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RESEARCH ARTICLE

From Rivals to Partners: Enabling Interoperability Between Relational Databases and Blockchain

Rakipten Ortaklığa: İlişkisel Veri Tabanları ve Blok Zinciri Arasında Birlikte Çalışabilirliğin Sağlanması

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ABSTRACT: Blockchain interoperability has often been discussed in the context of cross-chain protocols, cloud services, or IoT integration, but much less attention has been paid to its interaction with centralized systems. Most studies treat relational databases and blockchains as competing technologies rather than complementary ones, leaving an important gap in practice. In this paper, we introduce DECEN, a conceptual model that connects MySQL and Hyperledger Fabric, supporting transparent and systematic cross-platform data interoperability. DECEN links records across systems by generating a unique identifier with an MD5 hash. This simple connection enables information to be mapped, synchronised, verified and cross-checked between the two platforms. Therefore, blockchain is not treated as a replacement but works alongside relational databases as a complementary partner. Rather than migrating or duplicating entire datasets, we treat the blockchain as a supporting layer that can serve as an extra source of verification. Such that, it can improve reliability and trust without replacing the database. To show how this works in practice, we look at applications in higher education and use university transcripts as a case study. A prototype was developed and tested to show that the approach is technically viable, and its source code has been openly shared to encourage repeatability, validation, and further research.

Keywords: Blockchain, interoperability, relational database management systems, higher education institutions, data integration

ÖZ: Blok zinciri birlikte çalışabilirliği, genellikle çapraz zincir protokolleri, bulut hizmetleri veya Nesnelerin İnterneti (IoT) entegrasyonu bağlamında ele alınmış, ancak merkezi sistemlerle olan etkileşimi görece daha az ilgi görmüştür. Çoğu çalışma, ilişkisel veritabanları ve blok zincirini birbirine rakip teknolojiler olarak değerlendirmekte, bu da pratikte önemli bir boşluk bırakmaktadır. Bu makalede, MySQL ve Hyperledger Fabric'i birbirine bağlayan, şeffaf ve sistematik bir çapraz platform veri birlikte çalışabilirliğini destekleyen DECEN adlı kavramsal bir model sunulmaktadır. DECEN, sistemler arasındaki kayıtları MD5 hash ile oluşturulan benzersiz bir tanımlayıcı kullanarak birbirine bağlar. Bu basit bağlantı, iki platform arasında bilginin eşlenmesine, senkronize edilmesine, doğrulanmasına ve çapraz kontrolden geçirilmesine olanak tanır. Dolayısıyla blok zinciri, bir yedek olarak değil, ilişkisel veritabanlarının yanında tamamlayıcı bir ortak olarak işlev görür. Tüm veri kümelerini taşımak veya çoğaltmak yerine, blok zinciri ek bir doğrulama kaynağı olarak hizmet verebilen destekleyici bir katman olarak ele alınmaktadır. Böylece, veritabanının yerini almadan güvenilirliği ve güveni artırmak mümkün olabilmektedir. Bu yaklaşımın pratikte nasıl işlediğini göstermek için yükseköğretimdeki uygulamalara odaklanılmakta ve bir vaka çalışması olarak üniversite transkriptleri incelenmektedir. Yöntemin teknik olarak uygulanabilir olduğunu göstermek için bir prototip geliştirilmiş ve test edilmiş olup, kaynak kodu tekrarlanabilirlik, doğrulama ve ileri araştırmaları teşvik etmek amacıyla açık kaynak olarak paylaşılmıştır.

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Anahtar Kelimeler: Blok zinciri, birlikte çalışabilirlik, ilişkisel veritabanı yönetim sistemleri, yükseköğretim kurumları, veri bütünleşmesi

1. INTRODUCTION

Information technologies provide numerous benefits due to advancements and the introduction of new features. Currently, higher education institutions (HEI) are extensively employing centralized systems as an integral element of their operations. However, due to their centralized nature, these systems cause the rise of some kinds of concerns in terms of security and privacy, such as data leaks, corruption, or loss of data [1]. Currently, the data of HEIs is predominantly stored and managed via relational database management systems (RDBMS). Due to their centralized nature, these systems require a mediator to supervise and control the storage of data. The obligatory nature of trust in the mediator raises concerns regarding security, privacy, and traceability. Hence, there is a growing inclination toward the utilization of decentralized systems, blockchain, for data storage.

To address and eliminate these problems, in the realm of education at an increasing rate, as an emerging decentralized system, the blockchain is proposed by scholars to different problems of the domain [2-5]. Due to its decentralized nature, blockchain offers an alternative to the need for a trustworthy third party and ensures the immutability of stored data. It is employed in a variety of scenarios. The prominent reason is sharing educational credentials such as certificates, diplomas, and transcripts via the blockchain among higher education institutions (HEIs). By doing this, it aims to avoid fraud, and forgery besides saving time and money [6]. The main reason for this is the time-consuming nature of the validation process, which in some cases may not be possible. From a student perspective, another point of concern is that if an HEI closes in the future, all the stored data on the centralized database may disappear.

If the literature on blockchain is examined from a broader perspective, since it was introduced by Satoshi Nakamoto in 2009 [7], noteworthy advancements have emerged. In addition, if it is examined in terms of intendant use, it is seen that researchers are principally focusing on the remarkable features of the blockchain compared with centralized systems. On the other hand, it must be admitted that it is still in its early stages [4, 5, 8, 9]. Similar to centralized systems, blockchain has its limitations, issues, and cons. Hence, while centralized and decentralized systems differ structurally, each offers distinct advantages [10]. For instance, whereas centralized systems offer comparable benefits over decentralized systems in terms of higher throughput, lesser latency, and rich SQL queries or scalability features [8, 11], on the other hand, there is a possibility of data loss or modification by a central authority or being compromised, seized, or tampered with by a third party [6]. In the literature with a perspective of overcoming Blockchain's limitations, many transactional databases such as Microsoft SQL Server, MySQL, Oracle Database, etc. offer features for storing blockchain data to increase efficiency and throughput. However, we cannot limit the benefits offered by blockchain to the two different perspectives expressed above.

As a term relevant to blockchain, 'interoperability' has been used in many scenarios as an engaged research topic. From a computer science perspective, it is generally used in two different senses. The first is the interoperability of blockchain networks, and the second is the interoperability of blockchain with IoT devices or cloud-based services such as cloud storage, computing, or service integration. On the other hand, the interoperability of blockchain with a centralized system is another important point that has not received much attention. Namely, a cross-platform data interoperability model was not addressed. To overcome the limitations of the current literature, this study proposes combining the strengths of both systems. This approach emerged from the following two questions. These are:

RQ1: what are the potential benefits of data interoperability between cross-platforms, i.e., blockchain and centralized systems?

RQ2: To evaluate its benefits, it is questioned what type of conceptual model should be created and what type of features it should have.

To address the aforementioned concerns of centralized and decentralized systems, and to answer the research questions, a new conceptual model called DECEN is introduced. It aims to combine the advantages of both systems to create a mutually supportive system. Unlike the literature, the DECEN model does not employ blockchain technology to replace it with a centralized system or store blockchain records in an RDBMS. Instead, it is a novel hybrid conceptual model that migrates a copy of a relational data model of an RDMS, MySQL, to the blockchain, Hyperledger Fabric, by preserving its functional dependencies.

Although the DECEN model promises many benefits not only to higher education but also from a general perspective to computer science, its main contributions can be briefly listed as follows:

- The DECEN model establishes a theoretical connection between a centralized RDBMS, MySQL, and the blockchain, Hyperledger Fabric,
- Proposes a cross-platform data interoperability model between a centralized RDBMS, MySQL, and the blockchain, Hyperledger Fabric,
- Preserves the functional dependencies of a relational data model of an RDBMS in the blockchain, Hyperledger Fabric,
- Employs blockchain as a secondary data storage medium,
- Not required to complete the migration to the blockchain.

The model is prepared in section 3, elaborated in section 4, and its results are discussed in section 5. Finally, it is concluded in section 6.

2. LITERATURE REVIEW

In this section, the literature review is handled from two perspectives. The first is a broader review of active research topics in blockchain. And the second is a more narrowed framework that is its implementation in education.

With regard to blockchain, since its introduction by Satoshi Nakamoto in 2009 [7], noteworthy advancements have emerged. It has a shareable database – a ledger – that spreads over nodes in a network in a peer-to-peer manner. The data are stored inside sequentially chained blocks [7]. The intention to alter a block incurs huge computing and time costs. This makes it impossible to achieve mutability. Hence, it assures the immutability of the data [12, 13]. There are many public or private variants of it, and detailed reviews are available in this context [14].

Some of its prominent challenges are lower throughput, higher latency, and limited rich query or scalability options [8, 11]. In addition, some of its addressed issues and concerns are security [15], privacy [16], throughput, latency, and rich queries [11], cybersecurity [17], and scalability [18]. If examined from the domain-specific aspect (higher education), some of them lack standardization, scalability, adaptability, security, and privacy, as well as skills, awareness, expertise, support, financial barriers, and regulatory compliance [10, 19]. However, the interoperability of blockchain is one of the least focused points of the literature, although adopting it along with centralized systems can offer many benefits.

In terms of blockchain, some of the active research trends are data sharing or exchanging [12] in terms of big data, cloud storage integration [11], cloud computing integration [20], cross-chain interoperability, data interoperability, or interoperability of blockchain by microservices of IoT [21].

The term interoperability is an active research trend, and it has been dominantly used for interactions of one blockchain system or network with others [22-24]. Interoperability is an important challenge [25], and unfortunately, there is no regulation or standardization [26] for managing interoperability among blockchain networks [11]. There are reviews and surveys [27-29] that focus on the interoperability of different blockchain networks, which is called cross-chain interoperability. The present studies are applied to different domains' issues such as sharing medical records [30], supply chain [31], and microservices-oriented cloud systems for security and scalability [21]. Besides the aforementioned studies, there are others that handle the term from different aspects. Some remarkable research has investigated it in terms of semantics [29], possibility [32], or privacy

[22]. And in another distinct research [8] reviews blockchain's data storage mediums, namely ledgers and database management systems (DBMS), in terms of throughput, latency, and capability. And lastly, in [33], they have proposed a hybrid model that integrates a blockchain, Hyperledger Fabric, together with a non-relational NoSQL database, MongoDB, to increase the transaction performance of a system. This research ensures data interoperability that are stored on two different systems: a centralized database management system and a blockchain system.

Unfortunately, as it seen in the literature review, the object of interoperability is dominantly cross-chain interoperability. Although there are some studies that handle in terms of cross-platforms, it is clear that this is a subject that has not been sufficiently emphasized or studied.

If the review is narrowed to implementation of blockchain in education, two main sources of concerns are observed.

The first is the possibility of tampering or loss of data. These are criticized in different studies by scholars. For example, [34] criticized the current centralized systems in terms of e-learning courses because they may be manipulated or hacked by a third party. [35] have a similar viewpoint to online education. In addition, they point out that trusting a central authority is a drawback. Therefore, they proposed the development of trustworthy distributed data storage mechanisms.

The second source of the concerns regards traceability or validation of the generated data. In this context, some of the criticisms are as follows. In (36), the scholars highlight the absence of a globally approved academic information representation as well as decentralized record-keeping. They also point out that if an academic institution discontinues its activities, the centralized data may be lost. With a similar view [3], scholars criticize the non-traceability and ambiguities of centralized systems in terms of the fairness and trust of academic ranking systems. In the same manner, [1, 35, 37, 38] emphasize the issuing and validation concerns related to certificates and transtcripts. Finally, [39] states the challenges of digital rights management of online education platforms.

When it comes to the Blockchain, some HEIs have adopted their processes to the Blockchain [40], and some other frameworks have been developed: Blockcert [41], and EduCTX [42]. The principles of security and verifiability that blockchain offers are also being applied in other critical areas beyond education, as demonstrated by blockchain-based voting systems like VOTEMAT [43]. The basic reason for this transition is its immutability feature and distributed ledger. Collaboration among HEIs [34] preserves prevention from forgery and fraud, besides saving time and money [37, 44-46]. In addition, the introduction of smart contracts in Blockchain 3.0 allows for writing and deploying a conventional contract by a computer program without the supervision of a third party [7]. Currently, smart contracts can be deployed on some blockchain networks such as Bitcoin, Ethereum, and HyperLedger [13]. For the utilization of these features, many studies have been conducted on different problems in the field. Some of them are as follows: To address the hardships of attestation and verifications of academic credentials [46], automatization of administrative processes of education institutions [37, 47] review and ranking mechanisms of e-learning courses [34], minimization administrative costs and bureaucratic procedures [10], social inclusion or access to the education in less developed countries [9], validation of lost or falsified student documentation [4], Record keeping of academic activities, participated researches, and cultural activities 48], crowdsourcing to fund higher education students in developing countries [49], crypto credit system to getting a certificate of a student [38], fostering the United Nations (UN) Sustainable Development Goals (SDG) [50], Tokenization of successfully completed online courses, and generation of certificates from these [51], and evaluation of education [52]. For more detailed reviews [5, 53] can be examined.

However, regarding its challenges [54], it has been reviewed from many aspects by scholars such as governance [55], sustainability [56], scalability [18], security [15], privacy [16], and cybersecurity [17]. In addition, in terms of education, the literature categorizes these challenges into three categories. These are technical, organizational, and environmental barriers [10, 19]. While lack of standardization, scalability, flexibility, security, and privacy issues are evaluated as technological barriers [10, 19], lack of skills, awareness, expertise, support, and financial barriers as organizational barriers, and regulatory compliance issues such as European General Data Protection Regulation (GDPR), sustainability worries, and unreadiness are evaluated as environmental barriers [10, 19]. In terms of technological barriers, one of the most criticized points is its immutability feature. This feature may contradict some circumstances. For a legitimate reason or compliance with regulations such as the European General Data Protection Regulation (GDPR) [1, 44]. It must serve the purpose of modifying. It is criticized from the viewpoint of centralized systems. Another technological challenge is the low speed of transactions. That is a scalability challenge.

In these studies, the blockchain was employed to store data as an alternative to centralized systems. In some studies, different methods have been proposed by scholars regarding the storage of data in different ways. Namely, it is the least studied subject in the field. Some of them are as follows: [57], the researchers employed the InterPlanetary File System (IPFS) for storing data instead of centralized systems. They deployed a smart contract to store the hash values of the data on the blockchain. In [38], scholars store only the scores of courses taken in the blockchain. The rest of the data is stored in a centralized database. They employ a smart contract to issue a certificate if a student reaches a predefined score. Finally, in [51], scholars store the credentials of students in a CSV file. With the completion of a course, it is converted to a token, and the tokenized credits are transferred to the student’s blockchain wallet.

3. PRELIMINARIES

3.1 Developing Environment and Implementation Details

To illustrate the stated operations in the following section, a development environment was prepared: Ubuntu 22.04.2 LTS, Hyperledger Fabric v2.5 [58], Go1.20 [59], MySQL 8.0.35 [60]. CouchDB was preferred as a world-state DB on the Hyperledger Fabric. This is because it supports rich queries.

A new smart contract was developed and deployed to the Hyperledger Fabric test network to perform the operations.

A manual approach was preferred during development. Therefore, the command prompt bash was used to carry out all the aforementioned operations between the user and the platforms, as well as between the Hyperledger Fabric and the MySQL platforms.

To implement the conceptual model as a case study, a Fenerbahçe University transcript was selected. For security reasons, the conceptual model does not depict the exact relationships between the entities. The model can be implemented with different numbers and types of relations, such as one-to-one, one-to-many and many-to-many.

3.2 Dataset

In the implementation, a dataset was created for testing. It comprises three relations, tables, and 127 records. For the sake of privacy, it is constructed from synthetic values.

To simulate interactions between MySQL and Hyperledger Fabric, the dataset was shared as an SQL script file named 'MySQL_Queries', which the reader can use to create a database consisting of three relations from scratch, as illustrated in Figure 1. The relevant file is included in the “DECEN/construct a MySQL database” subfolder that was shared on GitHub [61]. This allows the operations referred to in the following section to be performed. Additionally, the developed smart contract contains one student's records, which are used during the initialization of the model.

3.3 Assumptions

In the study, a hash algorithm, MD5 (RFC 1321), was used to generate a unique identifier with the assumption that a hash algorithm does not generate the same outputs for different inputs.

3.4 Source Codes

For academic integrity, the source codes of the developed smart contract and the dataset are shared publicly on the Git Hub via [61]. The developed smart contract also contains samples of transactions. Using the shared dataset and smart contract developed for the DECEN model, the model can be simulated.

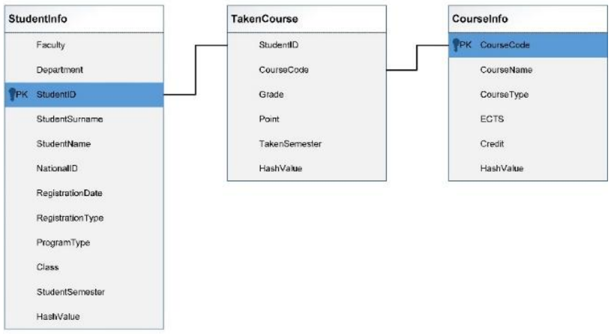

Figure 1: UML diagram of the relational data model.

4. THE PROPOSED DECEN MODEL

As seen in the literature review, blockchain has been proposed as an alternative data storage medium, although it has some issues and concerns. On the other hand, centralized systems also have concerns and challenges. In this context, this paper proposes a novel distinct conceptual model, DECEN, from the literature that employs centralized systems together with blockchain instead of employing each one separately as an alternative to another.

To imitate a decentralized and centralized system, Hyperledger Fabric and MySQL were preferred.

To employ centralized and decentralized systems together (see Figure 2), the model should provide a tool to associate records of both systems. We named the conceptual model DECEN, which is an abbreviation for decentralization and centralization. If a theoretical connection can be established, the following operations can be performed: (1) Records of an RDBMS can be mapped to a blockchain network. Thus, records of an RDBMS can be transferred to a blockchain network, (2) records of both systems can be matched, (3) synchronization can be ensured, (4) verification of records of a centralized and a decentralized system can be performed, and (5) cross-validation between the two systems can be ensured.

To establish a link between the two systems, a unique identifier was used. This is a generated hash value. To generate it, the MD5 hash algorithm was employed. The MD5 hash algorithm (RFC 1321) is based on a specific assumption. That is, a hash algorithm does not generate the same output for different inputs. The algorithm takes input and produces a unique, fixed-length string of 32 characters (CouchDB recommends using a UUID, or Universal Unique Identifier).

With the generated hash value, a record - tuple - of a relation - table - of a relational model could be matched with a record stored in NoSQL (Namely Hyperledger Fabric CouchDB). This means mapping from a relational model to a schema-free data model. Therefore, mapping a relational data model to a NoSQL-based data model is a challenging operation. If we have managed to match the records of both systems, then mapping, synchronization, verification, and cross-validation can be performed.

To establish the connection, a relational model of an RDBMS is modified, if did not. In this method, to modify relations, a new attribute (a Hash) is included in each relation. It stores a generated hash value from the values of the attributes of the relevant record, except a Hash. We will explain this in detail in the following paragraphs. For now, let us focus on the modification.

To modify relations, let us assume R is a set of four relations, and each relation may contain a different number of attributes: $R=\{R_1,R_2,R_3,R_4\}$. For each element ($\llbracket \forall R \rrbracket_x \in R$) of this set, include a new attribute ($R_x \leftarrow R_x \cup a\_Hash$).

Following the modification of the relational model, we can now generate the hash value (see Figure 2). To elaborate on this, let's assume a relation ($R_1 \in R$) except a_Hash is a m x n table in an RDBMS in which m corresponds to tuples $\llbracket T= \{t\} \rrbracket_x: x=1,2,\dots,m\}$ (records) and n to attributes $\llbracket A= \{a\} \rrbracket_x: x=1,2,\dots,n\}$ (columns).

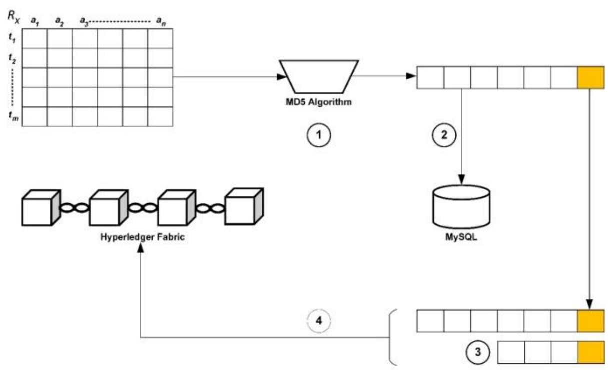

Figure 2: Conceptual framework of the proposed model.

Table 1: Generation of a hash value.

Step	Operation
1	For ∀t ∈ T do
2	values ← Get values of attributes except a_{Hash} : { a − a_{Hash}}
3	string ← Convert to String(values)
4	hash_value ← MD5(string)
5	a_{Hash} ← hash_value

To generate a hash value for a record (t_x 〚∈R〛_1) of a relation (see Table 1), the values of the attribute are concatenated as a string by separation with commas. Then, it is passed as an argument to the hash algorithm MD5, and a unique hash value is obtained. Finally, it is placed into the corresponding field in the relation - 〚a〛Hash.

Then, to map a record of the RDBMS to the blockchain, the generated hash value - 〚a〛Hash- is utilized to generate a new record on the blockchain. As it is known, the CouchDB stores records in key-value pairs. So the generated hash value (〚a〛Hash) serves as the key, namely the Universal Unique Identifier. The rest of a tuple t (a-a_Hash) is stored as a value. So mapping of records is performed as seen in Table 2.

Up to now, the modification of the RDBMS and mapping of its records to the Blockchain has been illustrated. But these are not enough. So to maintain the functional dependencies of relations of RDBMS in the Blockchain, a separate record is created to serve this task as well as mapping records. This also enables interrelated records to be brought together without the need for an RDBMS. It is meta-data. In the case scenario of the transcript, the meta-data ensures that constitutes a transcript. In other words, it acts as a linker and allows fetching relevant data.

Table 2: Mapping records of a relation of an RDBMS to the Hyperledger Fabric.

Step	Operation
1	For ∀t ∈ T do
2	if a_{Hash} is not exist in Hyperledger Fabric Couch
3	key ← a_{Hash}
4	value ← { a − a_{Hash}}
5	CouchDB ← (key, value)

In the case study, meta-data consists of four fields: the owner of the record (HEI), the student ID, the relation name (Name of Relation of RDBMS) and the generated hash value. A composite key was created from these fields as its key. The generation of meta-data is performed as shown in Table 3.

Table 3: Generation of meta-data of records.

Step	Operation
1	For ∀t ∈ T do
2	value ← {owner, studentID, relationName, a_{Hash}}
3	key ← Generate Composite Key
4	CouchDB ← (key, value)

The deployed smart contract obtains data in two ways. These are: (1) if the hash value for the record is known, or (2) with the record's owner (HEI) and student number information. Additionally, the institution (the data owner) can access all hash values and the associated metadata. Consequently, students can access the transcript using their institution name and student number. However, they cannot view the transcript's hash values. The smart contract gathers relevant hash codes using metadata and generates a transcript. Therefore, only authorized institutions can access hash codes. Finally, students who know the hash values can access their records directly.

The sequence diagram for constituting a transcript based on the records is illustrated in Figure 3.

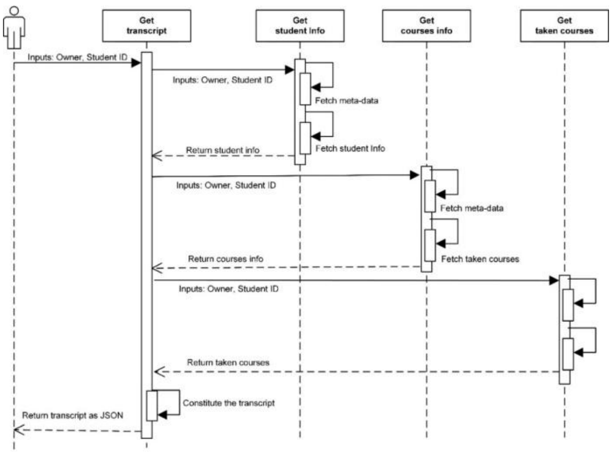

Figure 3: Constituting a transcript by the deployed smart contract.

5. RESULTS AND DISCUSSION

Depending on technological advancements in blockchain and whether it reaches a level of competency comparable to that of RDBMS in terms of scalability, low latency and high throughput, and whether regulatory standardization is in place, a complete transition from centralized systems to blockchain or decentralized systems may occur in the future. Currently, however, most cases have a centralized design. A review of the literature reveals that many studies view blockchain as a rival or an alternative. In a few other studies, researchers have sought to integrate blockchain with the InterPlanetary File System (IPFS) or cloud storage in order to increase scalability or to store data in CSV files or another NoSQL database in order to increase efficiency.

However, if data stored in an RDBMS can also be stored in the blockchain, this can provide different benefits with a unique perspective. This study proposes a distinct hybrid conceptual model that combines centralized and decentralized systems. It also evaluates the theoretical implications based on practical implementation. The main goal is therefore to overcome the limitations stated in the literature by exploiting the strengths of both systems and establishing a cross-platform data interoperability framework. Therefore, it is not recommended to migrate to the blockchain or vice versa, as this brings blockchain features to centralized systems.

To achieve this goal, the main objective is to employ the blockchain as a secondary data storage medium by preserving the functional dependencies of the relations of a relational data model of an RDBMS in the blockchain. To establish a foundation for this objective, a theoretical connection was defined between the two platforms. This connection was created by utilizing a common unique identifier generated with the MD5 hash algorithm. In practice, both systems share this hash value, which allows them to be linked and coordinated.

This requires the RDBMS to be modified to include a new attribute. To achieve this, the RDBMS relations were modified to store this value. Specifically, a new attribute (a_Hash) was added to each relation of the relational data model.

Whereas a relation's record's hash value was used as a key in the blockchain, the rest of the attributes were used as a value. Therefore, RDBMS records can be transferred to the blockchain in key and value pairs. However, this is not the sole condition for maintaining a relational data model in the blockchain. In addition, functional dependencies can be managed and preserved in the blockchain by creating new metadata for each record and employing a smart contract. RDBMS records can be transferred to the blockchain either when it is created or at a later date, by invoking a transaction.

In this regard, the model ensures the following features: (1) Mapping: Records of an RDBMS can be mapped to the blockchain network. Thus, records of an RDBMS can be transferred to a blockchain network. (2) Matching: Records of both systems can be matched based on the common hash value. (3) Synchronization: By establishing a control mechanism among both systems, records can be synchronized. (4) Verification: A hash value can be used to verify a record in an RDBMS or blockchain. (5) Cross-validation: Records of both systems can be used for cross-validation. If cross-validation is required, the institution can acquire the hash values. These can then be cross-validated against records in the institution's relational database.

The stated features were illustrated within the development environment by deploying a new smart contract to the Hyperledger Fabric test network. The smart contract can perform the following three tasks: (1) mapping a new record to the blockchain; (2) fetching student or HEI records from the blockchain for matching, verification or cross-validation; and (3) creating a student transcript from records.

We can compare the current methods with the proposed model based on the state-of-the-art (SOTA) approach in Table 4. The table assesses current systems under the title centralized systems, and in the same way, the blockchain is decentralized. and compares these two with the proposed DECEN model.

The first point to note in the table is that there is no globally accepted data-sharing schema among HEIs via centralized systems. However, blockchain and the DECEN model can be used. This is one of the core reasons why blockchain is being proposed. Its decentralized nature increases accessibility to data. Another point to mention is the lack of data mapping to facilitate data migration between the two platforms; DECEN, however, has this feature. Therefore, except for the DECEN model, there is no mechanism for data validation between the two platforms, centralized and decentralized. Cross-validation is an important feature because having a copy of the data allows it to be validated across both systems. This prevents the data owner from making modifications and increases the system's reliability and security.

The architecture of relational data models and the DECEN model prevent data repetition, but this is not available in the blockchain. Therefore, the same data can be recorded in the chain more than once. For example, in blockchain, students may receive the same grade from a common course and this incurs duplicated data, whereas in DECEN, this would be prevented by hash value checking its existence. As a result, only one entry is created for this case. This prevents data repetition.

Another major weakness of a centralized system is the possibility of losing data for many reasons, such as failure, collapse, attacks, or if the owner of the data institution is going to close in the future. This is another core point that the literature proposes the blockchain as an alternative. DECEN also has this feature but handles the problem differently.

It introduces the blockchain as a secondary data source, and the data remains in the centralized system too. As a result, the blockchain and DECEN are more resistant to collapsing or crashing systems. With this, another important point related to the modifying or tampering risk of data of the centralized systems. In this regard, whereas centralized systems may have the prospect of losing data integrity, the blockchain and DECEN methods are inherently resistant to this.

In addition to the stated features in the table, some other features are as follows: A well-known drawback of blockchain is that it has an inverse relationship between transaction amount and performance. Keeping both systems means that not all transaction loads need to be transferred to the blockchain. For example, a document can be acquired from a centralized system and validated by the blockchain. Therefore, if the transaction load is not entirely transferred to the blockchain, it would contribute to throughput and latency.

Table 4: DECEN versus state-of-the-art methods.

	Centralized Systems	Blockchain	DECEN
Data sharing between institutions	Is not present	Possible	Possible
Mapping of data	Is not present	Is not present	Present
Data validation	Is not present	Is not present	Present
Data repetition	Prevents	Possible	Prevents
Data modifying	Possible	Immutable	Immutable
Data tampering	Possible	Immutable	Immutable
Data Integrity Risks	Possible	Resistant	Resistant
Data traceability	May not, if tampered	Possible	Possible
Loss of data	Possible	Immutable	Immutable
Collapsing or crashing of the system	Possible	Resistant	Resistant

For regulatory reasons, whereas centralized systems provide for modification and blockchain does not, if data needs to be modified, in the DECEN model, a new record can be included to replace it with the older one. This would preserve older data and ensure data traceability. By improving the proposed model, this might be made practicable. Finally, in the DECEN model, because the data is stored in a fragmented form in the blockchain, a student's data can only be obtained holistically by combining it with a smart contract. This would contribute to privacy.

The proposed model can alleviate or eliminate the stated current concerns and issues of the higher education domain. This would have a significant impact on issues related to the issuing of documents by higher education institutions.

After comparing the DECEN model with the state-of-the-art methods in Table 4, its features can now be assessed in terms of the four roles stated in this study for the higher education transcript issuing case (see Fig 4). These are (1) students, (2) the owner of data (the HEI), (3) the authorized organization for auditing, and (4) other HEIs that participate in the DECEN model.

However, as stated in the following subsection, before we can delve into the details, it should be noted that the developed smart contract does not have an access control mechanism for the different roles. Therefore, although it is able to perform each operation shown in Fig. 4, this should be included in further studies.

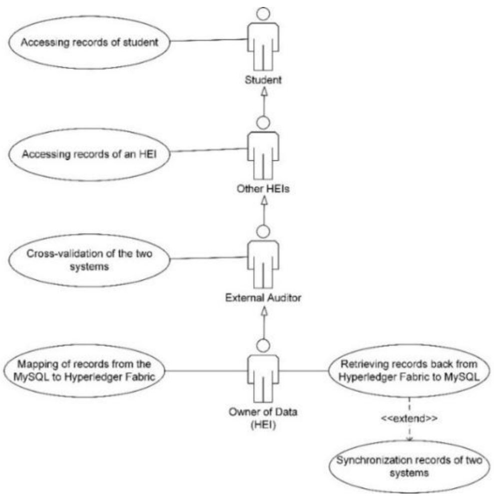

Figure 4: Use case diagram of the proposed model for the four defined user roles.

From the student's perspective, the following operations can be performed: A student can access an issued transcript or use it to prove the validity of a printed hard copy document. Moreover, if a relevant institution for a student closes because of records residing in the blockchain, there are no concerns about accessing data.

In addition to the powers of a student role, another HEI can access all created records of the data owner. Additionally, in design, if an auditor has, it can perform a cross-validation except from having rights of other HEIs. This means that the auditor has the right to access the centralized system of an HEI and can compare records in the blockchain with those in the institution's centralized system.

Finally, the owner of the created data has all rights assigned as explained before and can create new records on its own. In addition, it can perform mapping of records from the source centralized system MySQL to the destination blockchain, Hyperledger Fabric, for duplication of data that is stored in the centralized system to be stored in the decentralized system. In case of centralized system collapses or is damaged, it can retrieve data from the blockchain as well. In other words, mapping from the source blockchain to the destination centralized system, MySQL, is possible. These can also be used for synchronization or cross-validation between the two systems.

The first point regarding limitations is the objective of the study. The focus of this study is the feasibility of the proposed model. Therefore, the applicability of the proposed model was tested using a developed prototype. Hence, the performance or throughput test was not executed.

The second limitation concerns how the connection between platforms was managed. The connection between the two systems was simulated using a manual approach. All interactions with the blockchain, Hyperledger Fabric, and MySQL were performed using the Ubuntu command line interface; bash and Fabric Application APIs were not used.

The third limitation concerns access control mechanisms. No access control mechanism was established using public– private key pairs, and no app was developed to automatically communicate between the two systems.

The last one is the prospect of being misleading regarding whether it is an academic representation model is or not. Although it can benefit from the development of such a system, the model does not propose a global academic representation model. This may be the subject of another study. Therefore, certain points must be addressed, improved, or implemented in future studies.

6. CONCLUSION

The main research question in this study is what the potential benefits of data interoperability between cross-platforms (i.e. blockchain and centralized systems) are. In order to evaluate these benefits, the following questions are asked: what type of conceptual model should be created, and what features should it have? Having established the research questions, education was chosen as the specific field in which to propose and implement potential solutions.

To address these questions, a hybrid conceptual model is proposed. This model ensures the interoperability of data across platforms, including a decentralized blockchain network (Hyperledger Fabric) and a centralized one (MySQL), while preserving the records of a relational data model in the blockchain.

The identified requirements for the conceptual model are as follows: (1) the ability to map records of a relational data model stored in an RDBMS to the blockchain, (2) matching, (3) synchronization, (4) verification, and (5) cross-validation of data stored in both systems.

To preserve a relational model's relations in blockchain, first, a theoretical connection between the records of two systems is established by employing a unique identifier that is generated from a hash function. Then, using a deployed smart contract, processes regarding the transfer and maintenance of functional dependencies of relations in the blockchain are performed. In addition, the smart contract can constitute a transcript from prerecorded recordings or perform the necessary operations for identified requirements for students or institutions. In this context, the developed prototype's source codes for clarity have been shared. And in the corresponding sections, it is explained in detail.

Contribution of the proposed model can be evaluated from two aspects: (1) computer science and (2) education.

In terms of computer science, the first point is that the model ensures the transfer of data between a centralized system and a decentralized system by preserving the functional dependencies of a relational data model. So, both systems can be synchronized effectively. In this context, the model does not propose the blockchain as a rival or alternative to centralized systems. Instead, it proposes the blockchain as a secondary data source. As a result, any modification that occurs in the centralized system can be traceable in the blockchain. Hence, it provides for the cross-validation of the two systems. With these aspects, it contributes to security and privacy.

The education domain also benefits in several important ways. Under the proposed model, students can access or verify documents issued by higher education institutions (HEIs), regardless of whether the institution is still operating, and without time or location restrictions. Other HEIs or authorised organizations can retrieve or check a student's records to confirm the validity of a document, or cross-validate data between their centralized system and the blockchain. Finally, the HEI that owns the data retains full control: it can create new records, map data between the two systems in both directions, and keep them synchronised.

Several directions are possible for future work. Firstly, the potential benefits of interoperability between centralized and decentralized systems could be explored in greater depth. Secondly, the prototype could be extended with new features to improve its capabilities. Thirdly, a hierarchical institutional-level model, together with its governing principles, could be proposed. Finally, possible areas of impact should be examined and implementations should be carried out and evaluated in practice.

Author Contribution: Osman Selvi was responsible for designing the conceptual framework and the DECEN model, determining the research methodology, developing the software prototype, and writing the original draft of the manuscript.
Adil Gürsel Karaçor contributed to the review and editing of the manuscript for academic content, language, and narrative flow, took part in the writing of the manuscript, and managed the process of preparing the study for publication in accordance with journal requirements.
Yıldız Karadayi was involved in reviewing and correcting the manuscript for grammar, consistency, and academic formatting, as well as verifying the accuracy of the presented information.

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