope to find the common characteristics to implement a Blockchain that is acceptable by all the applications (see Table I).

TABLE I. PAPER SELECTION CRITERIA

S. NO	Criteria
1	Relevant to the study of Blockchain.
2	Different Domains and different applications of Blockchain.
3	Characteristics of Blockchain and their challenges.
4	Blockchain Research articles related to research.
5	Blockchain applications related to Industry.
6	Limitations of applications oriented Blockchain

Using this survey paper researcher can be motivated to implement in different sectors by considering the different characteristics of the Blockchain. The rest of the paper is organized as follows. Section II discusses Blockchain and Smart Contracts, Section III discusses the key characteristics required to develop the applications for Education, Health Care, Agriculture, Food Industry and Public Sector. Section IV discusses the survey of Research and Industrial applications in different domains, Section V discusses Research challenges and opportunities. Finally, Section VI concludes the paper.

II. BLOCKCHAIN AND SMART CONTRACTS

A Blockchain is a chain of blocks that contains a collection of transactions and expands continuously, whenever new transactions are added. This holds the complete information about each transaction, the same as a public ledger. All the transactions are transparent to the participants in the network. Each block contains a hash value, block version, timestamp, nonce, and multiple transactions. The initial block in the Blockchain is known as the genesis block, which does not hold a hash value. The remaining blocks store the hash value of the previous block, and it is continued till the end of the chain. Before the transactions are committed and stored in the block, their identities are validated and verified.

Each block contains information about the block's version; a 256-bit hash value is used to point the previous block; a timestamp; and a nonce, which is usually a 4 byte that starts with 0 and changes.

There are three types of Blockchain: public, private, and consortium. Each has its advantages and disadvantages. In a public Blockchain, all the nodes can participate to win the reward and get a chance to add a new block, but efficiency is low compared to the other types of Blockchains. In a private Blockchain, only selected nodes are allowed in the network, and in consortium Blockchain, based on the scenario, it can be either public or restricted.

Consensus is critical in ensuring that all nodes in the network make the same decision. Proof of Work was the first consensus mechanism introduced in Bitcoin. Other consensus mechanisms, such as Proof of Stake, Proof of authority, Delegated Proof of Stake, and so on, have since been introduced in the Blockchain. Each consensus follows a unique technique to maintain the consensus among the nodes.

Smart contracts are simply programmes stored on a Blockchain that run when predetermined conditions are met. They are typically used to automate the execution of an agreement so that all participants can be immediately certain of the outcome without any intermediary's involvement or time loss. They can also automate a workflow, triggering the following action when conditions are met. Nowadays, smart contracts have become very popular along with the Blockchain. These smart contracts are the same as regular legal contracts, which are maintained between two parties. These digital contracts are in the form of programmes that are stored on a Blockchain, and these digital contracts run based on some conditions that are already predetermined. Smart contracts are usually automated to maintain the same state among all network participants without any mediator's interference. Even by using smart contracts, the workflow can be automated whenever the predetermined conditions are met by using triggers.

III. ANALYSIS OF BLOCKCHAIN IN DIFFERENT DOMAIN CHARACTERISTICS

As illustrated in Fig. 1, this part addresses five domains: education, health care, agriculture, food industry, and public sector (land registration), as well as their features and a few applications in each area.

A. Blockchain in Education

This section discusses key characteristics required to develop the applications in education using Blockchain. The essential characteristics needed to create a Blockchain in education application are covered in detail in this section. For example, a person's educational history might reveal their prospective expertise. The

academic records must be kept in a safe place that is impenetrable to tampering, accessible, and cannot be changed. Most of the old systems are significantly slower, unreliable, and involves complex process for managing and validating certificates. In order to store and retrieve certificates safely, certificate management must be digitized.

Different businesses, industries, and organizations utilize educational records to confirm student's identification and the legitimacy of their education at recognized institutions.

Key characteristics of Blockchain in Education domain are as follows:

1) Tamper proof

After completing any course, the institution issues a certificate of completion that includes score, grade, marks, and so on. The result should be tamper-proof so that no changes can be done to the already existing one. *Secure storage*: The results and other information regarding students should be preserved securely and may be further used to verify student identity. *Easy Access:* All the education records should be easily accessible to the students, institutions, companies, and other parties if required for verification. *Authentication*: The student's details should be authenticated by the institutions or schools. So that authenticated details can be stored and used further for any student identity.

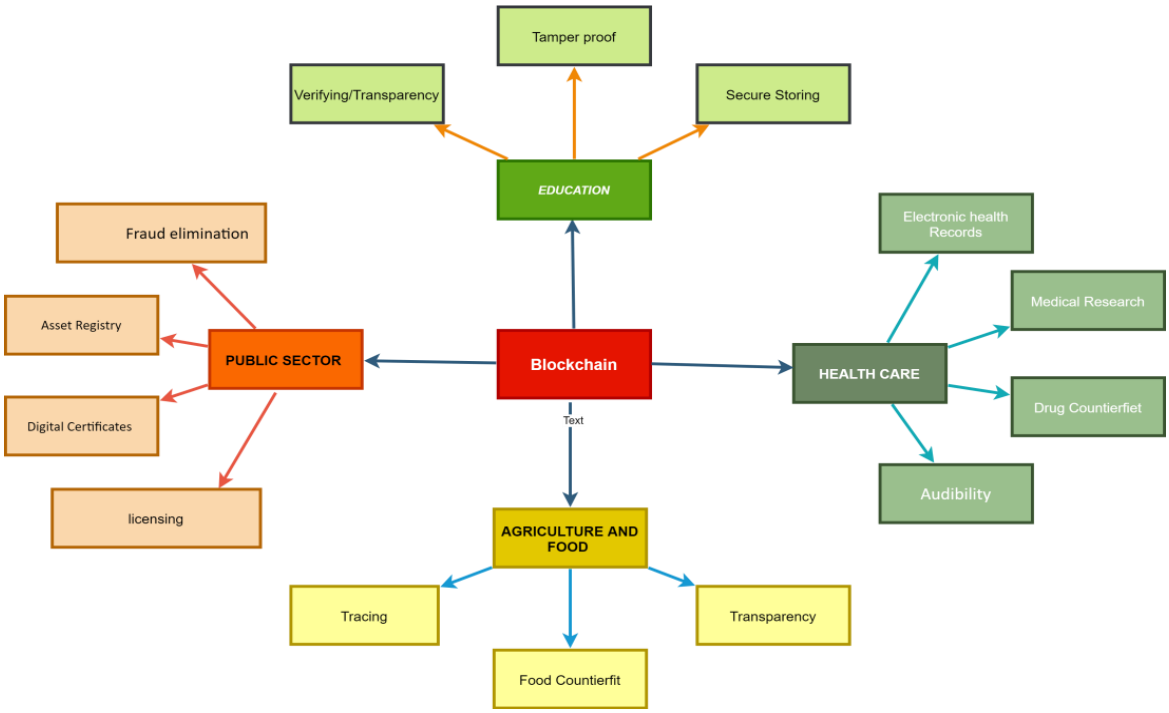

Figure 1. Application of different domains.

2) Authorized sharing

Education records such as certificates should be shared only to the authorized people like companies, Industries, and Higher education institutions. The unauthorized people may change or modify the information contained in original certificates.

B. Blockchain in HealthCare

This section discusses key characteristics required to develop the applications in Health Care using blockchain.

Recently, personal health information has been collected from each individual to analyze their health status. The health data may contain some sensitive information and accurate. As a result, this information should be stored securely to protect it from illegal access. There are some concerns such as privacy, authorized sharing, tamper-proof data, and so on. Blockchain is employed in health care because of its unique qualities patient information or health records are stored and monitored in regular time intervals to improve the health condition at lowest possible cost. Management of electronic health records, drug counterfeit, medical research, authorized sharing, medical claim, and fraud detection are all part of healthcare Key characteristics of Blockchain in Health care domain are as follows:

1) *Disintermediation*: Personal health information can be accessed between the patient, doctor, and other parties without any intermediate persons or applications.
2) *Transparency:* All the authorized stake holders can access the health information. If any person tries to manipulate the information it is accessed by everyone.
3) *Auditability:* Higher-level experts perform audits in healthcare to examine, enhance and evaluate the patient's health condition.
4) Industry *collaboration:* To advance the future of healthcare, industries collaborate across the organizations, academics and government.
5) *Integrity tracking:* Integrity tracking involves valid data, accurate information, complete details,

trustworthiness, and timely identification of individual patients.

6) *Privacy:* The information which is provided by the patients, like medical reports, health monitoring reports, insurance and so on should be maintained in privacy.
7) *Fragmentation:* Fragmentation is caused by factors like misleading incentives, insurances amount which lowers Quality, cost and outcomes.
8) *Immutable:* The health information collected from the patients should be kept from being modified or tampered. The slight modification leads to a significant cause.
9) *Availability:* Personal health records can be accessed by the authorized stake holders at any time, and the data is not allowed for modification.

C. Blockchain in Agriculture and Food Industry

This section discusses key characteristics required to develop the applications for Blockchain in Agriculture and Food Industry.

Some nations, like India, rely heavily on agriculture to support their economic growth. Incorporating the abilities of Blockchain technology in this area could lead to an improvement in agriculture in different aspects. Blockchain is a trending technology with various characteristics like transparency, security, safety, trust and privacy. In agriculture, different stake holders such as farmers, vendors, distributors, retailers, and so on are involved from the initial stage of a field or crop to the final stage, till the product reaches markets or godowns. There are Some untrusted parties are engaged in committing malpractices such as buying the agricultural products at high cost, low quality fertilizers, cheating the farmers, and so on. Many companies, manufacturing units, food industries, packaging industries, processing units, and many more have come into existence to serve the hungry population. However, some of the company's food safety standards must be improved. In addition to food safety concerns, the food business also faces a number of additional issues, such as less enriched or corrupted ingredients in food preparation and misuse of labels.

Key characteristics of Blockchain in Agriculture and Food domain are as follows:

1) *Transparency:* In agriculture, transparency is maintained from initial stages such as s soil type, suitable for crop or field, fertilizers used, suitable seeds based on soil, and the outcome of the crop or field. In the processing of food from initial to final stage all the information including origin of a product, processing and packaging of food are transparent to all the stakeholders.
2) *Immutability:* The information regarding the processing of food, ingredients used for production, the rules and standards of food should be immutable to judge the food efficiently.
3) *Traceability:* The effect of any damage caused to the crop/field can be traced out, and the farmers can trace the cause of the damage, whether due to the low-quality seeds or fertilizers within an expected time. The Consumer needs clear information and should be creditability because, in case of any damage or rotten foods being found, the consumers can easily trace.
4) *Data integrity:* Data integrity should be maintained so that accurate and complete information about the material used in food processing is known and beneficial audit team.
5) *Safety:* Food safety is achieved by preserving the material properly and hygienically. It contains a set of guidelines and requirements at each level of manufacturing or processing to avoid illness-causing and to safeguard the customer's health. This determines whether the generated goods are suitable for consumption or not. Safety precautions and standard protocols must be followed to obtain high quality products.
6) Quality *control:* Quality is directly proportional to the food supply. Quality means standards, the food should be accepted by the wide variety of customers and includes many factors like color, material, chemicals used etc. This consists of Quality of the land, fertilizers, water, and cultivation process to get the quality products from agriculture.
7) *Tamper-Proof:* The information which is stored cannot be modified or removed. The sensitive information may be used to access the status of the loan, and proofs of quality of agricultural products.

D. Blockchain in Public Sector (Land Registrations)

This section discusses in detail key characteristics required to developthe applications for Blockchain in Public Sector.

The government's primary goal is to retain and safeguard each person's personal information effectively. Unique identities such as Pan Card, bank information, passport information, marital status, license information, birth and death certificates are just a few examples of the information to be secured. Most of these certifications or proofs exist in paper formats, such as land records and agricultural passbooks. Some of them are available in digital form but need to be safe. In order to efficiently deliver a wide range of services to a huge population, the governments of several nations throughout the world have begun investigating smart services and putting different emerging technologies into practice.

Key characteristics of Blockchain in public sector domain as follows:

1) *Transparency:* The certificates should be transparent to the authorized people, so that they use them whenever necessary.
2) *Security*: The documents or proofs of identity should be stored securely because they play essential role individual lives.
3) *Identity management:* There are a huge number of certificates and documents, these so should be managed efficiently. Because these play an important role in individuals' life.

4) *Authentication:* The information should be authenticated because these documents are used in many ways and for many purposes.
5) *Easy access:* The documents or the identity proof papers of each individual should be easily accessible by the authorized persons.
6) *Integrity:* The stored information should be accurate and correct because it acts a proof of individuals.
7) *Tamper proof*: The information and documents should be tamper-proof so that no modifications can take place.
8) *Authorized sharing*: The documents should be shared to the particular person and only to the authorized persons. For example, Bank details should be shared if you are applying for a loan.

IV. Applications in Different Domains

This section discusses the survey of both research and industrial applications in different domains of Blockchain such as in Education, Health Care, Agriculture and Food Industry and Public Sector.

A. Blockchain in Education: Applications

This section discusses the various research and industrial applications in Education domain using Blockchain Technology.

1) Research

Han *et al*. [13] proposed an efficient method of storing, accessing, and sharing individual education records using some features of Blockchain technology like decentralization, security and privacy.

Chen *et al*. [14] focused on "learning is earning," in which students are motivated to learn and the performance is evaluated based on assignments, Quizzes, and Projects which are stored securely. Not only the student data but teacher's lecture recordings are also stored. The behavior and performance are evaluated based on the recorded videos. An effective educational approach may be developed through student and instructor evaluation. Based on the outcome of the students, they reviewed potential fascinating applications, their merits, and obstacles.

Kolvenbach *et al*. [15] focused on implementing a practical solution for issuing, monitoring, and validating educational certificates based on Ethereum Blockchain. In recent years, the certificates were issued on paper. However, there are several challenges in monitoring and validating the issued certificates. First, there are different types of certificates such as training certificates, skill development certificates and so on. All certificates are available in digital format, and these are generated in digital form by using smart contracts. Turkanovi [16] proposed a global higher education platform called EduCTX based on Credit Transfer and Accumulation System (ECTS). All the student's education information such as credits and grading is saved permanently. As proof of student educational details such as certificates, grades can be accessed by various organizations, companies, and institutions to pursue higher education. EduCTX processes, manages, and controls student information using ECTX tokens. The student details are transparent and stored in a digital format. Students can view their completed courses and HEIscan maintain up-to-date data without regard for the data's provenance. Lizcano [17] discusses training and its significance to students and trainers. Trainers deliver the sessions in various ways including online (through videos, sessions, and quizzes) and offline. The training might be both theoretical and practical, after completing the training procedure, the student should be able to be placed in any of the firms. Students can be instructed to work in conjunction with academic curriculum courses and placements.

Many challenges are present in assessing the different skills that students should acquire for their employability. One challenge is evaluating the the student's knowledge based on academics and training. So, the institution management or Company recruiter needs a tool to evaluate the student. Blockchain technology solves some of these challenges such as content delivery, teaching, trainers, employees, job specific training to fill the gap between working and learning. Sharples [18] proposes reputation management for educational systems by storing the data in the distributed record and providing a reward. Blockchain technology, offers a single secure record of educational details, easily accessible and distributed across many institutions. Once the Blockchain is built, educational institutions can securely record their students' achievements, certificates, and personal information. The recorded data is used to process scholar reputation based on academics. Comparisons of key characteristics of above discussed work in Blockchain of Education domain are listed in Table I.

2) Industrial applications

Arnaud [19] ODEM—The On-Demand Education Marketplace is a Swiss start-up founded in 2017 and implemented on the Ethereum Blockchain, which uses smart contracts to allow all educators and learners to connect directly without any mediator like institutions and at minimum cost. Implementing a learning platform where students can safely store and access their records on the Blockchain perpetuity. El-hajj *et al*. [20] work with university teachers to gain skills for fast-chaining employment marketplaces. AI and machine learning testing and evaluations are carried out as part of this. The student's profile, needs, and assessments are calculated using AI, and the learner is allocated to the educator based on the findings. Vidal *et al*. [21] is a collaborative effort between MIT and Learning Machine. This is a standard Blockchain designed to create and verify academic records. It is open-source, and one hundred eleven students obtained their digital certificates using Blockchain. Blockcerts Wallet is a smartphone application that allows students to build profiles. The Wallet creates public and private keys and indicators to establish ownership and integrity. Using this, making, sharing, and validating educational credentials is simple. These certificates provide basic information such as the recipient's name, the name of the granting institution, the

issuance date, the degree received, and so on. TrueRec, a safe and reliable digital wallet for storing professional credentials such as passports, driving licences, unique identification cards, and academic certificates (graduate, skill development), was launched in 2017 [22] by the SAP Innovation Center Network.

B. Blockchain in Health Care: Applications

This section discusses the various research and industrial applications in Health Care domain using Blockchain Technology.

1) Research

Azaria *et al.* [23] proposed a unique record management system to manage electronic medical reports gathered from patients and hospitals to provide accurate information about patient health status. This is implemented based on Blockchain technology, where the information is kept on blocks that are very easy to retrieve, a report summary is conveniently accessible.

These documents include sensitive information, which has to be carefully preserved and safeguarded. Miners, such as public health officials, stakeholders, researchers are introduced to mine and awarded. This suggested system allows patients to get electronic medical reports or information and can conduct research using this information.

An intelligent Healthcare system was presented by Attaran *et al.* [24]. The decentralized database feature of Blockchain Technology is used to monitor the patients' health. If a patient had been suffering from an illness from many years, this data is continuously documented and saved in the database using this method. Other authorized medical stakeholders engaged in this patient's health care, such as pharmacy, illness kind, medical treatment, specialists, hospitals, check-ups, scans, bill payments, medical insurance, claims, investigations, hospital moments, and so on can be monitored easily (see Table II).

TABLE II. COMPARISON OF KEY CHARACTERISTICS OF DIFFERENT APPLICATIONS IN BLOCKCHAIN IN EDUCATION

Author/ Characteristics	Tamper Proof	Secure Storage	Easy access	Authentication	Authorized sharing	Performance	Monitoring	Validating
Han *et al.*	Y	Y	Y	N	Y	N	N	N
Chen *et al.*	Y	Y	N	N	N	Y	N	N
Kolvenbach *et al.*	Y	Y	N	N	Y	N	Y	Y
Turkanovi *et al.*	Y	Y	N	Y	Y	Y	Y	N
Lizcano *et al.*	Y	Y	Y	N	N	N	Y	Y
Sharples *et al.*	Y	Y	Y	Y	N	Y	Y	Y

All patient information is saved in a decentralized database and the information is transparent to the authorized stakeholders who are involving in this system. Zaho *et al.* [25] used a body sensor network to create a lightweight backup and efficient recovery strategy. A smart health care system that combines BSN with Blockchain together for lightweight backup and recovery. Tens of sensors are deployed on a patient's body, with some sensors being wearable nodes, implanted nodes and a gateway device. These nodes are used to retrieve the various physiological signals (Blood Pressure, ECG, etc), which are then forwarded it to the gateway node. The data from the gateway is recorded in the health Blockchain utilizing a consensus process, digital signature and hash chain. When the Blockchain gets a message from a gateway device, it uses a consensus method to validate it. Valid communications are kept in the Blockchain, and all patient data is eventually appended to the blockchain. The data is available continuously because duplicate copies of it are stored in the remaining nodes.

A person visits several hospitals in various locations over n number of times during their lifetime. All the health information and records should be stored and transferred from one hospital to the other based on the patient's condition or when required. Based on flow of information, decisions can be made easily regarding the treatment or medication required. FHIRChain, a safe and scalable data sharing platform that makes efficient decisions, was suggested by Zhang *et al.* [26]. FHIRChain is a Blockchain-based architecture used to verify users so that they may choose remote cancer care. Five requirements are addressed such as user identifiability and authentication, secure data exchange, permission data access, consistent data formats, and system modularity. First, the user identification is validated and then the data or information is stored on the Blockchain. However, there are several concerns that health information technology (HIT) systems must deal with, chief among them being the problem of data theft in medical records. Most patients are worried about data leakage, which is the most sensitive information when using different electronic devices and gadgets such as a defibrillator [27] pacemakers, insulin pumps, etc. The author conducted the implementation of healthcare applications by using other Blockchain platforms and comparing them.

Kim *et al.* [28] concentrated on medical questionnaires based study. He proposed a system for gathering questions from many perspectives, and verifying them before offering answers to specific issues. Blockchain technology is used to collect queries and provide responses or replies, which is employed in medical research and clinical trials. A diagnostic system can be developed and utilized by everyone. The information which is collected should be stored in a secured way. This system follows the processes to create, collect and share the collected information. The question is transformed into a predefined format for validation before being answered. Rather than the patient, only authorized people can access the data about the patient. Comparison of key characteristics of above discussed work in Blockchain in Health care domain is listed in Table II.

2) Industrial applications

GEM, a US startup, has announced the Gem Health Network built on public Blockchain known as the Ethereum Blockchain technology. All the information about the patients is stored in distributed database, and the different stakeholders retrieve the required data to enhance health and efficiency by offering services to patients from the initial to final stages based on the patient information. This can improve the relationship between the patient and all stakeholders due to the transparent and tamper-proof nature [29].

The drug production process is quite sensitive since it contains several phases of processing formulae in order to manufacture the final drug without any hurdles. Compared to traditional approaches, drug production can be more effective by utilising Blockchain benefits such as tamper-proof, transparency, and distributed databases. By using this technology, the drug production can also be monitored.

The WHO survey says that ten percent of drugs are counterfeit worldwide. In some developing countries, the number increases up to 30 percent. The worldwide issue of drugs or medicines counterfeit causes an extreme loss to the human organisms which utilise those drugs or medicines. Not only has that, but the reputation of the pharma companies decreases without their influence. Due to these counterfeit drugs affects not only the lifestyle products like weight reducing and increasing hair improvement and pigment but also other sensitive treatments like cardiovascular, cancers, contraceptives, tumors and so on. These drugs use the same formulae and ingredients but are in different amounts than the exact and accurate prescribed amount.

In 2011 Estonia's digital health infrastructure cooperated with the Gaurdtime [30], a company dedicated to strengthening the interaction between patient and physician. A Netherland based information security startup that uses Blockchain technology to validate patient identity by delivering a smart card that connects Electronic health records. When the EHR hash is updated, it is assigned and recorded on the Blockchain. The EHR data is immutable and cannot be modified. For example, if patient wants to schedule a checkup, the data is authenticated and appended to the Blockchain. This is reflected in hospitals which are Blockchain nodes. As a result of this collaboration, Estonia people's medical insurances, health care providers, and others can retrieve information from the database and provide treatment, insurances, and other services at the appropriate time with genuine and accurate information. Estonia has demonstrated that it may use Blockchain technology to administer all aspects of public health care (see Table III).

TABLE III. COMPARISON OF KEY CHARACTERISTICS OF DIFFERENT APPLICATIONS IN BLOCKCHAIN IN HEALTH CARE DOMAIN

Haracteristics/ Author	Transprency	Auditabilty	Industry collaboration	Integrity tracking	Privacy	Fragmentation	Immutable	Availability
Azaria *et al.*	N	Y	X	N	Y	N	Y	Y
Attaran *et al.*	N	N	N	Y	Y	N	Y	N
Zaho *et al.*	N	N	N	Y	Y	Y	Y	Y
Zhang *et al.*	Y	N	Y	Y	N	N	Y	Y
Kim *et al.*	N	Y	N	Y	N	N	Y	N

Nowadays, the data is increasing exponentially from various sources. Therefore, numerous applications are implemented that are related to health care and storing information about the various kinds of citizens of the world. In addition, it can help us for many other purposes, such as knowing the improvement of patient status from the previous and can be used for conducting research. Healthbank, a global Swiss digital health startup, is innovatives in handling of data transactions and the sharing personal health data by creating secure environment where they can store and manage information.

With the capabilities of Blockchain technology, can securely store patient information (e.g., number of visits, blood pressure, diabetics, sleep patterns, use of medicines, different kinds of test, and so on) on the platform. In some scenarios, information can be retrieved from other sources like health applications and used for future medical research. In return, the users who provide the data can get acceptable financial compensation. This platform creates a one-of-a-kind data trading platform by incorporating creative concepts such as clinical research, clinical trials, and research projects from multiple institutions. Care proposes a platform that is patient-centric and connects all the stake holders like Doctors, medication, specialized care if required, pharmacies, insurance companies that apply to the patient, and advisors from different hospital managements. This platform is based on the Ethereum Blockchain and with ERC20 token standard.

C. Blockchain in Agriculture and Food Industry: Applications

This section discusses the various research and industrial applications in Agriculture and Food Industry domain using Blockchain Technology.

1) Research

Blockchain technology is used to store product data and share information securely and tamper-proof digitally. This distributed ledger contains the information passed from the initial stage and continuously stores all information exchanges between the people involved in the food industry like a producer, distributor, marketing, consumers, and so on. As a result, the information about the product's origin, processing, and manufacturing is transparent for consumers to decide about the product.

Kshetri *et al.* [31] Every year, about 600 million individuals become unwell from eating poor food. The

authors primarily concerns on food safety, transparency, and accountability in food supply networks. They explored issues such as the high cost of employing Blockchain engineers and the scarcity of competent workers. They have addressed some of the most promising Blockchain applications implemented related to food supply chains. Rejeb *et al.* [32]conducted a detailed evaluation of the advantages and concerns in the food supply chain and addressed them utilizing upgraded Blockchain capabilities. Using Blockchain Technology, researchers analyzed 61 scientific papers and focused on improvements in the food supply chain such as traceability, cooperation, and food trade. Technical difficulties and regulatory considerations are also addressed.

Traceability in the agri-food industry is presented by Demestichas *et al*. [33] who also clarify the concepts and resources needed to deploy Blockchain technology. Qualities include lowering costs and risks, saving time, boosting trust and transparency, and suggesting a strategy that increases productivity. This clarifies data gathering, ownership, data management and network data collection methods.

Amilaris *et al.* [34] focused on existing and ongoing projects in agriculture and the food supply chain. Our findings indicate transparency in food supply chains and food related issues like food safety, food processing and distribution. The public and private sectors are striving to incorporate Blockchain and resolve the challenges in different sectors to provide a reliable, secure storage, transparency in food safety and supply chains, data integrity.

2) Industrial applications

One of the American merchants that are a part of the IBM Food Trust is Walmart. Blockchain technology allows the storage of information about green leafy vegetables so that the origin, date, size, and location of the vegetables can be quickly determined. The import of mangos, pig products and green leafy vegetables is monitored. Before the development of Blockchain technology, it would need many days to trace the items (see Table IV).

TABLE IV. COMPARISON OF KEY CHARACTERISTICS OF DIFFERENT APPLICATIONS IN BLOCKCHAIN IN AGRICULTURE AND FOOD INDUSTRY DOMAIN

Author/ Characteristics	Transparency	Immutability	Traceability	Data Integrity	Safety	Quality Control	Tamper Proof
Kshetri *et al.*	Y	N	N	Y	N	N	Y
Rejeb *et al.*	N	N	Y	N	Y	Y	N
Demestichas et.al	Y	N	Y	N	Y	N	Y
Kamilaris *et al.*	Y	Y	N	Y	Y	Y	N

French retailer Carrefour is a member of IBM food Trust. Its milk products use QR codes to track with the help of Blockchain technology. Consumers can scan the labels, get information regarding the products, and decide to buy. The labels contain date, packaging details, cattle fed, and farm location. In addition, Blockchain technology lets stakeholder know to which country the products belong, such as France, Spain and so on.

Jing Dong is a Chinese retailer using Blockchain to track the meat supply chain and products. And it tracks goods movement from the initial stage to the final stage. Likewise, Bumble Bee adopts this technology to track sea food and its origin.

D. Blockchain in Public Sector (Land Registrations)

This section discusses the various research and industrial applications in Public Sector domainusing Blockchain Technology.

1) Research

Alketbi *et al*. [35] examined some security challenges and solutions. The authors discussed the potential characteristics that can deliver public services at a low cost. However, security challenges in IoT environments and implementations should be investigated in the future.

More precisely, Lee *et al*. [36] proposed an interesting digital identity management and authentication concept. Introduced a new service, BIDaas (Blockchain-based ID as a service) and a detailed explanation of the practical implementation of how BIDaas works for authentication and identity management. The cloud platform is used for permitted services between the two parties and various cryptographic techniques.

A slight modification in any government-related proof is that the individual must meet directly with a Higher authority. For example, Cheng *et al*. [37] Estonia has started to employ Keyless Signature Infrastructure (KSI) to safeguard all residents data. Another advantage of adopting Blockchain is that it allows you to track the owner's properties and prevents unauthorized persons from changing them. Berryhill *et al*. [38] address data management and transaction security challenges. They described two analogies: e-mail analogy for sharing integrity information and the bank analogy for a trusted third party.

Discussed many use cases, some of which are the land registry, vehicle wallet, voting and consensus mechanisms.

Hyvarinen *et al.* [39] In the financial world, the persons or local companies who had invested in different foreign companies has to pay tax to the local and foreign governments. All the stakeholders are paying twice due to the lack of information about payment. Blockchain has used one of its primary qualities to overcome this issue in order to prevent this duplicate payment. Most governments are working on bilateral taxation so investors can claim a tax refund from any country based on their profit. The main challenge is due to forged documents can cause tax returns. Provides a feasible solution for eliminating tax fraud and getting the estimated profit.

2) Industrial applications

Factom [40] documents, records and various forms of data are stored, verified, and validated using this platform. For example, in collaboration with Factom, the Land

Registry initiative, the government of Honduras has started to stores the Land ownership documents.

In order to integrate Blockchain technology into diverse industries, such as bank's regulatory client on boarding and KYC- Know Your Customer procedure, Deloitte began working with various clients around the globe. In addition, everyone involved in the banking industry may collaborate securely. This technology targets a range of citizen and government-licensed assets, including homes, cars, and patents. For example allowing each voter to cast a single ballot during elections [41] (see Table V).

TABLE V. COMPARISON OF KEY CHARACTERISTICS OF DIFFERENT APPLICATIONS IN BLOCKCHAIN IN PUBLIC SECTOR DOMAIN

Characteristics/ Authors	Transparency	Security	Identity	Authentication	Easy access	Integrity	Tamper proof	Authorize Sharing
Alketbi *et al.*	Y	Y	Y	N	Y	Y	Y	Y
Lee *et al.*	Y	Y	Y	Y	N	N	Y	Y
Cheng *et al.*	Y	Y	Y	Y	Y	Y	N	N
Berryhill *et al.*	Y	Y	N	Y	Y	N	Y	Y
Hyvarinen *et al.*	Y	Y	Y	Y	Y	N	N	N

V. RESEARCH CHALLENGES AND OPPORTUNITIES

Blockchain is considered the most popular technology used in industry and academia. This technology is decentralized where no central authority to control the network. Due to its tremendous advantages, the majority of industries are exponentially adopting Blockchain technology. Furthermore, Blockchain technology is expected to be advantageous to other businesses because it can store tamper-proof data and manage an enormous trail of documents efficiently and effectively. However, Blockchain, like other new technologies, has limitations and is unsuitable for all business models. Many issues are related to performance, scalability, privacy, interoperability, and security. Despite that, some problems need to be addressed in different domains such as healthcare, financial, and education so on.

A. Performance

Consensus mechanisms act as an essential factor in the Blockchain. The performance depends on the type of consensus selected. Most of the mechanisms are theoretically proposed but have yet to be implemented and evaluated. The performance depends on three parameters: latency, throughput, and bandwidth. The proper selection of a consensus mechanism is required, to improve the Blockchain's performance, and all mechanisms should concentrate on the above three core parameters.

B. Scalability

Technical network scalability is one of the most significant challenges in this technology, as there are different technical network scalability difficulties, particularly for public Blockchain, In the network, thousands of transactions are processed per second. However, the two largest Blockchain networks, such as Bitcoin and Ethereum, need to catch up regarding transaction performance. While the Bitcoin network can only process three to seven transactions in a second, Ethereum can process about 20 transactions per second. Since the nodes of private Blockchain networks are only intended to carry out transactions between parties that can be trusted, they are less impacted by this lack of scalability.

C. Privacy

Sensitive information can be secured using transaction addresses instead of their original addresses. Because the networked peers may use the public key to start a transaction, the blockchain may be susceptible to transaction privacy. Although it is said that a peer can remain private on the Blockchain network, current research on the Bitcoin platform has proved that a member's real identity can be revealed by linking their transaction history. Blockchain technology is particularly susceptible to data leaks since any member of the network can see the transactions and information of every public key. Therefore, the need for privacy should be established at the beginning of Blockchain applications.

D. Security

In PoW, the miners play an important role because, as fast as they mine, they can win and have the right to add a new block to the chain. But there is a challenge if most of the nodes join together to mine the number of blocks and know the nonce value. There is a possibility of a 51% attack where all the nodes join together and get control over the Blockchain, giving a chance to misuse the rights by modifying transactions. So, there is a security challenge to be resolved. Forks are also another security challenge. When there are any upgrade or new versions installed on the nodes, it might be an incompatibility issue.

E. Opportunities

Blockchain has a wide range of opportunities in both academia and industry. We have discussed only some of the areas where the blockchain can be improved.

F. Smart Contracts

Smart contracts are code fragments automatically executed whenever they trigger (some conditions are met). Therefore, smart contracts should be developed and appropriately tested because if a bug cannot be

determined during the implementation but creates a massive loss if it is executed automatically, the smart contracts should be smarter and tested properly.

G. Big Data

Big data combined with Blockchain can do better than anything an individual can do alone. Analysis and managing data can be improved by using Blockchain. As some of the characteristics of the Blockchain are distributed and secure, it could be used to store essential data, which proves that it is authentic. For example, Blockchain is used to store the students' data, where the data cannot be modified and it can be viewed and analyzed by an authorized person only.

Not only these but also in many areas such as artificial intelligence, testing and validation, improving the performance, developing smart contracts and so on.

VI. Conclusion

Nowadays, Blockchain Technology is highly acceptable and most of the companies are incorporating this technology due to its powerful Characteristics such as immutable, enhanced security, persistency, distributed ledger, transparency, and auditability. This paper, presents a detailed survey on applications and research characteristics of different domains such as Education, Health care, Food industry, and the Public sector. Furthermore, we also analyzed and listed summaries of the application characteristics of the domain, as mentioned earlier in both research and industry.

In Future work, we plan to perform an extensive survey and an in-depth investigation of consensus algorithms of these applications.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Jorika Vedika conceived and designed the study performed the literature review, wrote the first draft of the manuscript, and contributed to the analysis and interpretation of the data. Nagaratna Meddishetty provided critical feedback on the manuscript, contributed to the analysis and interpretation of the data, assisted with the preparation of the figures, and edited the draft. Both authors had approved the final version.

Acknowledgment

I would like to thank Dr. Battula Sudheer Kumar, for his advice and assistance in keeping my progress on schedule and supporting all the time.

References

[1] A. A. N. Patwary, A. Fu, S. K. Battula, R. K. Naha, S. Garg, and A. Mahanti, "FogAuthChain: A secure location-based authentication scheme in fog computing environments using blockchain," *Comput. Commun.*, vol. 162, pp. 212–224, August 2020.

[2] A. A. Patwary, R. K. Naha, S. Garg, S. K. Battula, and M. Gong, "Towards secure fog computing : A survey on trust management, privacy, authentication, threats and access control" *Electronics*, p. 1171, May 2021.

[3] H. Wang, Z. Zheng, S. Xie, H. N. Dai, and X. Chen, "Blockchain challenges and opportunities: A survey," *Int. J. Web Grid Serv.*, vol. 14, no. 4, p. 352–375, October 2018.

[4] H. T. M. Gamage, H. D. Weerasinghe, and N. G. J. Dias, "A issues," *SN Comput. Sci.*, vol. 1, no. 2, pp. 1–15, April 2020.

[5] D. D. F. Maesa and P. Mori, "Blockchain 3.0 applications survey," *J. Parallel Distrib. Comput.*, vol. 138, pp. 99–114, 2020.

[6] X. Li, P. Jiang, T. Chen, X. Luo, and Q. Wen, "A survey on the security of blockchain systems," *Futur. Gener. Comput. Syst.*, vol. 107, pp. 841–853, April 2020.

[7] A. A. Monrat, O. Schelén, and K. Andersson, "A survey of blockchain from the perspectives of applications, challenges, and opportunities," *IEEE Access*, vol. 7, pp. 117134–117151, August 2019.

[8] J. Al-Jaroodi and N. Mohamed, "Blockchain in industries: A survey," *IEEE Access*, vol. 7, pp. 36500–36515, March 2019.

[9] W. Chen, Z. Xu, S. Shi, Y. Zhao, and J. Zhao, "A survey of blockchain applications in different domains," in *Proc. 2018 International Conference on Blockchain Technology and Application*, 2018, pp. 17–21.

[10] S. Banaeian Far and S. M. H. Bamakan, "Blockchain-based reporting protocols as a collective monitoring mechanism in DAOs," *Data Sci. Manag.*, vol. 5, no. 1, pp. 11–12, March 2022.

[11] Q. H. Mahmoud, M. Lescisin, and M. AlTaei, "Research challenges and opportunities in blockchain and cryptocurrencies," *Internet Technol. Lett.*, vol. 2, no. 2, p. e93, February 2019.

[12] S. Zeadally and J. B. Abdo, "Blockchain: Trends and future opportunities," *Internet Technol. Lett.*, vol. 2, no. 6, p. e130, September 2019.

[13] M. Han, D. Wu, Z. Li, Y. Xie, J. S. He, and A. Baba, "A novel blockchain-based education records verification solution," in *SIGITE 2018 - Proc. 19th Annu. SIG Conf. Inf. Technol. Educ.*, 2018, pp. 178–183.

[14] G. Chen, B. Xu, M. Lu, and N.-S. Chen, "Exploring blockchain technology and its potential applications for education," *Smart Learn. Environ.*, vol. 5, no. 1, pp. 1–10, January 2018.

[15] M. Koch, "Coctoral colloquium series editorin," in *Proc. 15th European Conference on Computer-Supported Cooperative Work*, vol. 2, no. 2, 2017.

[16] M. Turkanović, M. Hölbl, K. Košič, M. Heričko, and A. Kamišalić, "EduCTX: A blockchain-based higher education credit platform," *IEEE Access*, vol. 6, pp. 5112–5127, January 2018.

[17] D. Lizcano, J. A. Lara, B. White, and S. Aljawarneh, "Blockchain-based approach to create a model of trust in open and ubiquitous higher education," *J. Comput. High. Educ.*, vol. 32, no. 1, pp. 109–134, February 2020.

[18] M. Sharples and J. Domingue, "The blockchain and kudos: A distributed system for educational record, reputation and reward," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 9891 LNCS, pp. 490–496, September 2016.

[19] 10 of the most promising European blockchain startups to watch | EU-Startups. [Online]. Available: https://www.eu-startups.com/2020/06/10-of-the-most-promising-european-blockchain-startups-to-watch

[20] I. Vaidian, M. Azmat, and S. Kummer, "Innovation arabia 12," *Policy on Management of Health, Safety and the Environment*, pp. 1–164, 2022.

[21] F. Vidal, F. Gouveia, and C. Soares, "Analysis of blockchain technology for higher education," in *Proc. 2019 Int. Conf. Cyber-*Enabled *Distrib. Comput. Knowl. Discov. CyberC 2019*, 2019, pp. 28–33.

[22] Meet TrueRec by SAP: Trusted Digital Credentials Powered by Blockchain | SAP News Center. [Online]. Available: https://news.sap.com/2017/07/meet-truerec-by-sap-trusted-digital-credentials-powered-by-blockchain/

[23] A. Azaria, A. Ekblaw, T. Vieira, and A. Lippman, "MedRec: Using blockchain for medical data access and permission management," in *Proc. 2016 2nd Int. Conf. Open Big Data, OBD 2016*, 2016, pp. 25–30.

[24] M. Attaran, "Blockchain technology in healthcare: Challenges and opportunities," *Int. J. Healthc. Manag.*, vol. 15, no. 1, pp. 70–83, January 2022.
[25] H. Zhao, Y. Zhang, Y. Peng, and R. Xu, "Lightweight backup and efficient recovery scheme for health blockchain keys," in *Proc. 2017 IEEE 13th Int. Symp. Auton. Decentralized Syst., ISADS 2017*, 2017, pp. 229–234.
[26] P. Zhang, J. White, D. C. Schmidt, G. Lenz, and S. T. Rosenbloom, "FHIRChain: Applying blockchain to securely and scalably share clinical data," *Comput. Struct. Biotechnol. J.*, vol. 16, pp. 267–278, July 2018.
[27] C. C. Agbo and Q. H. Mahmoud, "Comparison of blockchain frameworks for healthcare applications," *Internet Technol. Lett.*, vol. 2, no. 5, 2019.
[28] M. G. Kim, A. R. Lee, H. J. Kwon, J. W. Kim, and I. K. Kim, "Sharing Medical Questionnaries based on Blockchain," in *Proc. 2018 IEEE Int. Conf. Bioinforma. Biomed. BIBM 2018*, 2018, pp. 2767–2769.
[29] The Blockchain for Healthcare: Gem Launches Gem Health Network With Philips Blockchain Lab - Bitcoin Magazine - Bitcoin News, Articles and Expert Insights." [Online]. Available: https://bitcoinmagazine.com/business/the-blockchain-for heathcare-gem-launches-gem-health-network-with-philips-blockchain-lab-1461674938
[30] O. Williams-Grut, "Estonia is using the technology behind bitcoin to secure 1 million health records," *Bus Insid*, 2016.
[31] N. Kshetri, "Blockchain and the economics of food safety," *IT Professional*, vol. 21, no. 3, pp. 63–66, May 2019.
[32] A. Rejeb, J. G. Keogh, S. Zailani, H. Treiblmaier, and K. Rejeb, "Blockchain technology in the food industry: A review of potentials, challenges and future Research directions," *Logistics*, vol. 4, no. 4, p. 27, October 2020.
[33] K. Demestichas, N. Peppes, T. Alexakis, and E. Adamopoulou, "Blockchain in agriculture traceability systems: A review," *Appl. Sci.*, vol. 10, no. 12, 2020, https://doi.org/10.3390/app10124113
[34] A. Kamilaris, A. Fonts, and F. X. Prenafeta-Boldύ, "The rise of blockchain technology in agriculture and food supply chains," *Trends Food Sci. Technol.*, vol. 91, pp. 640–652, September 2019.
[35] A. Alketbi, Q. Nasir, and M. A. Talib, "Blockchain for government services—Use cases, security benefits and challenges," in *Proc. 2018 15th Learn. Technol. Conf. L T 2018*, 2018, pp. 112–119.
[36] J. H. Lee, "BIDaaS: Blockchain based ID as a service," *IEEE Access*, vol. 6, pp. 2274–2278, December 2017.
[37] S. Cheng, *et al.*, "Using blockchain to improve data management in the public sector," *Digit. McKinsey*, no. February 2017, pp. 1–10, 2017.
[38] J. Berryhill, T. Bourgery, and A. Hanson, "Blockchains unchained: Blockchain technology and its use in the public sector," OECD Working Papers on Public Governance, OECD Publishing, no. 28, 2018.
[39] H. Hyvärinen, M. Risius, and G. Friis, "A blockchain-based approach towards overcoming financial fraud in public sector services," *Bus. Inf. Syst. Eng.*, vol. 59, no. 6, pp. 441–456, November 2017.
[40] P. Snow, "Business processes secured by immutable audit trails on the blockchain," OECD Working Papers on Public Governance, pp. 1–38, November 2014.
[41] V. L. Lemieux, "Trusting records: Is Blockchain technology the answer?" *Rec. Manag. J.*, vol. 26, no. 2, pp. 110–139, July 2016.