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Research Article / Araştırma Makalesi

A Smart Contract-Driven Architecture for Decentralized Portfolio Management on Blockchain

Blockchain Üzerinde Merkezi Olmayan Portfolyo Yönetimi için Akıllı Sözleşme Tabanlı Bir Mimari

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Abstract

This study presents the design and implementation of a blockchain-based decentralized portfolio management system that enables secure, immutable, and transparent storage of user records. The system is developed using Ethereum smart contracts and evaluated within a testing environment consisting of Remix IDE, Ganache, and MetaMask. The proposed architecture allows authorized actors to create records while enabling users to access and verify their data through blockchain-based identity mechanisms. Experimental results, based on gas consumption and insertion-time measurements, demonstrate that although smart contract deployment incurs relatively high initial costs, routine operations such as record insertion and retrieval remain efficient and predictable. The findings highlight the practical feasibility of the proposed system, while also revealing challenges related to scalability, cost variability, and system usability.

Anahtar Kelimeler: *Blokzincir, akıllı kontratlar, merkeziyetsiz sistemler, ethereum, portfolyo yönetimi.*

Öz

Bu çalışma, kullanıcı kayıtlarının güvenli, değiştirilemez ve şeffaf bir şekilde depolanmasını sağlayan blok zinciri tabanlı merkeziyetsiz bir portföy yönetim sisteminin tasarımını ve uygulamasını sunmaktadır. Sistem, Ethereum akıllı sözleşmeleri kullanılarak geliştirilmiş ve Remix IDE, Ganache ve MetaMask'tan oluşan bir test ortamında değerlendirilmiştir. Önerilen mimari, yetkili aktörlerin kayıt oluşturmasına olanak tanırken, kullanıcıların blok zinciri tabanlı kimlik mekanizmaları aracılığıyla verilerine erişmelerini ve doğrulamalarını sağlar. Gaz tüketimi ve ekleme süresi ölçümlerine dayalı deneysel sonuçlar, akıllı sözleşme dağıtımının nispeten yüksek başlangıç maliyetlerine yol açmasına rağmen, kayıt ekleme ve alma gibi rutin işlemlerin verimli ve öngörülebilir kaldığını göstermektedir. Bulgular, önerilen sistemin pratik uygulanabilirliğini vurgularken, ölçeklenebilirlik, maliyet değişkenliği ve sistem kullanılabilirliği ile ilgili zorlukları da ortaya koymaktadır.

Keywords: *Blockchain, smart contracts, decentralized systems, ethereum, portfolio management.*

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1. Introduction

Education is a systematic process to improve the knowledge, skills and competencies of individuals. Education is necessary to support the personal and professional development of individuals, to raise individuals who are beneficial to society and to move society forward [1]. It is extremely important to follow the personal development stages of a student and to have information about these stages in the next educational institution. Recording all the student's information in a blockchain based portfolio provides a great advantage in terms of continuity and security [2].

Blockchain technology appears as an open source ledger that runs on computers at different nodes. Each node can be accessed transparently and transactions can be queried from these ledgers. All recorded information is available on all nodes in the network. Blockchain technology is used to store data in a secure, transparent and immutable way [3]. A blockchain is a database system consisting of blocks that are usually decentralised, distributed, timestamped and cryptographically securely connected. It provides a platform for recording and sharing transactions [4]. The blockchain distributes control of the database among all nodes in a network instead of a single central authority. This ensures a balance of power and ensures that there is no single weak point in the system [5].

The data is divided into small packets called blocks. Each block contains a link containing the data of the previous block and a timestamp. Blocks are interconnected, so if one block changes, the entire chain is affected. Each transaction or block is marked with a timestamp. This determines when the transactions or blocks took place and makes them difficult to manipulate. Cryptographic techniques ensure the security of the blocks. Blockchain uses a consensus mechanism that requires agreement to be reached between different nodes in the network. The most widely known include algorithms such as "Proof of Work" and "Proof of Stake". Programmable contracts used in blockchain platforms are private transactions that are automatically executed and adhere to the terms of the contract [6].

Blockchains are often the basis of cryptocurrencies. These coins are used to perform transactions on blockchains, provide security and distribute them as rewards to miners [7]. Blockchains ensure that transactions are transparent and traceable. Anyone can check the blockchain and verify transactions, which increases trust [8]. Blockchain technology is constantly being improved to deal with scalability issues. This means the ability to process more transactions more quickly [9].

Blockchain technology has the potential to revolutionize many areas in the education sector. This technology can be used in areas such as digitizing educational documents and certificates, creating student portfolios, sharing educational data, keeping educational records and tracking students [10].

Developed in collaboration with MIT and Learning Machine, the Blockcerts platform offers a blockchain-based certificate verification system. This allows employers, academic institutions and students to check the authenticity of diplomas and certificates directly on the blockchain. This process aims to prevent fake diplomas and documents.

In this paper, a digital portfolio is modeled using smart contracts by considering the potential benefits of blockchain technology in the field of education. Unlike existing studies that primarily focus on certificate verification, this study proposes a decentralized portfolio management system that supports lifecycle-oriented storage, retrieval, and management of user records through blockchain-based identity mechanisms. This approach extends the role of blockchain from a verification layer to a persistent system architecture for decentralized data management.

The main motivation for this study is permanence, decentralised environment, educational inquiry and documentation. The privacy of the student's private information has been given utmost importance by matching it with his/her secure wallet. The modelling and software were tested on the Ethereum test

network and Ganache via MetaMask wallet and all scenarios were reviewed. The main contributions of this study are as follows:

- A decentralized portfolio management architecture based on blockchain identities.
- A smart contract-driven mechanism for secure, immutable, and transparent record management.
- An experimental evaluation of system feasibility based on gas consumption and data insertion time.
- An analysis of practical engineering challenges including cost variability, scalability, and system limitations.

As a result, with the system developed, the infrastructure required to record the received document or accessed achievement information in the student's area has been created, thus providing a retrospective, indelible, decentralised and confidential modelling. The study also analyses the average cost of the smart contract.

In the second part of the article, the infrastructure of blockchain technology is given. In the third section, similar studies in the literature are presented. In the fourth section, the research and study methodology is mentioned and the details of the modelling are given. The stages of modelling and the principles laid down in the design stages are also presented. The roles of students and teachers in this modelling will be examined and their roles in the blockchain are emphasised. In the following sections, the application, testing and results of the algorithms are given.

2. Materials and methods

2.1. Ethereum

Ethereum is a blockchain platform designed for the development of distributed applications (DApps) and smart contracts. Ethereum is a blockchain platform consisting of a series of blocks that record transactions over time. Each block contains transactions performed by users on the network. Ethereum's own cryptocurrency is Ether (ETH). Each transaction uses an amount of "gas", which indicates the resources required to perform a transaction on the network. This gas varies depending on the complexity of the transaction and how intensively it uses the network [11].

The main feature of Ethereum is that it supports programmable smart contracts. Smart contracts are snippets of code that execute automatically when certain conditions are met and are executed by all nodes in the network [12]. On the Ethereum network, users can set up Decentralized Autonomous Organizations (DAOs) to make decisions together and automate management processes. DAOs are autonomous organisations that operate based on programmed rules through smart contracts [13].

Ethereum historically used PoW and later transitioned to PoS. Miners create blocks by solving complex mathematical problems and thus earn Ether rewards. However, with the development of Ethereum 2.0, the Proof of Stake (PoS) consensus mechanism was also introduced [4]. Ethereum runs on the Ethereum Virtual Machine (EVM), a virtual machine. EVM serves as a virtual processor that executes smart contracts and ensures consistency across all nodes on the network [13].

Ethereum has a large developer community and a rich ecosystem. This community contributes to Ethereum's continuous development, security and hosting of innovative projects. Ethereum is a general purpose blockchain platform that can be used in many different industries. The programmable and distributed nature of Ethereum allows for the development of many innovative applications and protocols [14].

Ethereum testnets are virtual Ethereum networks that allow Ethereum developers to test smart contracts and applications on the real network. These test networks allow developers to test and debug their smart

contracts and applications before running them on the real network. Testing on the real Ethereum network can be costly and risky. Test networks provide a safe environment by reducing these risks [15].

Ether used on Ethereum test networks does not represent the same value as Ether on the real network. Testnet Ether is often referred to as "testnet Ether" and has no value on the actual Ethereum network. Developers must follow certain protocols to participate in testnets. DApps (Decentralized Applications) can be deployed on the real Ethereum network after being developed and tested on test networks [14].

The reason why the Ethereum blockchain was preferred in this study is that it supports smart contract infrastructure and its test networks are highly functional. For these reasons explained in detail, the Ethereum blockchain has become very popular and preferred.

2.2. Smart contracts

Smart contracts are programmable contracts that automatically execute and manage data on the blockchain when predetermined conditions are met [16]. Smart contracts can be thought of as a piece of software. However, unlike traditional software, they are contracts that can embed the code they contain in the blockchain and thus run on a distributed network. Smart contracts are automatically executed when certain conditions are met. These conditions are determined by predetermined rules and trigger conditions. For example, a certain transaction can be automatically executed when a payment is received or when a certain date passes [17].

Smart contracts are executed on a virtual machine running on blockchains such as Ethereum. This virtual machine processes the code of the contracts and ensures consensus among all nodes in the network. Smart contracts are implemented between all nodes in the blockchain network, and consensus (agreement) between these nodes is required. This ensures that the blockchain remains reliable and consistent [4]. The execution of smart contracts utilises the processing capacity in the network and is paid for by a fee, "gas", which specifies the resources used to perform these transactions. The amount of gas used in each transaction depends on the complexity of the contract and the execution time. Smart contracts are usually written in specialised programming languages. One of the most widely used languages in Ethereum is Solidity. Solidity is an Ethereum specific language for writing and compiling contracts [14].

Smart contracts operate transparently on the blockchain. Transactions and contract status can be clearly traced and verified. This increases trustworthiness. Smart contracts are a powerful tool for building trust between parties, eliminating intermediaries and creating transparent contracts that can be automatically executed. This is used in many application areas, especially in finance, supply chain management, voting systems and many more [18].

Automatically running code pieces exist at every stage of the software, but a program piece that is automatically triggered on the blockchain attracts a lot of attention. By preparing this study on the basis of a smart contract, an automated system has emerged while using the advantages of the blockchain and without human intervention.

Ethereum's ERC-20 and ERC-721 standards are the most widely used standards that enable the management of digital assets via smart contracts on the Ethereum blockchain. These standards define specific rules for how digital assets are created, transferred, and processed. ERC (Ethereum Request for Comments) refers to a set of technical standards developed by the Ethereum community. ERC-20 and ERC-721 are the two most popular of these standards and have different functionalities.

2.3. MetaMask

MetaMask is a popular wallet and browser plugin used to interact with Ethereum based dApps (decentralized applications) and smart contracts. MetaMask provides users with an Ethereum wallet. This wallet allows you to store Ether and other tokens on the Ethereum network. MetaMask is a plug-in that is integrated into your web browser. MetaMask uses industry standard security measures to securely store users' private keys. MetaMask allows users to run and interact with Ethereum-based dApps in their browsers. MetaMask offers the ability to store and manage tokens that comply with Ethereum ERC-20 and ERC-721 standards [19].

MetaMask enables user authentication when using Ethereum-based applications on websites. Users can interact with smart contracts using MetaMask. This is used for token transfers, ICO participations and other smart contract transactions. MetaMask stores users' private keys locally and protects user privacy on the browser. Users can use MetaMask to secure their authentication and authorization processes [20].

2.4. Related works

Blockchain technology has started to enter every aspect of our lives day by day. There are many studies in the literature, but here, studies related to education will be examined. Gatteschi et al [21]. divides the development phase of the blockchain into three:

- Blockchain 1.0 was conceived as a decentralised means of money transmission.
- Blockchain 2.0 is the process developed with the introduction of automated smart contracts [22].
- Blockchain 3.0 is the stage of application development in every field on the blockchain[23].

Thinking in terms of blockchain 3.0, the integration between education and blockchain technology has been an important area of research that offers the potential to transform traditional education models. One of the primary focal points of work in this area is that blockchain enables secure storage and sharing of student data. Data such as student records, exam results and certificates can be stored transparently and securely on the blockchain, reducing the risk of fraud [24].

Han et al [25]. present an education model based on blockchain technology. Gradesheets and documents received can be recorded in the blockchain by authorised persons. The student can access his/her data but cannot change it.

Furthermore, the impact of blockchain technology on the verifiability of diplomas is also analysed. Reliable verifiability of academic history is important for employers and other educational institutions. Smart contracts offer the potential to optimise the management of education by offering students automatic rewards for achieving certain goals or regulating the payment terms of educational services [26].

Nespor [27], and A. Baba,2018) considered blockchain as a place for document generation and verification. In this work, privacy and security are at the forefront. This study further emphasises the principle of creating official documents with blockchain. Duan et al. [11] emphasised the developments until the graduation process and the evaluation process. MIT Media LAb. and Nicosia University have conducted studies on digital documentation on the Bitcoin blockchain [28].

Grather et al. [29] also proposed a model using blockchain to issue training certificates. The point they drew attention to was that these certificates could be issued securely. Chen [30] designed a blockchain-based education tracking and development system called Echo. The blockchain can also support personalised education programmes through secure storage of student data. This allows for more transparent tracking of student progress. The distribution and tracking of financial aid and scholarships through the blockchain contributes to a fairer and more transparent distribution of resources. Smart

contracts can automatically manage copyrights on educational content, thus ensuring fair sharing between content creators and users [8]. While existing studies mainly focus on certificate verification and diploma authentication, relatively fewer works address comprehensive portfolio management systems that support long-term, user-centric record storage and retrieval. This gap highlights the need for system-oriented approaches that combine blockchain identity, smart contract automation, and lifecycle data management.

Finally, blockchain technology can change traditional education models by allowing students to move their learning records and switch between various education providers. This gives students more flexibility and portability, allowing them to personalise their educational experience. These extensive studies are being conducted to understand the potential advantages of education and blockchain integration and how this technology can be used in various fields in the education sector [8].

2.5. Research methodology

The proposed system consists of two primary actors: an authorized data provider and a user. The data provider is responsible for creating and submitting records to the blockchain, while the user interacts with the system through a blockchain wallet to access and verify stored records. Each user is represented by a unique Ethereum address, which enables decentralized identity-based access control. The system follows a transaction-based workflow in which records are submitted through smart contracts and stored in an immutable manner on the blockchain. The interaction between actors is managed through predefined authorization rules embedded within the smart contracts.

The first aim of the developed system is to have a blockchain-based digital portfolio based on the theory of lifelong learning. It is aimed that the learner can connect to the system with a blockchain-based wallet and see his/her documents, activities and certificates, and the educator can create a new record in the system with the unique and decentralised blockchain network ID of the student.

The automated system created with smart contracts is stored securely and privately on the Ethereum blockchain. The student cannot change his/her information, he/she can only list and print. The teacher, on the other hand, can create new records or make listing and printing with smart contracts over the blockchain. Thus, while creating a long-term education record (portfolio), a decentralised query mechanism is created. This is in favour of both the learner and the training centres. Although there is no right, an unchangeable and indelible structure has been created. A decentralised and indelible digital portfolio will accompany students throughout their lives and will not cause any loss of rights. From this point of view and considering this need, such a modelling was tried to be developed. Figure 1 shows the founding smart contract executed and activated on the Ethereum test network.

Figure 1. Compilation of the smart contract.

After this stage, the smart contract is published on the Ethereum Test Network. It will run automatically as soon as any data or trigger occurs. The fee for the compilation process was paid once. In the following stages, it will be sufficient to pay only the gas fee required for use. Figure 2 shows the working values of the smart contract that will run on the teacher's input screen.

Figure 2. Smart contract created for teacher's document or training record.

Figure 3 shows the working values of the smart contract for the area where the student can enter his/her own account and list the trainings he/she has received. The estimated budget seems to be very low. This may also vary according to the density in the Ethereum network. It is foreseen that educational institutions will undertake this budget. Thus, there is no extra expenditure item for the student.

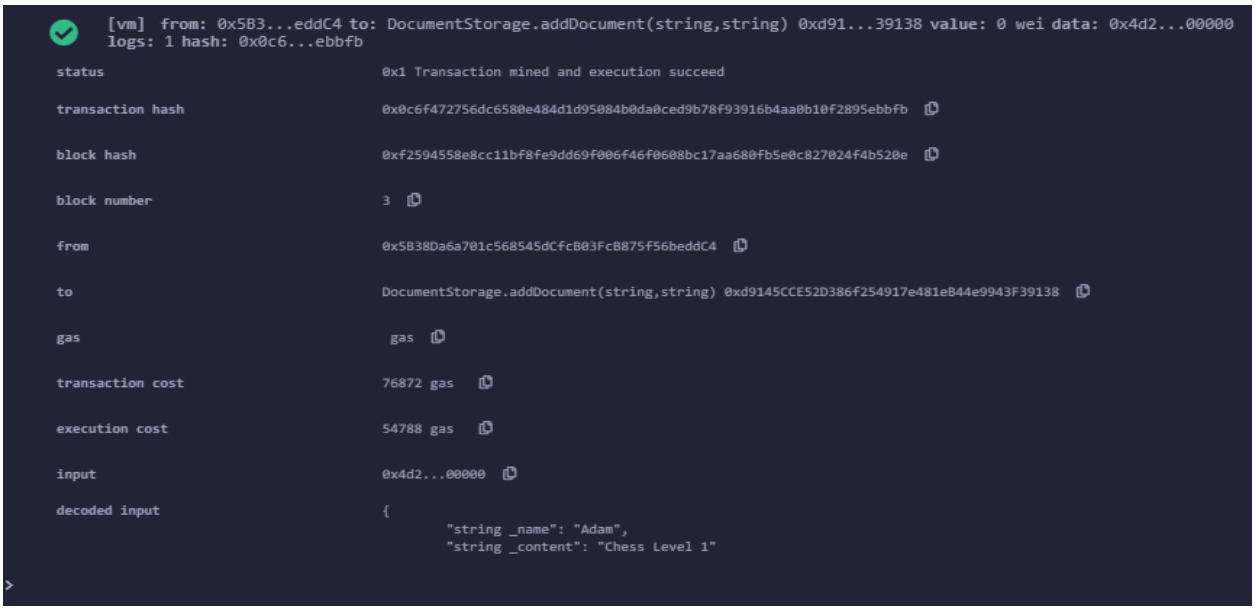

Figure 3. Smart contract of the student's own account with listed documents.

2.6. Implementation of algorithm and technology

The developed system starts with checking whether the student has an account on the teacher's blockchain. In this way, confusion between people is prevented. The student's unique Ethereum network ID number is used as a distinguishing feature here. Once the student is on the network, the teacher can add education related documents and certificates to the system. After this stage, the student's information

cannot be deleted, changed and is reliable. The biggest goal of the lifelong learning education model is achieved in this way. Now the documents have become registered, without being connected to a central management. The pseudocode of the algorithm of the teacher interface is given in Algorithm 1.

```
Input: userAddress, recordData
Output: successFlag

Procedure AddDocument(userAddress, recordData)

    if IsAuthorizedProvider(msg.sender) = true then
        if UserExists(userAddress) = true then
            AddRecord(userAddress, recordData)
            successFlag ← true
        else
            RegisterUser(userAddress)
            AddRecord(userAddress, recordData)
            successFlag ← true
        end if
    else
        successFlag ← false
    end if

    return successFlag

End Procedure
```

Algorithm 1. Teacher account.

Algorithm 1 presents the record insertion procedure performed by an authorized provider. The algorithm first checks whether the sender has the required authorization. If the target user already exists in the system, the new record is added directly. Otherwise, the user is first registered and the record is then inserted. This procedure ensures controlled and secure record creation within the proposed blockchain-based system.

Listings are made in the student's own account. MetaMask Ethereum wallet is used as authentication here. Thus, a high level of protection is provided. In fact, if the student wishes, he can keep all his documents physically with portable high security devices. The pseudocode of the algorithm of the student interface is given in Algorithm 2.

```
Input: userAddress, walletKey
Output: recordList

Procedure GetMyDocuments(userAddress, walletKey)

    if AuthenticateUser(userAddress, walletKey) = true then
        if UserExists(userAddress) = true then
            recordList ← RetrieveRecords(userAddress)
        else
            recordList ← Empty
        end if
    else
        recordList ← Empty
    end if

    return recordList

End Procedure
```

Algorithm 2. Student's account.

Algorithm 2 presents the record retrieval procedure for the user side. The algorithm first authenticates the user through the associated wallet credentials. If the user is successfully authenticated and the corresponding blockchain address exists in the system, the stored records are retrieved. Otherwise, an empty result is returned. This procedure ensures that only the owner of the relevant blockchain identity can access the associated records.

The teacher adds a certificate, document or training to the system using the Web 3.0 interface with the Ethereum address received from the student. At this stage, the "addDocument" smart contract is automatically activated and transmits the data to the Ethereum blockchain. In the first stage of the Ethereum network, miners perform mathematical operations with verification algorithms. After the verification process, the verified blocks are stacked and a new block waits to be created according to the reward money coming from the network. The miner, who receives his fee from the network, allows the formation of a new block. Thus, blocks are added to the blockchain in a distributed and verified manner across multiple processors. Each verified computer has a backup of the block. This means that data is backed up on countless computers. This meets the safety and longlasting usage criteria. On the student side, the first process is to connect to the network with the MetaMask wallet and access the block created by the teacher. Here, the function of the wallet is to automatically use the student's Ethereum address and use the wallet as a digital portfolio. In this way, data is accessed with high security. Figure 4 shows the schematic of the developed platform.

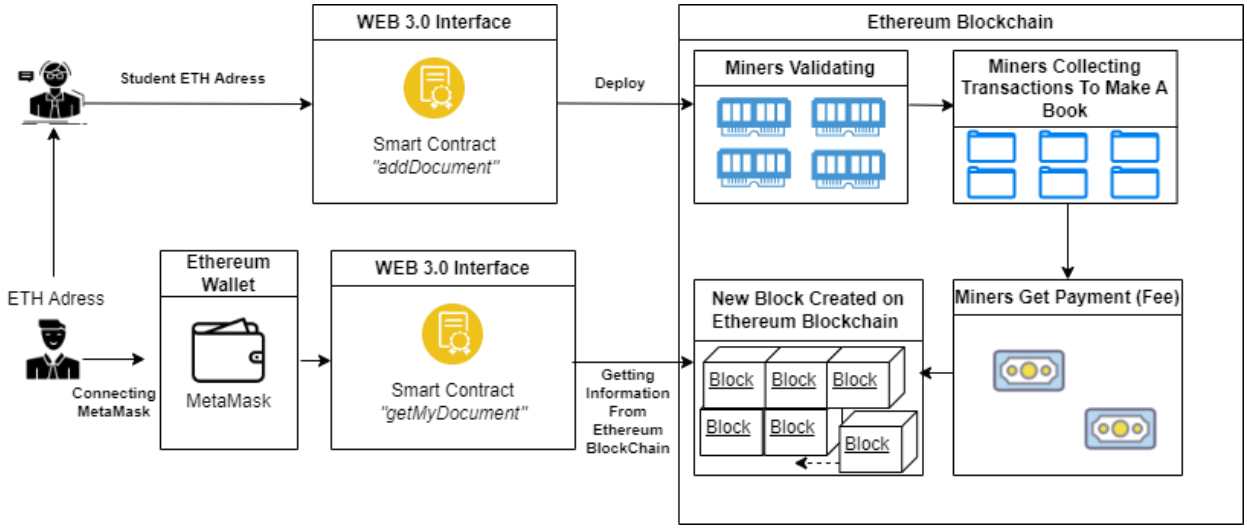

Figure 4. Detailed working flow of the solution.

3. Results

The proposed platform was developed in the REMIX IDE environment. Rich library support and the fact that the text editor is extremely useful for the Solidity language led to this choice. In addition, the testing opportunities offered by Remix Ide are extremely rich during the testing of the code. Having both a browser and a desktop version and being synchronized with each other has been extremely efficient in terms of ease of working.

The developed smart contracts were first tested on Ethereum test networks. Among the networks defined in the system as Remix VM, Shanghai, Merge, London, Berlin, Mainnet Fork and Custom Fork were preferred. No operational problems were encountered in these networks. In the next stage, in the Remix Ide environment, the Dev Ganache Provider option was selected and the Ganache virtual Ethereum server was connected. At this stage, the fees spent and the number of contracts were checked. Final tests were carried out by connecting to the wallet (MetaMask) using the Wallet Connect option.

During the testing phase of our project, gas fees at different time intervals and network densities were examined. Table 1 shows the gas fees in the test results in the network environment at different times.

Table 1. Comparison of gas fees.

Process		T1 (gas)	T2 (gas)	T3 (gas)	T4 (gas)
Compilation of Smart Contract	Transaction	879446	745866	901445	725478
	Execution	766942	687412	792541	654283
Calling the Smart Contract Teacher	Transaction	9762	7986	11080	7684
Calling Smart Contract Student	Transaction	76872	71025	84221	68745
	Execution	54788	50487	63574	48521

Table 1 examines the costs of modeling in the Ethereum network in four different time periods. The time intervals selected were determined randomly. This method was preferred because the fee is determined according to density in the Ethereum network.

When gas prices are examined, it is seen that there is a 20% difference between the highest and lowest pricing. This difference drops to 5% when the network density is taken into account and the uses to be made are taken into account. This is seen as an acceptable fee.

The stage where the most fees are paid is during the creation of the smart contract. In the subsequent stages of adding documents or listing the student's documents, a fee decrease of between 50% and 90% is observed.

The insertion times of 300 data to the blockchain are given in Table 2. The total time was recorded by considering the insertion time (0.05 seconds) for each data. The insertion times for the first 10 data are as follows:

Table 2. The insertion times data to the blockchain.

Data	Insertion Time (seconds)
Data_1	0.000187
Data_2	0.050760
Data_3	0.103775
Data_4	0.153927
Data_5	0.206084
Data_6	0.258659
Data_7	0.308989
Data_8	0.359671
Data_9	0.410737
Data_10	0.461001

The data insertion process proceeds with a 0.05 second delay between each insertion. Similar times were recorded for all data. This can help understand how the time increases and how the process works when adding big data to the blockchain.

The experimental findings indicate that the proposed system is feasible for practical deployment in decentralized portfolio management scenarios. The results show that the highest cost occurs during smart

contract deployment, while subsequent operations such as record insertion and retrieval require significantly lower gas consumption.

Furthermore, the insertion-time measurements demonstrate a stable and nearly linear progression, indicating predictable system behaviour under sequential data entry conditions. This suggests that the system can handle moderate-scale workloads without significant performance degradation.

4. Discussion and Conclusions

In this paper, a platform has been developed for the permanent and secure storage of documents, certificates and trainings that a student will receive throughout his/her life. The developed system is designed as a decentralised data storage system using blockchain technology. Thus, a transparent, indelible and unmanaged system has emerged. The proposed platform includes smart contracts that run automatically. In the student's wallet, a digital portfolio is created, so that indelible and unchangeable information will be securely stored for life. Since there is no intervention of any institution, it has a structure that highly protects the student against a certain authority. At the same time, in a system that is open to everyone, information such as which teacher provides which training and to whom is easily accessible. This demonstrates the success of the training centre in terms of transparency and security. These are the advantages of the study.

On the other hand, blockchain technology is a costly technology because miners who perform verification and block addition operations have electricity and execution costs. This cost is covered by receiving rewards through the Ethereum network. This cost is covered by the person who creates or uses the smart contract. In this sense, the cost of the system should be well calculated in blockchain projects.

Blockchain technology is an internet-based project. For this reason, it can be used limitedly in geographies where there is no internet or poor connection quality. This reduces access to the proposed modelling. Wallets and derivative intermediary equipment used in blockchain technology may be subjected to security attacks or the password may be exposed by the user's error. In such cases, if the student's account is stolen, his/her entire education life may be at risk. For this reason, blockchain security training should be the first subject of all training provided. These are the limitations of the study.

The working logic of the blockchain includes obtaining confirmation and adding new blocks. This may require waiting for a certain period of time while the information is entered and saved in the system. While this waiting period is not a problem for small data, it can lead to loss of time when working with large data. To prevent this, algorithms can be used to prevent data accumulation.

The proposed model includes all the certificates and documents he received throughout his education life. With greater modeling, all personal data of the student can be transferred to the blockchain, paying attention to the security of personal information. States can even include their own education databases on the blockchain.

By increasing students' awareness of the blockchain, they can act in accordance with security measures. Since interinstitutional communication will be via blockchain, the trust problem is eliminated and the student's rights are protected forever thanks to transparency. Laws are passed with blockchain costs, or the government can reduce the cost by introducing its own blockchains. Based on this model, network costs should be added to the tuition fee as an average cost after calculation. In free education, this responsibility should be undertaken by ministries of education. In fact, a tax can be created for this situation or the expenses can be reduced to zero by creating a fund. In cases where the teacher enters incorrect information and cannot be updated or deleted, a note can be made on the proposed model for that student and the actual nature of that education can be written. Thus, student grievances are eliminated.

The proposed system has several limitations. First, transaction costs may vary depending on network congestion, which can affect cost predictability. Second, scalability remains a concern, as storing large volumes of records directly on the blockchain may increase latency and operational costs. Third, the immutability of blockchain data, while ensuring integrity, may create challenges in correcting erroneous entries. Additionally, the security of the system depends on user wallet protection, and risks such as wallet loss or unauthorized access must be considered.

From a conceptual perspective, it is important to distinguish between security and privacy within the proposed system. Security refers to the protection of data against unauthorized access, tampering, and malicious activities [31]. In this study, security is primarily ensured through blockchain properties such as immutability, cryptographic integrity, and decentralized validation mechanisms. These features prevent unauthorized modification of stored records and enhance trust in the system.

In contrast, privacy relates to the protection of sensitive user information and the control over data visibility. Although blockchain provides strong security guarantees, it does not inherently ensure privacy, as data stored on public blockchains may be accessible to all participants [32]. Therefore, the proposed system must carefully balance transparency and confidentiality, particularly when handling user-related records. Sensitive data exposure, linkage attacks, and identity traceability remain potential risks.

To address these concerns, future implementations may incorporate privacy-enhancing techniques such as off-chain storage, encryption mechanisms, and zero-knowledge proof-based approaches. These methods can help preserve user privacy while maintaining the integrity and verifiability advantages of blockchain technology.

Future work may focus on integrating hybrid on-chain/off-chain architectures to reduce storage costs while maintaining data integrity. In addition, Layer-2 scaling solutions and permissioned blockchain infrastructures can be explored to improve scalability and transaction efficiency. Further research may also investigate advanced access control mechanisms and privacy-preserving techniques for decentralized record management systems.

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Conflict of Interest

There is no conflict of opinion between the authors. The authors contributed equally

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