2020 International Conference on Innovation and Intelligence for Informatics, Computing and Technologies (3ICT)

Revolutionising Higher Education by Adopting Blockchain Technology in the Certification Process

Mona Alshahrani
dept. of Informatics
University of Sussex
dept. of Information Systems
Al Imam Mohammad ibn Saud Islamic University
Brighton, United Kingdom
m.alshahrani@sussex.ac.uk

Natalia Beloff
dept. of Informatics
University of Sussex
Brighton, United Kingdom
n.beloff@sussex.ac.uk

Martin White
dept. of Informatics
University of Sussex
Brighton, United Kingdom
m.white@sussex.ac.uk

***Abstract*— Distributed ledger technologies such as blockchain have recently gained prominence as one of the latest technological revolutions. Therefore, many studies are currently exploring blockchain adoption in various fields, including the higher education sector. Recently, the education sector has emerged as one of the fields in which investments for blockchain-based systems and services are desirable. However, the extant literature lacks a guiding framework for the integration of blockchain and other relevant technologies in the use of certificating systems that issue authentic and sharable student credentials. Existing credentialing systems use analogue operations to manage certificate generation. These systems are slow and unreliable and, in some cases, may raise other cultural and social issues depending on the context of the education system. Consequently, this paper presents an analysis of blockchain adoption in this field, specifically with regard to the process of generating and sharing higher education student certificates. The paper outlines the first phase of an ongoing research project by proposing a validating and sharing framework for certificates that will guarantee the authenticity of shared higher education certificates by providing high privacy and security aspects in a blockchain network. It includes the design of a blockchain-based certificating system architecture to address issues and solutions in higher education systems. Thus, deploying blockchain in the higher education sector is expected to be beneficial as it solves some existing issues with the certification process.**

Keywords — Blockchain adoption, Distributed ledger technology, Higher education institution, Certificates, Decentralised application, Universal modelling language.

I. INTRODUCTION

Blockchain technology has had a powerful impact in various fields in the last few years. Blockchain is a novel innovation that offers a new paradigm for data integrity, reliability and authenticity in the financial industry and beyond. Recently, the education sector has emerged as one of the fields in which investments for blockchain-based systems and services are desirable.

Studies [1], [2] have noted that the major motivation to deploy blockchain in various fields is that it is considered trustworthy technology that removes the centralisation barrier in transactions between network participants in various industries. In this way, blockchain eliminates the need for a central authority to store and approve network transactions. For this reason, deploying blockchain in the higher education sector is expected to be beneficial as it solves some existing issues, such as printed certificate fraud, cost of issuing certificates and time consumed to verify issued certificates [3]. However, the extant literature lacks a guiding framework for the integration of blockchain and other relevant technologies in the use of certificating systems that issue authentic and sharable student credentials.

This paper presents an overview of blockchain technologies and briefly describes the reasons for choosing one of them as a solution for higher education systems. It also proposes a designed system solution in which blockchain distributed technology emerges in the context of higher education. Finally, the paper presents a complementary modelling approach for decentralised applications (dApps) based on the universal modelling language (UML) standards, in particular, use case and sequence diagrams.

The rest of this paper is organised as follows. Section 2 provides a brief description of the blockchain revolution and discusses the benefits and challenges of blockchain. Section 3 describes the current problems faced in higher education systems and the motivations of this study. Section 4 describes the solution proposed to solve the problem presented in Section 3. Finally, Section 5 presents the conclusions of this study.

II. BACKGROUND

A. Blockchain Revolution

Blockchain can be considered a revolutionary development. It is defined as a distributed record of digital events stored across all participating computers in a linked chain [4], [5]. According to Chen et al., blockchain technology is considered the fourth industrial revolution after the invention of the steam engine, electricity and information technology, and it has been called 'the Internet of Value Exchange' [6]. Contrary to what most people believe, the use of blockchain is not limited to cryptocurrencies and finance because it also considers, but is not limited to, other applications [7], [8]. Perhaps one of the most common applications is supply chain management [2], though the authors have also considered blockchain in societal, political and other general applications and, of course, education [6], [9], [10], [11]. A classic blockchain application example, however, is bitcoin, which is not equivalent to blockchain; it is simply a blockchain-based application that has been developed [12]. Hence, one of the most important research issues that has arisen recently is the need to focus on other blockchain applications in different fields.

Chen et al. report that blockchain development followed three stages: Blockchain 1.0, 2.0 and 3.0. Blockchain 1.0, the first stage, saw the development of the digital currency known as bitcoin, the first innovation of a blockchain-based cryptocurrency application [6], [13], [14]. Bitcoin is generally regarded as a very popular application amongst the different blockchain-based technologies [15]. According to Zheng et

978-1-7281-9673-2/20/$31.00 ©2020 IEEE

al., the bitcoin capital market reached 10 billion dollars in 2016 and has gained a hugely positive reputation amongst the cryptocurrencies currently used [16]. Blockchain 2.0 saw a tendency towards expansion, with the use of blockchain extended to other financial applications such as cash transactions, stocks, bonds, loans, smart property and smart contracts. With Blockchain 3.0, the current version, more environments and areas have been developed under the blockchain infrastructure. The developers in this phase have tried to take the concept of bitcoin as a blockchain-based application and applied it in other fields [6], [13], [14].

The three main types of blockchain are public (permissionless), private (permissioned) and consortium blockchains [13], [17]. In a public blockchain, any participant can access and add to the chain, and all nodes are allowed to join the blockchain network; examples include the Bitcoin and Ethereum blockchains [18]. Private blockchain is a centralised network that is controlled by only one organisation; only a predefined list of participants can access and make transactions in the chain. Consortium blockchain is a combination of public and private blockchains; the participants operate as predefined nodes that can use and participate in the distributed consensus process [13]. Private and consortium blockchains are both considered permissioned blockchains because they are not open for use by any nodes other than invited ones.

The blockchain revolution has gained great importance in both industry and academia owing to its beneficial characteristics, which can be used in various fields. Different studies have noted that blockchain technology has four main characteristics: transparency, immutability, decentralisation and traceability [19]. Sharples et al. also note that one of the major reasons for using blockchain is its ability to offer services and transactions that are characterised by trustworthiness, anonymity, authenticity, reliability and accessibility [20]. Blockchain-based systems have high capability to store more data and share resources amongst all participants; Turkanović et al. describe such systems as flexible, secure and resilient [13]. Most features of blockchain technology are related to providing transparent and secure applications. Blockchain technology helps protect data from being tampered with and provides many other features that can solve various system problems [21].

Although blockchain-based systems provide many benefits, blockchain adoption has some challenges that need to be overcome to increase the acceptance of blockchain technology in various fields. The first challenge is the scalability of network transactions. Reyna et al. note that scalability is a major concern in using blockchain when the amount of data and the number of transactions grow very fast; for example, bitcoin transactions increase by a megabyte per block every 10 minutes [22]. In addition, according to Zhang et al., the Ethereum public blockchain defines a 'gas limit' that limits the capacity of data operations to prevent attacks from manifesting through infinite looping [23]. Various studies have argued that the main reason for adopting blockchain technology is its security characteristics. Conversely, other studies have demonstrated that security is one of the disadvantages of adopting blockchain technology [15], [24]. Privacy can be maintained in a blockchain by adopting both a private and a public key mechanism. Users can make transactions using both public and private keys and thereby avoid exposing their real identity. However, Kondor et al. [24] show that blockchain cannot assure the privacy of transactions because the balances and values included in the transactions are clearly visible to the public in every public key.

According to Gartner, in supply chain management systems, the benefits of using applications based on blockchain reside in operations such as goods traceability, tracking counterfeit items or efficient paperwork handling [25]. From this perspective, various large and powerful companies around the world have started to conduct their supply chain systems based on blockchain technology. Walmart, IBM and Nestle are examples of companies performing studies on blockchain technology to tighten their supply chain systems and thus increase their process efficiency and ensure food safety [26], [27].

B. Blockchain in the Education Sector

Turkanović et al. [13] state that different higher education institutions (HEIs) in different countries are considering the adoption of blockchain technology as an aid in designing approaches and solutions for higher education. Several of these systems and solutions have adapted the bitcoin and Ethereum blockchain-based technology. Blockchain technology has been adopted predominantly in various domains and fields because of its accessibility, auditability and distributed storage benefits [13].

In the education sector, most challenges arise because of the sensitivity of students' academic records and the complexity of management regulation [13]. All data can be recorded and shared with a network of need-to-know parties, including school administrators and prospective employers. Jirgensons et al. show that using blockchain technology may help modernise traditional academic transcripts in HEIs [28]. As noted by Sharma et al., the benefits of using blockchain in Indian education systems include reducing the amount of public spending, enriching and increasing opportunities for the employment of graduates and enlarging the collaboration between public and private sectors in the hiring process [29]. In fact, the above features of blockchain enable new and innovative applications across many fields and environments.

The recent global trend has been to adopt blockchain in different fields owing to its tremendous impact. As Masaaki Isozu, President of Sony Global Education, stated, 'Blockchain technology has the potential to impact systems in a wide variety of industries, and the educational sphere is no exception when educational data is securely stored on the blockchain and shared among permissioned users' [30]. The higher education sector is considered a promising field in which to adopt new technology because of its complicated transactions and the sensitive nature of the data to be processed. Accordingly, adopting blockchain for some vital processes, such as generating learner certificates, could greatly enhance educational outcomes.

Jirgensons et al. [28] indicate that in the United States, MIT Media Lab is the only institute that has established and developed a complete education credentialing system based on blockchain technology. The MIT team depends on the bitcoin framework instead of on Ethereum to develop the credentialing system. Seeing the bitcoin as a stronger technology than Ethereum to hold the transactions was the reason for their selection [28]. Blockcerts have been developed and are known as an open standard for creating, publishing, viewing and validating blockchain-based certificates. Many digital records are registered on the blockchain; they are cryptographically signed, tamper-proof and shareable. The goal behind innovation is that it raises the capacity of the individual's achievements and enables the sharing of official records [31].

Currently, most HEIs maintain a student's complete course records and transcripts in institute-specific, customised formats. HEI databases are designed and structured such that they can only be accessed by the given institution's staff members through a secure online system with no or very little interoperability with other systems. Educational institutions also tend to adopt specialised systems to maintain course records so they can preserve and secure the proprietary structure of the data in the database. When students apply for career opportunities in foreign countries and have to present their academic degrees and achievements in different languages and against different scoring standards, they face the challenge of having to use course records that are centralised, non-standardised and inaccessible.

C. *Digital Credentialing Systems*

Credentialing systems are HEI systems used to generate and manage student and alumni certificates, degrees and other achievements and rewards. These types of documents are necessary for university alumni to get jobs that match their degree. With the many issues currently facing university credentialing systems, digitising this process is an ideal way to solve the issues and seize some great opportunities. Existing credentialing systems use analogue operations to manage certificate generation. These systems are slow and unreliable and, in some cases, may raise other cultural and social issues depending on the context of the education system. Creating a digital infrastructure for certificate-generating systems provides an important opportunity to take advantage of many promising new technologies such as blockchain. Nevertheless, as such systems are dealing with highly sensitive data and represent an HEI's professional reputation, both need to be assured. When choosing an appropriate technology, decision makers should have a full awareness of technology design and characteristics in order to guarantee trust in the control of such an important system.

In recent months, according to Apurv [33], there has been increasing interest amongst many HEIs in using blockchain-based digital certificates. The adoption of blockchain technology can help build a certification infrastructure that enables students to control the complete record of their achievements. Thus, it would help the students to have full access to their awards and certificates even in the case where the issuing institute no longer exists [32]. Furthermore, students can share their credentials with other universities and prospective employers while being assured that they will be sharing this information with trusted parties only [33]. Although adopting blockchain technology will offer a number of opportunities to improve on currently used credentialing systems, using the technology does not offer a straightforward process to help overcome all the challenges facing credentialing.

D. *Notarisation Blockchain Use Case*

In [34], Eric W. reports that blockchain use cases have extended into different fields and domains and are no longer focused only in finance cryptocurrency. Notarisation is one example of a promising blockchain technology use case that applies blockchain. It is defined as the process of preventing any document's fraud and dishonesty, thus promising all the participants a document that is authentic and trustworthy. Notarisation is a process that authenticates documents and is usually, in most countries, an act executed by the 'notary public', who is responsible for ensuring the authenticity of the document and the signature and that the signer acted without pressure or intimidation. Moreover, notarisation helps fully apply the terms and conditions of the certified documents [35]. The immutability feature of blockchain technology prevents any edit or deletion of records; hence, it is an ideal technology to implement a notarisation process. Given that a blockchain record of a document is immutable, it implements the notarisation mechanism as proof of the authenticity of the document. Blockchain also inherits the concept of decentralised technology that does not rely on a third party who has authority and control, which further enhances the user's trust towards the documents stored on the blockchain (which is in effect the notary public).

As stated by Kirikov in [36], it is highly recommended to automate the process of verifying academic documents and digitally store proceedings of authenticated documents and signatures. In this way, we can guarantee them to be safe from future frauds and manipulations. In the context of biomedical applications, Kleinaki et al. conclude their work of a blockchain-based database query notarisation service by finding the huge benefits that could provide additional functionalities, such as developing the system to improve retrieved results over time [37].

III. Proposed Solution

This section highlights a proposed solution to overcome current problems in the field of higher education, especially in the certification process. It consists of three subsections: the proposed system framework, a high-level conceptual infrastructure and demonstrations of the system logic.

A. *Proposed System Framework*

Using blockchain technology helps eliminate the need for a third-party authority and enhances the interactions between all related participants. To overcome the abovementioned challenges and issues in the current process of handling and posting student certificates, we propose the structure and functionality of a dApp for smart certificates (DASC). As shown in Fig. 1, the system has five main actors: students, alumni, Admin, instructors and prospective employers.

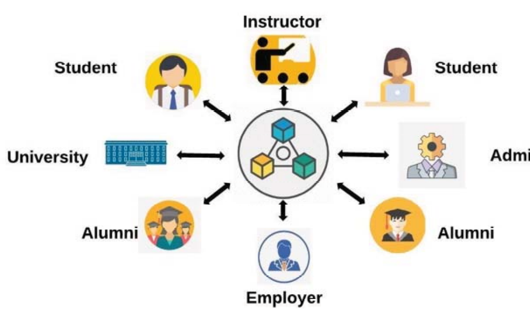

Fig. 1. Actors in the Proposed System

To achieve the research aims and goals, the DASC should provide solutions to the following questions: What are the benefits of blockchain technology in resolving the current problems faced in the higher education sector when generating learner certificates and accreditations? How can blockchain systems improve the efficiency of generating certificates in the higher education sector?

The aim of the DASC is to record student data, including registered courses, credits, skills and badges. This system should enable the sharing of student data with authorised parties (e.g. university administrators, academic staff and prospective employers). The resulting high level of transparency should help HEIs design and implement unique teaching methods for each student. The DASC should serve as a single repository of information that consolidates students' digital certificates, transcripts and achievements from different educational institutions. Thus, students will be able to keep authentic records of all their accreditations for use as a permanent e-portfolio and full record of their achievements, grades and courses. With prospective employers allowed to check the authenticity of a job candidate's transcript, accreditation fraud and dishonesty will accordingly be eliminated.

B. High-level Conceptual Infrastructure

Fig. 2 shows the DASC's high-level conceptual infrastructure, which represents the blockchain as the left dashed box (noted as **on-chain** transactions), directly connected to the front-end system and centralised database systems (**off-chain** transactions). On-chain transactions are the transactions that take place directly on the distributed ledger network, whereas off-chain transactions describe the external transactions performed outside the distributed ledger [38].

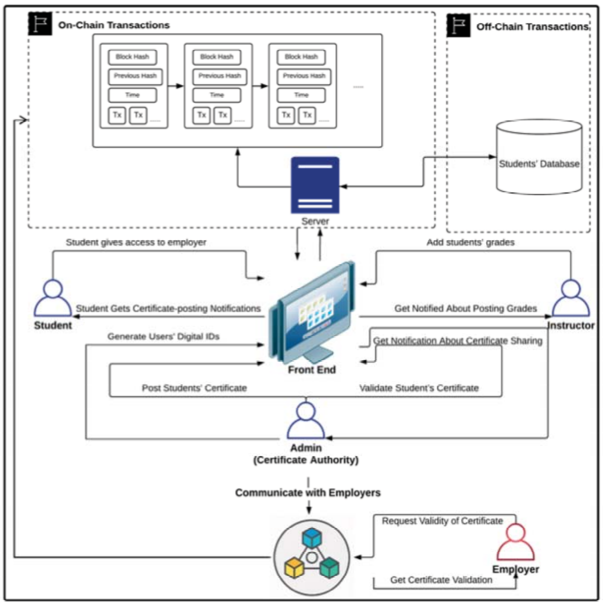

Fig. 2. High-level Conceptual Infrastructure of DASC

DASC allows students to get a single view of their credentials data with a guarantee of data integrity. Such a view can be shared with external parties with the student's permission. As represented in the conceptual infrastructure, the DASC allows direct interactions between prospective employers and front-end systems, which are controlled by system administrators giving the appropriate permissions.

C. Demonstrating the DASC Logic

A major step in developing a software application is to clarify the proposed solution's requirements, scope, limitations, exceptions and expected outcomes by using visual representations. To fulfil this aim, this section presents the logic of the proposed DASC by using UML.

UML is defined as a graphical representation for visualising, modelling and documenting object-oriented systems [39]. Using UML standards helps software engineers and developers understand the functions and data attributes of the proposed system [1]. First, use case diagrams are employed to model behavioural structure. Next, sequence diagrams are used to illustrate direct interactions between the system's participants.

- Use Case Diagram

This section focuses on the interactions between the actors and the system. Fig. 3 shows the use case diagram of the DASC that describes system behaviour. The use case diagram is a user-facing diagram that helps in the analysis of the requirements of a problem statement from the use perspective [38]. This diagram shows all the system's actors and the main functionality they can perform while using the system. For instance, students can interact with the DASC in full view of their digital portfolio, receiving updates and sharing certificates or achievements with others. The main actor in the system, Admin, has the authority to create and verify digital identities for other actors, post student certificates, verify student certificates before posting them in the portfolio and updating student grades.

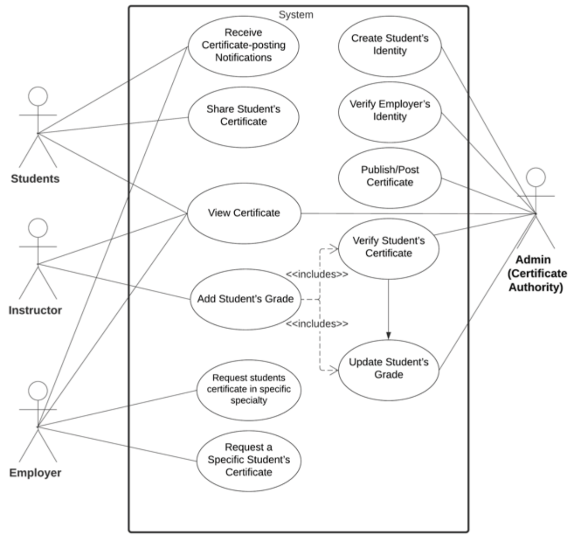

Fig. 3. DASC Use Case Diagram

- Sequence Diagrams

As noted by Ramamurthy, using sequence diagrams helps illustrate the operations and interactions between the user and different objects of the system in a timeline [38]. In the case of the DASC, the system consists of many operations that need to be illustrated in order to emphasise the interactions between the system's actors and objects. System objects include the centralised database that will be used to store the off-chain data. Data are stored off chain to reach the goal of not storing all related data on the chain. Thus, illustrating the system's main interactions with the actors should facilitate the implementation process for developers [40]. For instance, the Admin actor represents the main certificate authority in the system. For this actor, all the processes revolve around giving privileges, initiating digital identities and issuing student certificates. Figs. 4 and 5 show two main processes from DASC illustrated by sequence diagram standards.

Significantly, there are many processes in the flow of interactions which we could illustrate by using sequence diagrams. These include posting student certificates on the chain, granting access to external parties, setting user privileges and so on.

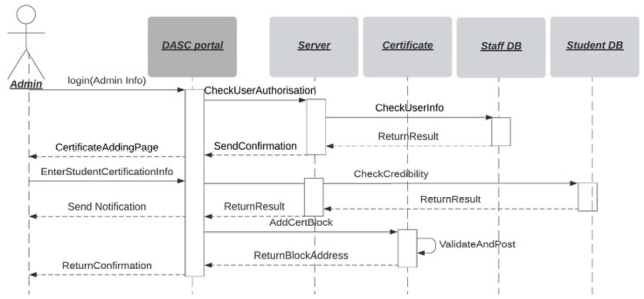

Fig. 4. Sequence Diagram to Add Student Certification

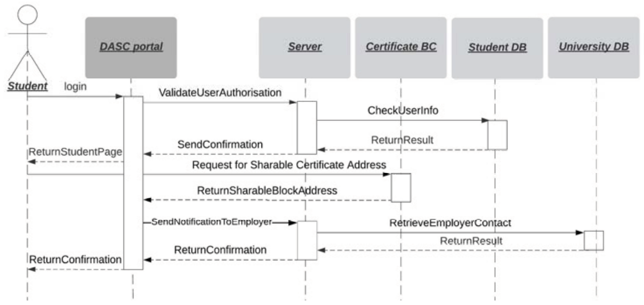

Fig. 5. Sequence Diagram to Share Student Certificate

IV. DISCUSSION AND LIMITATIONS

As we can see from previous sections, there is a gap in the existing literature with regard to research into adopting blockchain in the higher education sector. Accordingly, we were motivated to delve into this area and propose the DASC solution, which should enrich research into the adoption of blockchain technology in higher education. This paper contributes to the research through a review of the current literature about blockchain in higher education. It also highlights the differences between current certificating or credentialing systems (emphasising the issues they have) and the proposed DASC which will adopt blockchain technology. We believe this is a suitable framework because it involves all the prospective actors, processes and data storage units. It logically covers the main problems of the current system, including dishonesty and certificate fraud. Deploying blockchain provides the nature of immutability for student records, and we think this approach will resolve problems in the current credentialing process.

At this point, the design phase does not show any data storage problems that may face the system in real life because system scalability could not be explored. If the blockchain is used as a database to store student certificates, then massive numbers of records will be replicated in all chain nodes. This will be the case if, for example, the system stores all the information about the students in the chain, including student ID, name, date of birth, department, courses and badges achieved. Eventually, such a blockchain will suffer from storing and maintaining all these data for each student. This could have a detrimental effect on the expected benefits of the system.

V. FRAMEWORK FOR THE PROPOSED SYSTEM TESTING

As stated above, the current situation of generating and validating students' certificates on higher education is still a manual process that depends on hard copy certificates. The main aim of this study is to evaluate the adoption of blockchain technology in the certification process of the higher education sector. In the manner of technology adoption, we describe the process that starts with the user's awareness of the technology and ends with the user embracing the technology and taking advantage of it. We then articulate the factors affecting the adoption of the decentralised technology, especially blockchain, in the process of generating and validating students' certificates. The next step of this study is to collect the user feedback and testing result of the prototype.

Fig. 6. Blockchain Adoption Framework

The above framework in Fig. 6 illustrates the main influential factors towards adopting blockchain technology in the higher education sector that we will be testing in the coming work of this research. Mainly, it is about evaluating the certificates issuing system (i.e. DASC). It represents four main factor categories that reflect the essential requirements for the system to be adopted.

Trust: Understanding the meaning of trust involves complications as it is influenced by several quantified and non-quantified properties. In the manner of accepting and using new technology, trust plays a very important factor.

Security and Privacy: Various literature studies have argued that the main reason for embracing blockchain technology is for its security characteristic. However, multiple studies have also demonstrated that security is one of the disadvantages of adopting blockchain technology. Halpin and Piekarska state that the privacy and security of blockchain are the rich emerging fields that are critical requirements for further research [41]. In the education context, preserving the privacy of students' sensitive information plays an important role. Individuals are usually concerned about their privacy when they share some of their personal data with others [42].

Social Influence: In the blockchain field, social influence may expand to the user's perception of a service provided by the technology that is highly influenced by other fields' and domains' perceptions about adopting the technology. In [43], the unified theory of acceptance and use of technology states that social influence is one of the main four factors that affect the user's decision towards technology adoption.

Efficiency: By utilising the blockchain technology, any transaction can be efficiently completed in the decentralised environment. Therefore, it reduces overall cost and enhances transactions efficiency. Moreover, using blockchain decreases the value of transaction fees and the time required to execute the transaction [17]. Thus, we consider studying the effect of efficiency as a factor in the process of adopting blockchain in higher education.

VI. CONCLUSION AND FUTURE WORK

This paper started with an overview of blockchain technology and discussed the challenges and problems in current higher education systems. It then proposed the DASC, a solution to the abovementioned problems that uses a blockchain-based credentialing system for generating and maintaining student credentials. The paper presented the design phase as the first stage of the research. This phase includes the system's high-level conceptual infrastructure together with a demonstration of system logic (via use case and sequence diagrams). Finally, the paper represented the suggested framework for future work, which will involve implementing the proposed DASC as a proof of concept by following the models provided here. The team will also evaluate and validate the applicability of the designed solution. To validate the proposed DASC, the system should be tested according to specific criteria. We should verify how efficient the use of blockchain is as a decentralised technology in the higher education sector. Note that this is an ongoing research project, and its progress will be reported after we have completed the next phases.

REFERENCES

[1] H. Rocha and S. Ducasse, "Preliminary Steps Towards Modeling Blockchain Oriented Software," in *WETSEB 2018 - 1st International Workshop on Emerging Trends in Software Engineering for Blockchain*, 2018.

[2] M. M. Queiroz, R. Telles, and S. H. Bonilla, "Blockchain and supply chain management integration: a systematic review of the literature," *Supply Chain Manag.*, no. December, 2019.

[3] A. Curmi and F. Inguanez, "Academic Achievement Recognition and Verification Using Blockchain," 2020, pp. 153–165.

[4] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System."

[5] M. Conoscenti, D. Torino, A. Vetr, D. Torino, and J. C. De Martin, "Blockchain for the Internet of Things: a Systematic Literature Review," 2016.

[6] 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, p. 1, 2018.

[7] S. Huckle and M. White, "Fake News: A Technological Approach to Proving the Origins of Content, Using Blockchains," *Big Data*, vol. 5, no. 4, pp. 356–371, 2017.

[8] R. Bhattacharya, M. White, and N. Beloff, "A blockchain based peer-to-peer framework for exchanging leftover foreign currency," *Proc. Comput. Conf. 2017*, vol. 2018-Janua, no. July, pp. 1431–1435, 2018.

[9] S. Huckle, R. Bhattacharya, M. White, and N. Beloff, "Internet of Things, Blockchain and Shared Economy Applications," *Procedia Comput. Sci.*, vol. 58, pp. 461–466, 2016.

[10] S. Huckle, M. White, and R. Bhattacharya, "Towards a post-cash society: An application to convert fiat money into a cryptocurrency by," *First Monday*, vol. 22, no. 3, Feb. 2017.

[11] S. Huckle and M. White, "Socialism and the blockchain," *Futur. Internet*, vol. 8, no. 4, 2016.

[12] J. Golosova and A. Romanovs, "Overview of the Blockchain Technology Cases," *2018 59th Int. Sci. Conf. Inf. Technol. Manag. Sci. Riga Tech. Univ.*, pp. 1–6, 2018.

[13] M. Turkanović, M. Hölbl, and K. Košič, "EduCTX : A Blockchain-Based Higher Education Credit Platform," vol. 6, 2018.

[14] Y. Lu, "The blockchain: State-of-the-art and research challenges," *J. Ind. Inf. Integr.*, vol. 15, no. January, pp. 80–90, 2019.

[15] J. Yli-Huumo, D. Ko, S. Choi, S. Park, and K. Smolander, "Where is current research on Blockchain technology? - A systematic review," *PLoS One*, vol. 11, no. 10, pp. 1–27, 2016.

[16] H. W. Zibin Zheng, Shaoan Xie, Hong-Ning Dai, Xiangping Chen, "Blockchain Challenges and Opportunities : A Survey," *Int. J. Web Grid Serv.*, vol. 14, no. 4, pp. 1–25, 2017.

[17] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends," *Proc. - 2017 IEEE 6th Int. Congr. Big Data, BigData Congr. 2017*, pp. 557–564, 2017.

[18] J. Pitts, "Ethereum White Paper," 2018. [Online]. Available: https://github.com/ethereum/wiki/wiki/Ethereum-White-Paper. [Accessed on: 22-Jan-2020].

[19] M. Banerjee, J. Lee, and K. K. R. Choo, "A blockchain future for internet of things security: a position paper," *Digit. Commun. Networks*, vol. 4, no. 3, pp. 149–160, 2018.

[20] M. Sharples and J. Domingue, "The Blockchain and Kudos: A Distributed System for Educational Record, Reputation and Reward," vol. 9891, pp. 490–496, 2016.

[21] S. Rahmadika and K. H. Rhee, "Blockchain technology for providing an architecture model of decentralized personal health information," *Int. J. Eng. Bus. Manag.*, vol. 10, pp. 1–12, 2018.

[22] A. Reyna, C. Martín, J. Chen, E. Soler, and M. Díaz, "On blockchain and its integration with IoT. Challenges and opportunities," vol. 88, pp. 173–190, 2018.

[23] P. Zhang, D. C. Schmidt, J. White, and G. Lenz, "Blockchain Technology Use Cases in Healthcare," vol. 111, pp. 1–41, 2018.

[24] D. Kondor, M. Pósfai, I. Csabai, and G. Vattay, "Do the rich get richer? An empirical analysis of the Bitcoin transaction network," *PLoS One*, vol. 9, no. 2, 2014.

[25] K. Panetta, "The CIO's Guide to Blockchain," *Gartner*, 2018. [Online]. Available:https://www.gartner.com/smarterwithgartner/the-cios-guide-to-blockchain/. [Accessed on: 28-Mar-2019].

[26] D. Mao, F. Wang, Z. Hao, and H. Li, "Credit Evaluation System Based on Blockchain for Multiple Stakeholders in the Food Supply Chain," *Int. J. Environ. Res. Public Health*, vol. 15, no. 8, p. 1627, 2018.

[27] D. C. De Leon *et al.*, "Blockchain: properties and misconceptions," *Asia Pacific J. Innov. Entrep.*, vol. 11, no. 3, pp. 286–300, 2017.

[28] M. Jirgensons and J. Kapenieks, "Blockchain and the Future of Digital Learning Credential Assessment and Management," vol. 20, no. 1, pp. 145–156, 2018.

[29] C. Sharma, "Education In India Needs A Digitalization And Blockchain Push," pp. 1–3, 2018.

[30] ARMONK and TOKYO, "Sony and Sony Global Education Develop a New System to Manage Students' Learning Data, Built on IBM Blockchain," 2017. [Online]. Available: https://www-03.ibm.com/press/us/en/pressrelease/52970.wss. [Accessed on: 06-Dec-2018].

[31] "Blockcerts," 2019. [Online]. Available:https://www.blockcerts.org. [Accessed on: 23-Feb-2019].

[32] A. Curmi and F. Inguanez, "Blockchain based certificate verification platform," in *Lecture Notes in Business Information Processing*, 2019, vol. 339, pp. 211–216.

[33] S. Apurv, "Digital Certificates on Hyperledger Fabric," *Coinmonks*, Aug-2018.

[34] E. W, "BHD Network - Blockchain Technology Use Case for Notary Public - BHD Network." [Online]. Available: https://bhdnetwork.com/2019/07/19/blockchain-technology-use-case-for-notary-public/. [Accessed on: 11-Jul-2020].

[35] "What Is Notarization - National Notary Association | NNA." [Online]. Available: https://www.nationalnotary.org/knowledge-center/about-notaries/what-is-notarization. [Accessed on: 11-Jul-2020].

[36] K. Kirikov, "Notarization in Blockchain: Use Cases for Notary."

[37] A. S. Kleinaki, P. Mytis-Gkometh, G. Drosatos, P. S. Efraimidis, and E. Kaldoudi, "A Blockchain-Based Notarization Service for Biomedical Knowledge Retrieval," *Comput. Struct. Biotechnol. J.*, vol. 16, pp. 288–297, 2018.

[38] B. Ramamurthy, *Blockchain in Action*. Manning Publications Co, 2020.

[39] Object Management Group, "Unified Modeling Language Version 2.5," 2015.

[40] D. Torre, Y. Labiche, M. Genero, M. T. Baldassarre, and M. Elaasar, "UML diagram synthesis techniques: A systematic mapping study," in *Proceedings - International Conference on Software Engineering*, 2018, pp. 33–40.

[41] H. Halpin and M. Piekarska, "Introduction to security and privacy on the blockchain," *Proc. - 2nd IEEE Eur. Symp. Secur. Priv. Work. EuroS PW 2017*, 2017.

[42] M. J. M. Chowdhury, A. Colman, M. A. Kabir, J. Han, and P. Sarda, "Blockchain as a Notarization Service for Data Sharing with Personal Data Store," *Proc. - 17th IEEE Int. Conf. Trust. Secur. Priv. Comput. Commun. 12th IEEE Int. Conf. Big Data Sci. Eng. Trust. 2018*, no. August, pp. 1330–1335, 2018.

[43] V. Venkatesh, J. Y. L. Thong, and X. Xu, "Unified Theory of Acceptance and Use of Technology: A Synthesis and the Road Ahead," *Journal*, 2016.