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Review

Trusted Academic Transcripts on the Blockchain: A Systematic Literature Review

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Abstract: Much of the excitement around blockchain is mainly due to promising applications in the financial sector. However, many also believe in the technology's potential to disrupt non-financial sectors and applications, including supply chains, energy, e-voting, healthcare, and education. The application of blockchain within the education sector is expected to make improvements to academic transcripts, credentials, digital libraries, and student records. Research in this domain is rapidly increasing, and current reviews summarize the proposed improvements. On the other hand, the analysis undertaken has remained at a general level that lacks the depth required to cover diverging proposals that have emerged. This review focuses on the application of blockchain for academic transcripts. The aim is to find, among the proposed models, converging aspects that resolve common challenges and may lead to a universally accepted de-facto standard. Furthermore, since academic institutions will serve as oracles to the particular blockchain applications, a discussion on their trustworthiness will be outlined to explore if the proposed applications efficiently address the oracle problem. The outcome of this review highlights the need for a standardized approach built on a public blockchain to promote faster adoption and acceptance. Furthermore, oracles should be incentivized in order for the system to be sustainable, while their identities and activities should be known and identifiable.

Keywords: blockchain; oracles; academic records

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1. Introduction

In the last ten to fifteen years, the production of forged academic certificates' has become a global problem as educational qualifications have gained increasing commercial value [1]. The rising number of fake diplomas is often seen as a consequence of the crisis, where desperate people forge certificates in order to obtain job qualifications [2]. However, recent research shows that the counterfeiting of diplomas involves not only lower-tier staff but also activists, members of the Government, officials, and university candidates [3]. As a recent review has shown, transcript issuance administration and management face many adversities [4]. In its physical form, a transcript is easily to manipulate and hardly verifiable [5,6]. When digitized, transcripts are still shared with difficulty between institution's or employer platforms [7,8] while being highly exposed to security vulnerabilities. From a financial aspect, these issues can result in high costs and offer minimal rewards for those attempting to address them [9,10].

To solve this problem and to improve the burdensome and time-consuming administrative work surrounding certificates, many researchers have proposed blockchain technology to speed-up academic diploma issuance and verification [11–13]. The interest stems from the fact that, being decentralized, blockchain could quickly solve the manipulation problem and reduce resources required to store the records [14]. Its ability to improve traceability can enable fake diplomas to be spotted with ease. Thus, the use of smart contracts and automated processes could reduce the need for intermediaries. Finally, the consensus mechanism and the presence of a cryptocurrency could ensure a broad recognition of records as well as an incentive for contributions to the verification processes [15,16].

The Massachusetts Institute of Technology and the University of Nicosia were the first Universities to issue academic certificates on the Bitcoin blockchain [17,18]. Later, with the emergence of the Ethereum blockchain, other institutes such as the University of Singapore deployed their application and certificates [19,20]. As privacy and scalability limitations of public blockchains are notoriously hard to overcome, later prototypes were also developed on IBM Hyperledger, providing a permissioned chain [21,22]. Finally, institutions in China and Vietnam also proposed an ad hoc blockchain specifically deployed for academic applications [14,23]. Although all these projects are blockchain-based, their heterogeneity may prevent a common standard for academic applications from emerging. Without a standard or a homogeneous model, widespread adoption could be unlikely to happen soon [24].

On the other hand, the motivation behind the technology choice for preventing forgery of academic certificate lies in that, on the blockchain, it is possible to trace in a fast, secure, and trustless manner the origin of crypto assets and then to quickly spot fake, fraudulent, or unwanted transactions [25]. This traceability feature fueled the hypothesis that blockchain is also capable of tracing real-world assets (such as academic records) with the same degree of security, speed, and trustworthiness [26]. However, real-world assets constitute an externality to the blockchain and need to be attached by external third parties referred to as oracles [27]. Since oracles are centralized and trusted entities (e.g., universities), their roles and implications needs to be considered when developing and evaluating real-world decentralized applications. Known as "the oracle problem", the ability for oracles to upload unverified or false data to the blockchain could easily undermine the potential for blockchain's application to academic transcripts [18]. If oracles are not trusted, then the blockchain transcript will not be trusted too. Since the oracle problem is directly related to trust, it is not just a matter of addressing the problem from a technical point of view [28], and a multidisciplinary effort is required to find a solution [29].

This paper aims to determine if, among the heterogeneous models, prototypes, and proposals, there exist some common features which would be useful to blueprint a universally accepted standard. Secondly, given the oracle problem's significance within the area, this study will also highlight oracle problem-related contributions. To understand the extent of the models' heterogeneity and to address the oracle problem, this research aims to answer the following research questions:

RQ1: Are blockchain-based academic transcript applications converging to a standard?

RQ2: Is the blockchain oracle problem sufficiently and efficiently addressed within academic literature?

The methodology utilized to answer the two research questions is a Systematic Literature Review (SLR). Within the blockchain-based academic application domain, classic literature reviews [10,30–32] were useful in outlining and summarizing, in a broad sense, the potential and limitations of the technology. Those kinds of studies are appropriate in the early stage of research when resources are low and scattered [33]. A recent and exciting article by Fedorova and Skobleva [34] instead utilized a Multivocal Literature Review including also so-called "Grey Literature", (e.g., blogs, newspapers, and websites) in order to highlight the mediatic impact of blockchain applications within academic institutions worldwide. Their findings showed that although at its infancy, blockchain has already drawn a considerable amount of attention. Other articles, such as those of Alammary et al. [35], Hameed et al. [36], and Yumna et al. [4], presented systematic literature reviews. Yumna et al. [4] focused on unsolved issues and risks within the academic field. Hameed et al. [36] provide an overview of blockchain protocols proposed for academic applications. Finally, Alammary et al. [35] focused on the main benefits of implementing blockchain in academia. Systematic literature reviews tend to be chosen when a specific research question is to be answered, ensuring the results' replicability [37]. Our research aims to answer two precise research questions, of which one is focused on finding a widely accepted standard. Therefore, it requires sound analysis and accurate outcomes in order to ensure the community works in the right direction. It is then crucial to provide enough information for other authors to replicate this study for research expansion and validation. For those reasons, we opted for an SLR

The research involves the use of three scientific databases: Scopus, Web of Science, and EBSCO host. Reasons for choosing those platforms include the databases' reputation for indexing high-quality papers. Analysis undertaken in this work aims to provide a blockchain agnostic framework to efficiently address the oracle problem, and to provide a blueprint of an emerging standard for academic applications. On the one hand, the present research wishes to inform academics, students, and employers of the results heeded from this and related studies. On the other hand, developers could use the provided blueprint to create or adapt their prototype with the aim of enabling compatibility. As with other literature reviews, the outcomes are based and dependent on sample selection. Whilst we did opt for high-quality databases, there is still the chance that some relevant articles were excluded for not being indexed at the time or removed from the sample due to the excluding criteria. This paper's strengths are that first it focuses on specific real-world blockchain applications such as academic transcript and certificate issuance and verification. Second, to the best of the author's knowledge, it is the first paper that provides specific insight on the oracle problem within the context of academic blockchain-based applications. Third, it provides a blueprint for developers to build or adapt, which could help on the path to standardization and eventually mass-adoption. The article proceeds as follows. The next section introduces the background literature, while section three introduces the methodology. The fourth section of the paper outlines the results, while the fifth summarizes the findings. Section six provides a discussion as well as summarizing tables. The seventh section discusses the limitations and highlights future research directions, while the eighth concludes the paper.

2. Literature Background

Blockchain, comprised of peer-to-peer networking, proof-of-work, and cryptography, is one of the technologies proposed by a man or a group of people under the pseudonym Satoshi Nakamoto [38] to launch Bitcoin (the first proposed cryptocurrency) [39]. The system was meant to (finally) solve: (i) the double-spending problem, which allows for the owner of a currency or resource to spend currency at two different nodes simultaneously; and (ii) the problem of single points of failure. Blockchain and a consensus mechanism (briefly discussed below) provide solutions required to overcome these problems [40].

Prior to the solutions proposed by Nakamoto [38], no known application had been proposed to solve the double-spend problem in a decentralized manner. In order for the network to maintain consistency of the ledger, data are added by one node at a time (as otherwise, two different versions of the ledger would exist). Therefore, the system needed a method to decide (in a decentralized manner) which node will add data and when. Proof-of-Work (PoW) finally provided a solution to this [41]. Each node in the network will be trying to solve a computational problem, and the only way to solve the problem is to "brute-force" the answer. More specifically [42], the problem is to find a number x such that the hash of the number and the data being added to the ledger is less than d where d represents the current difficulty of the problem:

$$\{x \in \mathbb{Z} \mid Hash(x + data) < difficulty\}$$

The first node to find a number x that satisfies the above is the node that will be allowed to add data to the ledger next. There is no way to find an answer except for looping through all numbers until the problem is satisfied. Looping through all the numbers and computing the resultant hash requires time. So, the above provides: (i) a means of ensuring a "random" node is selected to add data next; and (ii) that data is added at a (rough) amount of time regulated by the difficulty value. In the case of Bitcoin this time, which is referred to as "block time" is around 10 min (whilst Ethereum for example provides a 10-s block time). This process is referred to as mining (in proof-of-work based systems) [39].

Among the underlying Bitcoin technologies, blockchain is the one that generated the most hype [43]. As can also be deduced from above, its motives were to provide immutability, transparency, and trustworthiness to the distributed ledger [44]. It was soon after realized that these characteristics were not only useful for cryptocurrencies, so an increasing number of blockchain-based applications have been developed [45]. Cheng et al. [46] describe the development of blockchain applications in three stages. The first stage mainly concerns ways to improve and simplify currency-based transactions [47]. Blockchain 2.0, on the other hand, aimed at decentralizing markets also by allowing transacting real-world assets through smart contracts and eliminating the needs of third parties [48,49]. Finally, Blockchain 3.0 is sought to disrupt entire sectors such as healthcare, education, and science [50].

In the academic administration sector, blockchain applications are still in their infancy and are mostly used to validate students' achievements or share academic certificates [10]. In this context, blockchain can provide a mechanism to ensure that certificates (including/excluding relevant information as required) can be uploaded, with guarantees that the information has not been altered. To be precise, the following can be guaranteed: (i) that the certificate or rather the information notarized to the blockchain has not been changed since its registration; (ii) that the certificate has been issued by the owner of the particular issuing wallet; and (iii) that the certificate are delivered to those who earned them. The main challenges that arise with such a solution are (i) how to verify that issuers are, who they claim to be, and (ii) that owners are those who earned the certificate. The latter can typically be resolved following a digital verification process using the wallet key.

On the other hand, ensuring the authenticity of the issuing entity is a cumbersome task. Although some solutions were proposed (e.g., disclosure of institution public key), none have been widely accepted.

Recent research by Fedorova and Skobleva [34] shows, however, that interest in this sector has spread globally, with prototypes and experiments taking place in many universities, academies, and professional schools. The most popular platforms, which are also at an advanced stage, are the following:

Blockcerts: The first blockchain application developed by the Massachusetts Institute of Technology (MIT) to store and share digital diplomas and certificates. Built-in 2016, it allowed any entity to generate digital certificates for "free" [51]. An essential feature of this application is that it is blockchain agnostic. Blockcerts is, in fact, the application built "on-top" of a blockchain and can work with Bitcoin as well as Ethereum or Hyperledger. This system's known limitations are that it does not allow for the upload of documents in bulk and has no well-developed revocation system [52].

Block.co: Developed by the University of Nicosia [17], similar to Blockcerts, it also serves as a system to upload certificates on a blockchain. The advantage of using Block.co lies mainly in its cost reduction since it allows to upload multiple documents on the blockchain that will be hashed together. Criticized by Ocheja et al. [51], this approach compromises privacy and access to the documents since the same hash points to multiple records.

BTCerts: This is an initiative of the University of Birmingham, UK, also inspired by Blockcerts. The approach proposes to solve some of the weaknesses found in the MIT solution, such as revocation. BTCert proposes identifying a revoked certificate, querying the address embedded in the digital diploma, and checking if there is a change in the previous transaction outputs using the revocation address [53].

EduCTX: It is a platform born to digitalize the European Credit Transfer and Accumulation System (ECTS). This platform is used to control and transact a native token of the ECTX as academic credits [54]. While institutions have their own EduCTX address [35], students and organizations/employers are instead users of the platform. The project was started using the open-source blockchain Ark, operating on a consortium-type network.

The advantage of using this platform lies in the multi-signature authorization process, which requires issuer and receiver approval to authorize an operation [52].

Technically speaking, applications involving real-world assets such as academic transcripts have different characteristics from those concerning cryptocurrencies [55]. Transparency to users is, of course, not guaranteed in private blockchains, which by definition denies access to non-authorized users. Immutability, on the other hand, is a peculiar feature of the Bitcoin blockchain, which unlike some other blockchain (that were altered as a result of a successful attack) has never been manipulated or modified [56]. Attacks are indeed possible given adequate resources but are highly improbable on large networks such as bitcoin [57].

Nevertheless, the main difference between a cryptocurrency transaction and a real-world one lies in the communication channel between the platform and the external world [58]. Since blockchains are blind to the real-world, information pertaining to assets such as food, stocks, natural resources, drugs, and documents need to be fed into the blockchain by trusted third parties known as oracles. Unlike blockchains, which are decentralized and trustless, oracles are centralized and trusted [59]. As centralized entities, they may be exposed to single points of failure, malfunction, or data tampering, while if endowed with their own will (via humans or artificial intelligence) they could collude with other parties to feed into the blockchain data that is untrue [60] or beneficial for their own interests. For the above-mentioned reasons, blockchain applications that rely on oracles can provide no guarantees on data's trustworthiness. Known as "the oracle problem", this issue retrieves only a few contributions in the literature [29,59,61], and some are highly skeptical [62].

While the latest research shows negative implications for the traceability of goods and natural resources [63], academic records' oracle problem is considered less impactful [64]. In a popular book, Andreas Antonopoulos, whilst discussing the oracle problem, states that for academic transcripts, since issuing institutions are trusted oracles, the information provided to the blockchain is also trusted. However, since not all academic institutions are equally trusted, it is also essential to understand how the degree of confidence endowed to academic institutions affects the oracle problem [29]. Herein, the intention is to distinguish this feature as well.

3. Materials and Methods

3.1. Source and Selection

Since the area under investigation is very specific, we opted for a Systematic Literature Review (SLR). The procedure to obtain the final sample is outlined as follows.

Kitchenham et al. [65] define a Systematic Literature Review as a "method of gathering, identifying and interpreting all available research in order to answer a specific research question". The procedure should be reproducible, allowing readers to obtain a similar set of papers and come to an analogous conclusion (unless newer papers are published) by adopting the proposed scheme. From the existing state of the art research, there is minimal work that discusses blockchain applications' trustworthiness within the academic, administrative sector. Furthermore, there seems to be heterogeneity within the proposed approaches as well as their intended purpose. In order to identify the heterogeneity and to provide insights to address the oracle problem, a specific research strategy was required.

Three scientific databases were queried: Scopus, Web of Science, and EBSCO host to gather relevant articles. Due to user interface differences, alternative search strings were required. Aware that this could result in potential bias, the authors tried multiple alternatives of keyword combinations (from those listed in Table 1) that lead, however, to a less inclusive sample. Table 1 outlines the queries and related databases.

3.2. Excluding Criteria

Even though the use of multiple databases ensures a broad inclusion of academic papers, it may also cause the inclusion of duplicates or off-topic articles. For that reason, robust excluding criteria were applied to ensure that only relevant papers were observed in the selection. First, analysis of the title and abstract was undertaken to be able to filter out clearly unrelated documents. When in doubt, the introduction was read to take a final decision. Quality was not an exclusion criterion as the databases already factor in quality selection; however, non-English articles were excluded ex-ante. The date of publication was not used to define exclusion criteria, as the subject is recent, and papers have only begun to be published over the past few years. Whilst other literature reviews were included, papers focusing purely on a theoretical approach (i.e., viewpoint or opinion) were excluded. The sample's core is mainly constituted of empirical papers on academic transcript blockchain-based applications at different stages of deployment. As per all reviews, although the strategy is meant to include all relevant articles, the authors are aware that some resources may have been unfortunately excluded. The chosen approach to address this limitation was to analyze all papers' references in the final sample to determine if any relevant related work was excluded. The retrieved articles were included in the final selection after undergoing the same exclusion criteria.

Table 1. Research String/Database.

Database	Research String
Scopus	(TITLE-ABS-KEY (blockchain) AND TITLE-ABS-KEY (university) OR TITLE-ABS-KEY (academic) OR TITLE-ABS-KEY (transcript) OR TITLE-ABS-KEY (education))
Web of Science	TOPIC: (blockchain university) OR TOPIC: (blockchain transcript) OR TOPIC: (blockchain education) OR TOPIC: (blockchain academic)
EBSCO Host (Business Source Premier)	TX blockchain transcript OR TX blockchain university OR TX blockchain education OR TX blockchain academic

3.3. Data Extraction

Data collected were required to be updated multiple times as more parameters were discovered and more papers were analyzed. The final set of parameters includes information about affiliation, the purposes of the application, and the stage of development. Due to the scarcity of data on the oracle problem, the entry was divided into (i) oracle/oracle problem and (ii) trust. The complete list of extraction variables is outlined in Table 2. The authors are aware that the different platforms (e.g., Bitcoin, Ethereum, Hyperledger) use different executable codes or smart contracts type (Bitcoin script, Smart contract, Chaincode). However, making distinctions also on this matter would have added more confusion on the subject. For that reason, we decided not to divide the sample further.

Table 2. Data extraction from items.

Data Item	Description
Title	Title of the paper
Resource Type	e.g., conference/workshop/journal
Field of Publication	Authors field of contribution
Paper Type	e.g., Theoretical/Empirical, Qualitative/Quantitative
Stage of the Prototype	The developing phase of the application described
Affiliation/Country	Affiliation/Country of authors (Only for prototypes)
Mentioned Oracle/Oracle Problem	Explicitly refer to oracles or oracle problem
Trust	If and how the paper discussed the trust issues related to blockchain
Blockchain Purpose	The aim of the application declared by the authors
Platform	e.g., Bitcoin/Ethereum/Hyperledger
Year	Publishing year
Comments	Remarks about the contributions of the paper

4. Results

The initial sample was composed of 1476 papers, of which 688 were extracted from Scopus, 307 from Web of Science and 481 from EBSCO Host. A first screening of title and abstracts reduced the sample to 120, 98, and 76, respectively. The first step aimed to remove off-topic articles, whilst a second screening was undertaken to withdraw papers that did not focus on specific blockchain applications in education. The second screening led to 56 entries after reading the introductory part and removing duplicates from each database. The sample was then reduced to 40 articles after a full-text reading, excluding those that could not provide all the data for extraction. Crossing the final sample's reference, we could identify another 18 articles that were cited as being focused on academic transcripts. After undergoing the same excluding criteria, nine items were added to the final sample, leading to 49 entries. Figure 1 summarizes the data collection process.

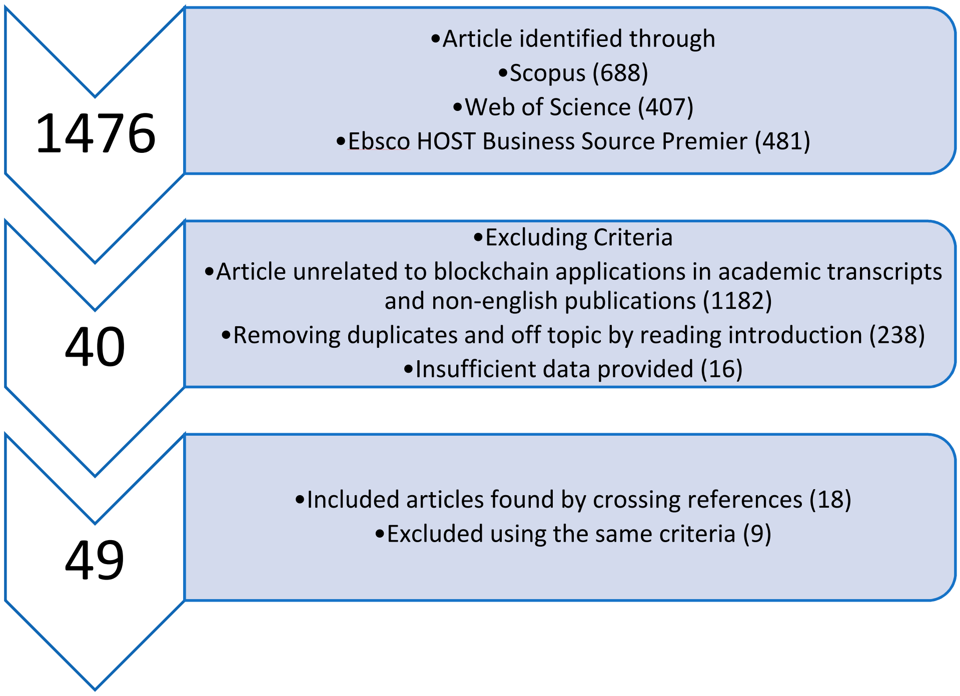


Figure 1. Literature Review Strategy.

4.1. Publication Year and Geographic Distribution

Figure 2 shows the distribution of articles ordered by year of publication. It can be seen that although no restriction was added, the timeframe is only five years (2016–2020). While one article was published in 2016, the number increases in 2017 with a further boost in 2018, which quintuple the retreived amount.

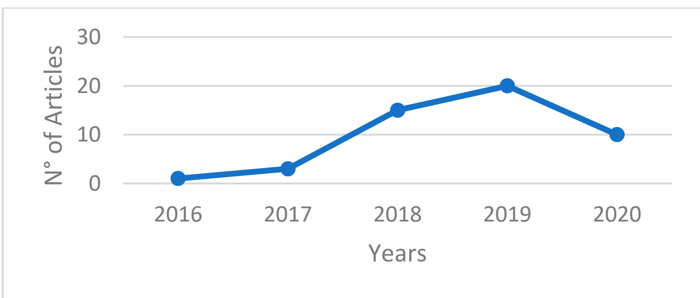


Figure 2. Publications distribution per years.

A peak is seen to be reached in 2019 with 20 articles published, while 2020 shows a slight decrease with ten items. Since the data gathering took place around October 2020 (articles were retrieved from the Scopus, WOS, and EBSCO host databases on the 30th of September, 8th of October, and 10th of October, respectively), this literature review lacks publications that had not yet been indexed and those from the last two months of 2020. Identifying whether the fewer publications imply a decrease of interest in the subject is troublesome. It must also be noted that since most of the papers are of an empirical nature and tend to be published in conferences, the COVID-19 pandemic may have interfered with tests and delayed publication processes.

Regarding geographical distribution, Figure 3 shows that publications hailed from Asia (35% n = 17), Europe (33% n = 16), North America (6% n = 3), and South America (2% n = 1). Concerning specific countries, the majority of contributions came from China (4) followed by India, Pakistan, Portugal, and the UK (3). Finally, the USA, Spain, and Portugal produced two while the others produced just one.

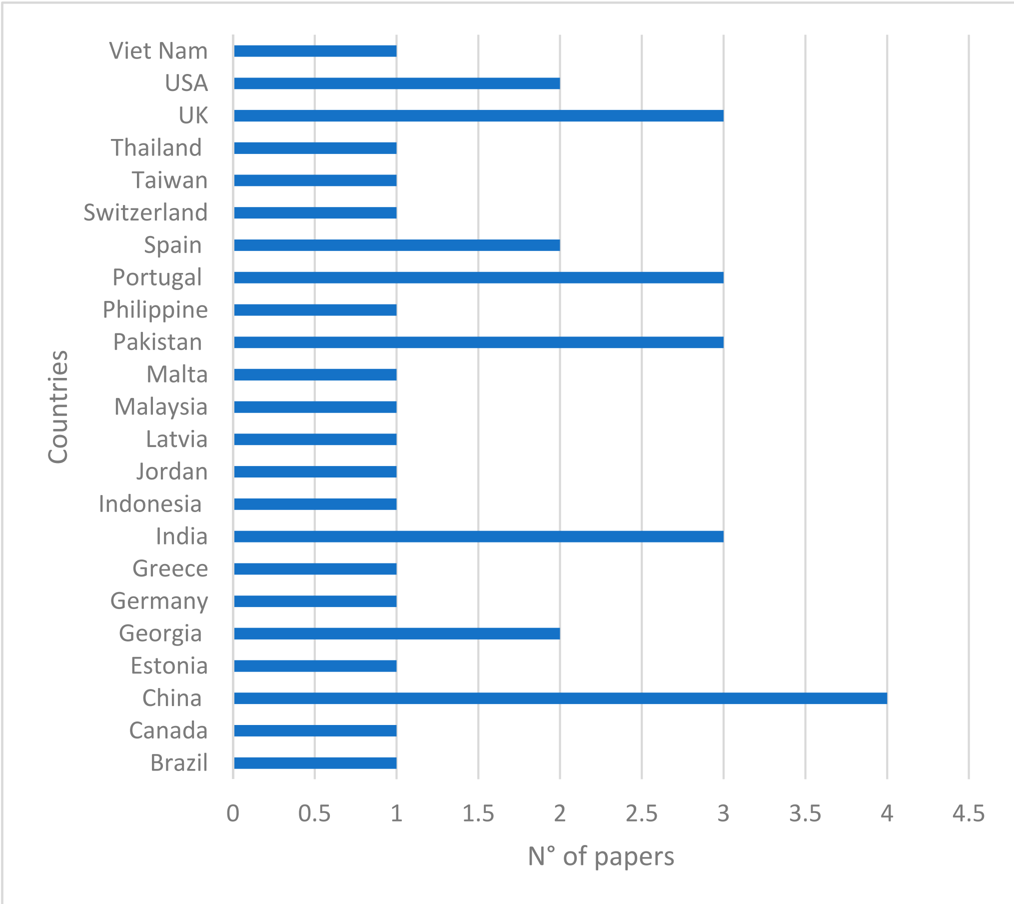


Figure 3. Author's country (prototypes).

4.2. Publication Venues and Contribution Field

Figure 4 shows the distribution by publication venues. The majority (25) were published in conference proceedings, while 19 were journal publications, and 5 were presented in workshops. Ten articles (20%) were published in Institute of Electrical and Electronic Engineers (IEEE) venues, which was the most common, and as for the topics of publication venues: Figure 5 outlines their distribution. The majority (69% n = 34) are technical venues, while the remaining comes from social sciences (31% n = 15).

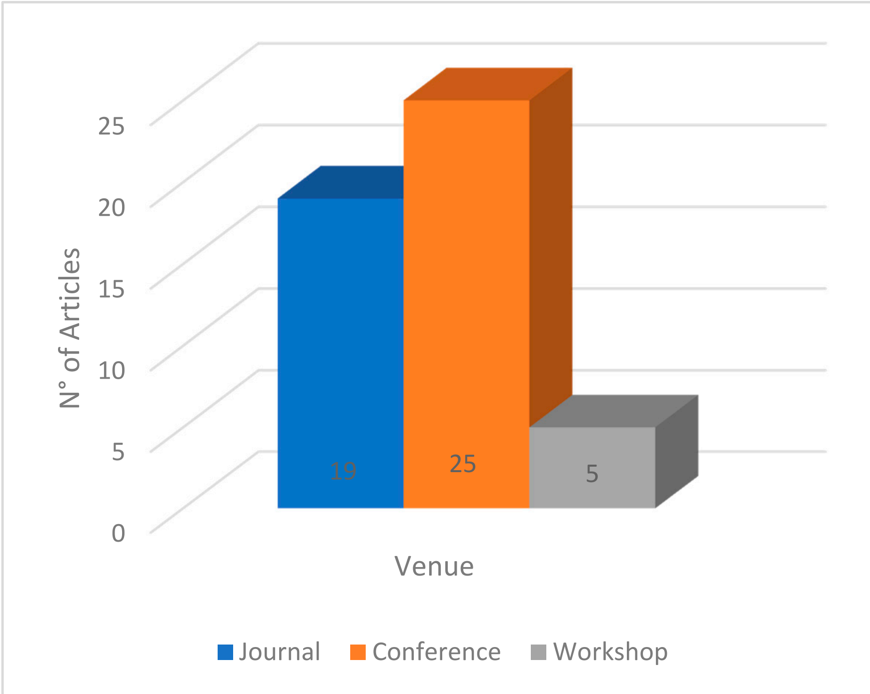


Figure 4. Venue of publication.

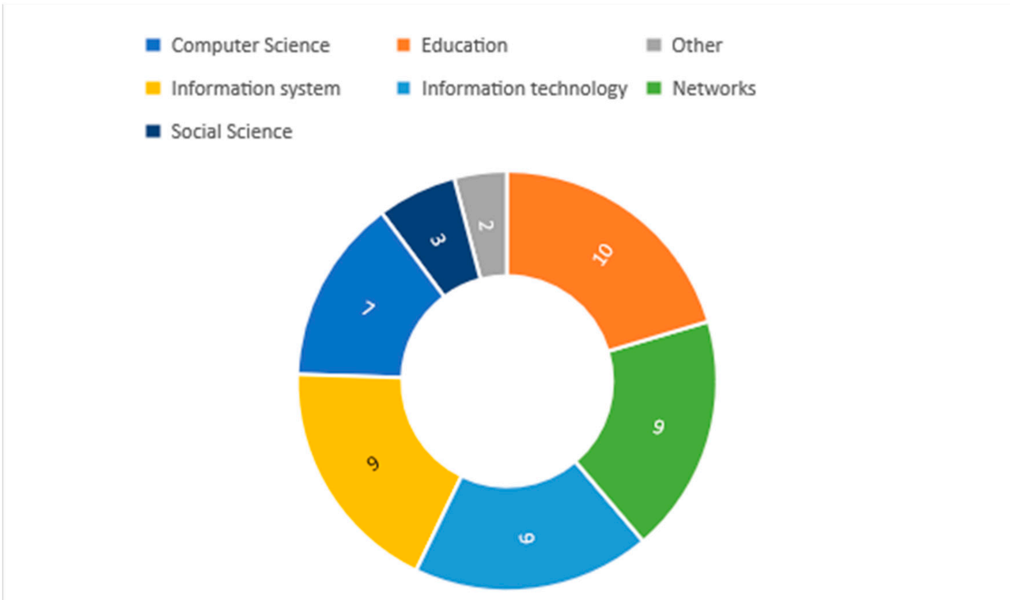
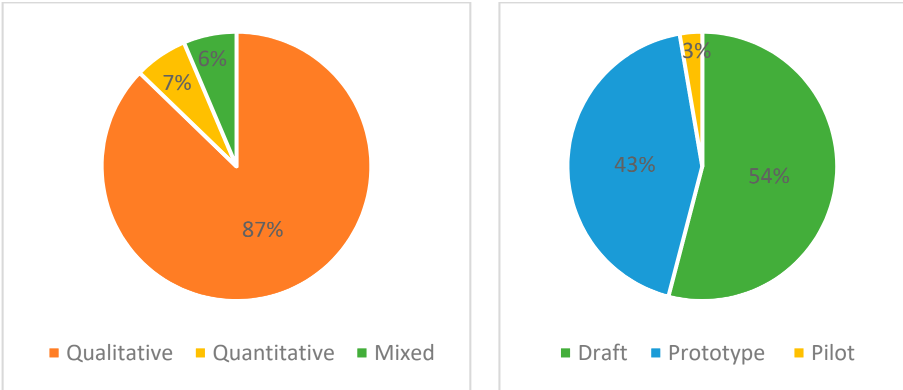


Figure 5. Subject distribution.

4.3. Contribution's Type

The papers included in this literature review are mostly empirical, but the level of development of the proposed prototypes are different. The majority of papers outline a draft prototype (54% n = 20) with some simulated data, while a considerable amount (43% n = 16), show data from real-world applications. The preferred methodology is qualitative (86% n = 41), while just three used a quantitative methodology and the other three used a mixed method. Figure 6a,b display the methodology types and prototype stages.



(a) (b)

Figure 6. Methodology and stage of research. (**a**,**b**) display the methodology types and prototype stages.

5. Contribution Overview

In order to answer our first research question, it is necessary to provide an overview of the characteristics and function of the prototypes. For the analysis to be more intuitive, the proposals will be first divided according to the selected blockchain or DLT platform and then analyzed as a group. As Table 3 shows, Ethereum was the main platform used (14 times), followed by Bitcoin (7) and Hyperledger (8). Some proposed new platforms (6) whilst a few (5) did not clearly specify the platform under which the project had been developed.

Table 3. The platform used in the prototypes.

Platform	Contributions
Bitcoin	(Bandara et al., [8]; Duan et al., [66]; Ghaffar and Hussain, [13]; Al Harthy et al., [30]; Li et al., [67]; Rahardja et al., [3]; Vidal et al., [68])
Ethereum	(Arndt, [69]; Bousaba and Anderson, [19]; Budhiraja and Rani, [70]; Cheng et al., [46]; Curmi and Inguanez, [12]; Farah et al., [71]; Gräther et al., [6]; Gresch et al., [72]; Kanan et al., [73]; Liyuan et al., [16]; Lizcano et al., [74]; Palma et al., [75]; Vargas and Soriano, [76]; Vidal et al., [52])
Hyperledger	(Aamir et al., [21]; Badr et al., [11]; Bhumichitr and Channarukul, [22]; Dinesh Kumar et al., [77]; Lam and Dongol, [78]; Liu et al., [79]; Pryia et al., [80]; Rachmat and Albarda, [81])
Other	(Arenas and Fernandez, [82]; Huynh et al., [23]; Kontzinos et al., [83]; Rasool et al., [84]; Sharples and Domingue, [18]; Wahab et al., [85]; Xu et al., [14])

5.1. Bitcoin Prototypes

Compared to Ethereum, Hyperledger, and custom blockchains, Bitcoin proposals constitute the smallest portion of the sample. According to Jirgensons and Kapenieks [17], reasons could be the high registration costs, the difficulty of deploying script code on the Bitcoin platform [86], or the limited capabilities of script code. Despite the fewer number of Bitcoin-related contributions, the more popular prototypes tend to utilize the Bitcoin blockchain [10,30]. Ocheja [51] explains that Bitcoin, being the largest network with the biggest community, is preferred because it has the highest chance of survival. Since the aim of introducing blockchain in the academic field is to make sure that records are retrievable regardless of their oldness, it makes sense to prefer the Bitcoin platform [87]. Despite the high-security standard, Duan et al. [66] underpin the idea of an additional consensus mechanism (Proof of Accreditation) to increase the trustworthiness of data uploaded on the blockchain. Less technical is the approach of Bandara et al. [8], which states that more than uploading and verifying the diploma on the blockchain, a useful solution would be to register students' courses and qualification and the course syllabus. A similar approach by Li et al. [67] would also include the students' skills attending the course. This system is sought to be more efficient for the student transfer processes when evaluating skills acquired in former institutions [88]. Ghaffar and Hussain [13] also support the idea of adding further data to the platform but with the support of an external database (ideally managed by the Government). Finally, a detailed contribution from a technical and organizational point of view is offered by Vidal et al. [68]. At Fernando Pessoa University, Blockcerts was implemented for managing academic diplomas on the blockchain. Recalling that it is open-source and blockchain agnostic [10], the system was initially built on the Bitcoin blockchain. The authors noticed that most of the issues concerning the Bitcoin platform could be overcome by adding diplomas in bulk with a "slow" transaction. On the other hand, addressing diplomas revocation, requires further investigation [52].

5.2. Ethereum Prototypes

Although trivial Bitcoin script code could be executed from 2012 on the Bitcoin blockchain thanks to the introduction of the pay-to-script-hash [89], it is only after introducing Ethereum that blockchain-based applications began to be adopted also in non-financial fields [90]. An attempt to explain in a straightforward manner how to issue a digital certificate on the Ethereum blockchain was provided in 2019 by Bousaba and Anderson [19]. The authors described the type of contract used for uploading, verifying, and updating users' data, as well as providing practical examples. The proposed features concerned the requirement of an open and public Blockchain, interoperability, accessibility, and the availability of a database to provide more data for every registered user. Similar conclusions were also highlighted by Kanan et al. [73] by interviewing academic employees and students. Data obtained was then used to build a prototype (on the Ethereum blockchain) that was meant to be open and user-friendly [6,76]. Along the same lines, Gresch et al. [72] explained how to implement smart contracts and gave an in-depth explanation of the importance of implementing a database to work alongside the blockchain [75]. In their opinion, because of the introduction of GDPR, data should not be permanently stored and available online. Therefore, while a hash could be registered on the blockchain, the database should be used to store personal users' data. A Cleveland State University study also developed two prototypes utilizing a hybrid blockchain database approach (making use of the BigChainDB NoSQL database) [69]. Although the work was in a very early stage, results show the improvement of data management and transfer thanks to the use of a peripheral database. A project that was more focused on user-experience was instead developed at the University of Taiwan. The application provided a user-friendly interface to issue and retrieve an academic diploma. Issued certificates are supplied with a QR code that, if scanned, redirects to the verification interface [46]. Focused more on a social and economic aspect, Liyuan et al. [16] proposed an equilibrium model to incentivize verifiers to cooperate with the platform and minimize the system's social costs. Although without going into details, this is the only paper that also considers social and economic aspects of academic applications.

5.3. Hyperledger Prototypes

Despite being open-source and adaptable for both public and private blockchains, Hyperledger is usually preferred for the latter [91]. Almost all the proposals and prototypes found in this study using Hyperledger share the characteristic of being permissioned. One main difference between Bitcoin and Hyperledger prototypes is the possibility to access or alter data according to the user's rights. Aiming to reduce the asymmetry between employees and academic institutions, Liu et al. [79] developed their proposal considering academic as well as employment data. Access on the Hyperledger blockchain, as also in Badr et al. [11], is restricted according to the user type. Their model, however, is more focused on transaction speed and ease of record transfer whilst also guaranteeing data integrity [80]. Rachmat and Albarda [81] also followed a similar approach, using simulated data to demonstrate the reliability of their prototype. The system also adopts a Byzantine Fault Tolerance consensus mechanism and enables a reduced number of nodes. In their research, of over 100 instances, the mean time for creating and verifying certificates was around three minutes.

Bhumichitr and Channarukul [22] offered a more comprehensive approach, which discussed the platform's content and reliability. Following Liu et al. [79] and Bandara et al. [8], the proposed system records the transcript and a student's performance on specific courses with skills acquired. Accordingly, the expected outcome would be the reduction of asymmetry between employers and academic institutions. Discussing the advantage of the implemented model, the authors confirmed the necessity of trusting humans behind the system, doubting then complete automation of the process. Finally, Dinesh Kumar et al. [77] proposed a system that appears to be more similar to ones that made use of Bitcoin (for encryption and output types), and is the only Hyperledger based system that makes use of a public ledger. Whilst it should be noted that their proposal is at a very early stage when compared to the others in the sample.

5.4. Other Prototypes

Apart from Bitcoin, Hyperledger, and Ethereum, many other proposals involve different or custom blockchain types. Since contributions for each other platform are low in numbers, they can all be summarized in this paragraph. Huynh et al. [23] propose a system based on UniCert/Unicoin, to verify the authenticity of certificates. Based on the authors' description, the platform poses similar features to Bitcoin in its use of the SHA-256 hash algorithm and a proof-of-work consensus mechanism, but apart from that, it does not display any unique characteristics. Trying to overcome the limitations of Blockcerts, Rasool et al. [84] proposed the DocsChain that aims to offer three new features to document verification. First, it allows one to upload documents in bulk over a single block; secondly, it is designed to work with hard copies and permit the receiver to accept and verify non-digital documents. For this feature to work, the system requires to use of an Internet-accessible camera to scan the certificates. Another peculiarity of this blockchain is its semi-private nature, which allows existing consortium members (the ones with specific privileges) to accept new members in the consortium. It is an essential feature for a network like the academic one that is hopefully increasing. For fast document management and retrieval, similar to Wahab et al. [85] the model makes use of a peripheral database to the blockchain. The choice of using a database, as other authors have highlighted [92], may, however, be less secure. The vulnerabilities of the chosen platform (Tangle/IOTA in this case) are then added to the database vulnerabilities, eventually increasing their number. An interesting but very early-stage proposal (having its consensus mechanism still not defined) by Kontzinos et al. [83] suggests that evaluation between students and professors should be bi-directional. That way, the rating of the professors could give more visibility to the student's skills. More complex and articulated is Xu et al.'s [14] work, which provides a complete blueprint of their platform. The proposed system is based on a permissioned chain and uses a consensus algorithm named "dynamic quorum". Inspired by zero-knowledge-proofs, similar to the Rasool et al., [84] model, it takes into account the increasing number of peers. The author states that due to the improved system stability, thanks to a modified Merkle tree (Patricia tree), it can easily handle issuance as well as revocation. Although it lacks practical cases, their experimental data shows a block time of 20 s for a block size of 200 kb. One recent and quite cited paper by Arenas and Fernandez [82] propose the credence ledger software working on Multichain. The authors' claim that the proposed system is superior to other software and platforms implemented for similar purposes. The main proposed characteristics are permissioned access on three-levels, a fast consensus mechanism, low fees, and a user-friendly app. The last discussed application is a system proposed by Sharples and Domingue [18], which implement Kudos as a currency representing academic reputation. Although little detail is provided with respect to how

Kudos are minted and distributed, this work introduces essential concepts and limitations related to blockchain, analyzed in the next paragraph.

5.5. Managing Trust and the Oracle Problem

The second research question focuses on contributions related to oracles and the oracle problem. By merely searching "oracle" and "oracle problem" strings in the text of papers collected, it seems that no research directly addressed the issue. Considering the unlikelihood of a complete neglection of the topic, we searched for contributions tackling the oracle problem by building on recent research [93]. Since the oracle problem is related to the trustworthiness of data provided to the blockchain, we searched for sentences involving the concept of trust and trustworthiness of information using computer-based text searches and, where not possible, by reading a paper in its entirety. The sample was then classified according to the recursion and pertinence. Selection criteria were the following:

In-depth: Dedicated paragraphs or the entire paper to data trustworthiness

Good: Multiple discussion on the data trustworthiness

Moderate: one or few sentences on the trust concept

Little: one or few uses of the trust concept and words

No: No discussion or reference to trust throughout the paper

As Figure 7 shows, nearly 70% of the sample dedicated little (23%) or no (47%) discussion over the trustworthiness of data on the blockchain and exclusively focused on technical aspects.

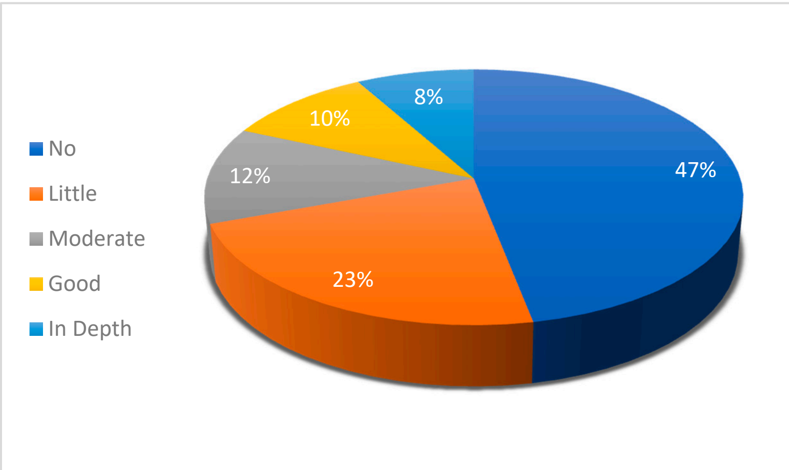


Figure 7. Consideration over the trustworthiness of data.

After full-text reading, the contribution that considered the oracle problem to a sufficient level is the paper by Sharples and Domingue [18]. Throughout the article, they specified multiple times that no guarantees are given on the data uploaded on the blockchain, also saying that "*A university could still award a bogus certificate, or a student could cheat in an exam*". Their model based on Kudos reproduces a trust mechanism such as the one used by Uber or Airbnb. Kudos should represent the reputation that students obtain by passing exams. Although the idea has fascinating roots, the paper does not give an exhaustive explanation of how this should technically function. Building on this paper, Lizcarno et al. [74] propose that the choice of awarding a skill to a student should not be completely in the hand of the instructor. Their model requires the student to solve a puzzle (test) based on the acquiring skill, and if successfully completed, Kudos are awarded; otherwise, they are lost. Kontzinos et al. [83] offered a similar approach, which proposes a bi-directional trust mechanism. Although students earn badges by passing exams, they can also evaluate the performance of the professor and the institution by deciding to issue or not a badge back to the professor. Exciting but incomplete, the presented project did not clearly specify the platform's architecture along with the consensus mechanism. On the other hand, many authors agree [46,70] that an open platform could be more adaptable for academic applications as data should be publicly auditable. Furthermore, certificate issuers should be known and identifiable. Despite being more privacy-friendly, a completely anonymous space would be more exposed to collusion [94]. Farah et al. [71] also explain that an academic blockchain application's "entire communication channel" needs to be trusted since "*It is always possible to upload spurious records on the blockchain*". In Srivastava et al. [88], the concept of a trusted environment is managed differently. Inspired by EduCTX, their approach based on Ark requires that the blockchain applications start from a trusted group of few academic entities, from which senior members can invite more peers. Information on the blockchain is then shared and recognized as valuable by all the institutions (nodes) that belong to the same trusted group. Finally, exciting research by Liyuan et al. [16] proposes an incentivization mechanism based on a Vickrey–Clarke–Groves (VCG) Nash equilibrium to ensure a trustworthy platform. Basically, the author proposes that the acquired skill verification is directly made by individuals called "verifiers" who have a defined weight score based on their age, education level, job title, and relationship with the requester. Assuming that a validation weight β is required for a skill (s) to be validated, then the amount of validator (ω) that agrees on the skill should be $\omega \geq \beta$. Although quite complete, the project does not specify the nature of reward that the verifiers receive, if it is a higher weight score or an actual payment. Furthermore, the process through which validators are chosen, and their skills verified is not specified.

6. Discussion

The breadth of research investigated and outcomes proposed herein is vast and non-trivial. The proposed blockchain applications diverge according to the issuing institution, underlying platform, and model. On the other hand, the selected material is perceived as sufficient and exhaustive to provide interesting remarks. Despite the plethora of studies proposing and experimenting with alternative blockchains, Bitcoin is still the most widespread and utilized platform for academic transcripts [51,52,68]. However, the solution to upload documents in bulk to overcome limitations related to high costs, congestions, and scalability is still debated. The most popular alternative is the Ethereum blockchain, which is moving to a proof-of-stake consensus mechanism. Unfortunately, all the studies are based on the proof-of-work consensus mechanism, and it is unclear how (and if) the change to proof-of-stake will impact academic applications [95,96]. Follow-up work should be conducted to determine any impacts on fees and congestion. Regardless of the platform type, it emerges from the selected studies that universities, students and employers, would like more than just the ability for a transcript to be notarized on a blockchain and that detailed skills should be permanently stored on the ledger [8,32]. Doing so, the amount of data to be managed would dramatically increase, raising also concerns about users' privacy. Clearly explained by Gresch et al. [72], the introduction of the GDPR makes it inconvenient to store students' records permanently online. Therefore, as well as for interoperability reasons, the implementation of a database is considered a must for academic applications [69,70]. On the other hand, the addition of a database would also increase centralization and potential vulnerabilities. Finally, a user-friendly interface that is easily utilizable by students, as well as employers or verifiers, is highly demanded [19,88]. Moreover, usage of the interface should not require any specific knowledge on blockchains to be operated. A summary of those characteristics can be found in Table 4.

Diverging views emerge on the concept of issuing authorities (nodes), whether a blockchain should be public, private, and consortium-based. Hyperledger or ad-hoc blockchain proposals mainly consider a closed system as the only one capable of guaranteeing privacy and tamper-proof certificates [11,21]. However, a closed system for the issuance of certificates clearly affects the oracles' trustworthiness and auditing process. Few but illuminating contributions to the oracle problem issue provide many insights into how a project may be more robust. Researchers agree that for the oracle to be trusted and the system to be auditable, it should run on an open and public blockchain [46,70].

A closed system requires users to rely on the good-faith of the institutions or unknown auditors. Furthermore, the communication channel between the academy and blockchain should be transparent, and the identity of human oracles known [28,98]. As a blockchain oracle, the university can surely benefit from its long-term reputation but will be able to provide less info on the student's specific skill. On the other hand, If a professor is himself a blockchain oracle, given his personal reputation and skills, he should be able to provide more detailed information on the students' performance. Furthermore, if the oracle's identity is unknown, then the transcript's data gain no more value for being on the blockchain. The oracle's reputation and skill give more value to certified talent and accomplishment [99,100]. Furthermore, providing false attestation would undoubtedly undermine the issuer's reputation, which should represent a sufficient deterrent to undertake selfish strategies. On the other hand, having identities and positions made identifiable exposes oracles to tampering, threats, and corruption. Drawing from popular platforms' feedback method (TripAdvisor, Uber, Airbnb), the receiver could also provide feedback in response to the completed course. Since trust is bi-directional, this proposal makes more sense than a one-way certificate and skill issuance process [8,22]. Although feedback should be transparent and freely accessible, restrictions should be added to ensure that only students and employers are able to write them. Lastly, as the oracle activity is risky, costly, and time-consuming, an adequate compensation scheme should accompany the application framework. Furthermore, the entire system should be economically and socially sustainable [16]. Even working and trustworthy platforms are unlikely to be implemented if their costs are higher than those of the actual ones. Characteristics of the oracle problem robust application are summarized in Table 5.

Table 4. Desired characteristics of an academic blockchain application.

Characteristics	Description	Challenges	Sources
Bitcoin-based	Perceived as the most likely to survive, it ensures the security and immutability of academic records	High costs, Congestion problem, Low Scalability Difficult Revocation	(Chen et al., [10]; Al Harthy et al., [30]; Jirgensons and Kapenieks, [17]; Ma and Fang, [87]; Ocheja et al., [51]; Vidal et al., [52])
Stores diploma and personal skills	Academic records should include students' specific skills, other than just a general certificate.	Storage constraint Privacy Concerns	(Bandara et al., [8]; Gräther et al., [6]; Bhumichitr and Channarukul, [22]; Lam and Dongol, [78]; Li et al., [67]; Liu et al., [79])
Works with a database	The database is perceived as necessary for interoperability as well as for GDPR compliance. However, it may determine security issues.	Security Concerns Centralization	(Arndt, [69]; Bousaba and Anderson, [19]; Gresch et al., [72]; Kanan et al., [73]; Wahab et al., [85]; Ghaffar and Hussain, [13])
User-friendly interface	The blockchain application interface should not require any specific competence on the technology to be accessible.	Blockchain Agnostic, Ease of use	(Bousaba and Anderson, [19]; Cheng et al., [46]; Gräther et al., [6]; Liyuan et al., [16]; Rasool et al., [84]; Srivastava et al., [88])
Multiple consensus mechanisms	Ad-hoc consensus mechanisms should be identified for adding new blocks, data to upload, and node selection.	Harmonization, consistency	(Duan et al., [67]; Rachmat and Albarda, [81]; Rasool et al., [84]; Xu et al., [14])
Social and economic sustainability	Although functioning and useful, a blockchain application will hardly be implemented if characterized by high economic and social costs	Low administrative costs Low social requirements	(Grech and Camilleri, [97]; Liyuan et al., [16]; Palma et al., [75])

Table 5. Features to address the oracle problem in academic blockchain applications.

Characteristics	Description	Challenges	Source
Public over permissioned	Data should be publicly auditable in order to be trusted	High costs Privacy concerns	(Budhiraja and Rani, [70]; Cheng et al., [46])
Identifiable Oracles	Oracles need to be known in order to be trusted. Institutional oracles are less efficient	Ensure that they are not exposed to tampering, threat, or corruption	(Farah et al., [71]; Lizcano et al., [74])
Transparent Feedback system	Oracles should be open to public feedback. On the other hand, anonymous feedback is unfavorable	Carefully select people allowed to send feedbacks.	(Kontzinos et al., [83]; Sharples and Domingue, [18])
Incentive mechanism	Oracles should receive compensation for their work. Or a fine if they fail to operate in the desired way.	How to make the system economically viable	(Liyuan et al., [16])

7. Limitations and Avenues for Further Research

Systematic literature reviews can be useful when making use of a rigorous methodology, but they also have some limitations. Results could be skewed, incomplete, or inaccurate due to: selection bias, publication bias, inaccuracy of data extraction, and misclassification [35]. Authors may be enticed to select papers that confirm their hypotheses, discarding those that do not (i.e., selection bias). To avoid this limitation, we used many keywords and retrieved articles from multiple databases to ensure our sample is as inclusive as possible. Furthermore, clear and replicable excluding criteria were described and followed [101]. To tackle publication bias, we relied on scientific databases renowned for their reputation to index papers from reputable sources. As for the paper extracted from references, the index's reputation was also checked. Aware that inaccuracy and misclassification may never be completely excluded in light of subjectivity, we tried to limit these biases by separating the tasks between the authors. That way, the data extraction was performed according to a unique line of reasoning. Nevertheless, different opinions were often discussed to reach an agreement.

This contribution aims to promote works that harmonize the procedure for registering academic transcripts on the blockchain. The findings show significant potential in this field. The shift of Ethereum from a proof-of-work to a proof of stake should also encourage researchers to undertake replication studies to see if their findings are supported with the new consensus type. In fact, it is still unclear how proof-of-stake will affect network usage, congestion, and transaction fees. Finally, ad hoc studies should be undertaken to attempt to address the oracle problem specifically within the application of blockchain-based academic certificates. Similar to the work proposed by Liyuan et al. [16], other game-theoretical studies could provide insight regarding various social and economic perspectives that could aid in solving the problem. A sample of our table is provided in Appendix A, to facilitate further research on the topic.

8. Conclusions

The aim of this study was to identify, through a systematic literature review, if among the plethora of proposed blockchain applications in the academic field, there was a potential de facto standard that could be used to blueprint a universally accepted model. Furthermore, as the oracle problem is often poorly discussed, this paper investigated the latest research that could help to mitigate the issue within the domain. Results support the view that although the proposals appear diverging, they share characteristics often requested by students and academic personnel [73,78]. Because of the importance of academic data, the application should run on a stable, secure, and trustworthy blockchain, which at the moment is typically recognized to be the Bitcoin network [51,52,68]. Accomplishments, as well as skills, should also be registered on the blockchain to be easily accessible for employers as well as other institutions. Finally, a database should accompany the application for interoperability with other systems, as well as for adherence to the latest changes posed by GDPR, which asks for non-permanent personal data on the internet. Regarding the oracle problem, the few contributions found agreed on an open and censorship-resistant blockchain for academic purposes. Furthermore, oracles' identities should be known and trusted, and available to receive non-anonymous feedback from students and employers.

On the other hand, both monetary and non-monetary incentives should be expected for the oracle service as it is challenging, risky, and time-consuming. Finally, we must say that full functioning and active prototypes are still low in numbers, making it hard to compare different blockchain applications, especially when they are at different development stages. Furthermore, the addition of these features also creates new and demanding challenges to face. The significance of this study is given by its originality. This is the first review that focused on blockchain applications for academic records. Secondly, it is the first study that outlines the contributions to the oracle problem in the academic field. Further research could implement the blueprint provided in this article and confirm the possibility of addressing the oracle problem with the above-mentioned prescriptions.

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Appendix A

Table A1. Sample of the data extraction with comments.

Author	Title	Year	Paper Type	Platform	Comments	Citations (Crossref)
Yumna H., Khan M.M., Ikram M.	Use of Blockchain in Education: A Systematic Literature Review	2019	Literature Review	-	Comprehensive analysis of opportunities and open challenges of blockchain for academic applications	9
Hameed B., Khan M.M., Noman A., Ahmad J.M., Talib R.M., Ashfaq A., Usman H., Yousaf M.	A Review of Blockchain based Educational Projects	2019	Literature Review	-	A discussion over blockchain protocols used in the academia	4
Fedorova E.P., Skobleva E.I.	Application of Blockchain Technology in Higher Education	2020	Literature Review	-	A comprehensive overview of the institutions launching blockchain projects	1
Vidal R.F., Gouveia F., Soares C.	Analysis of Blockchain Technology for Higher Education	2019	Empirical	Bitcoin Ethereum	A very clear and explanatory paper of how Blockcerts works	1
Vidal R.F., Gouveia F., Soares C.	Revocation Mechanisms for Academic Certificates Stored on a Blockchain	2020	Empirical	Bitcoin	A detailed study on Revocation Mechanisms	3

Table A1. *Cont.*

Author	Title	Year	Paper Type	Platform	Comments	Citations (Crossref)
Rachmat A.A.	Design of Distributed Academic-Record System Based on Blockchain	2019	Empirical	Hyperledger	Based on simulated data, it focuses on the timing of issuance and verification processes.	0
Liu Q.G., Yang X., Zhu H., Green G., Yin S.	Education-Industry Cooperative System Based on Blockchain	2018	Empirical	Hyperledger	Explains how the relationship between Academia and Employers can be improved with block data	15
Bhumichitr K., Channarukul S.	AcaChain: Academic Credential Attestation System using Blockchain	2020	Empirical	Hyperledger	An comparison between paper-based, computer-based, and blockchain-based attestation time.	0
Cheng J., Lee N., Chi C., Chen Y.	Blockchain and Smart Contracts for Digital Certificate	2018	Empirical	Ethereum	A blueprint for Ethereum based academic applications	20
Liu L., Han. M., Zhou Y., Parizi R., M.	E2C-Chain: A Two-Stage Incentive Education Employment and Skill Certification Blockchain	2019	Empirical	Ethereum	Adopting a VCG-Nash equilibrium, discusses the economic and social sustainability of blockhain projects.	3
Arndt T.	Towards an Implementation of Blockchain-Based Transcripts with NoSQL Databases	2019	Empirical	Ethereum	A push toward the evaluation of databases to support blockchain applications for Universities	0
Gresch J., Rodrigues B., Scheid E., Kanhere S.S., Stiller B.	The Proposal of a Blockchain-Based Architecture for Transparent Certificate Handling	2019	Empirical	Ethereum	A guideline for developing blockchain projects that also discuss the privacy and GDPR issues.	1
Wahab A., Barlas M., Mahmood W.	Zenith Certifier: A Framework to Authenticate Academic Verifications Using Tangle	2018	Empirical	Tangle	A study that supports the usefulness of other DLT technoloies in the Academia	8
Sharples M., Domingue J.	The Blockchain and Kudos: A Distributed System for Educational Record, Reputation and Reward	2016	Theoretical	Kudos	Probably the first paper that questioned the reliability of academic transcripts on the blockchain	118
Rasool S., Saleem A., Iqbal M., Dagiuklas T., Mumtaz S., Qayyum Z.	Docschain: Blockchain-Based IoT Solution for Verification of Degree Documents	2020	Empirical	Docschain	A proposal for registering physical transcripts on a consortium blockchain.	2

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