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[1]Astana IT University, Astana, Kazakhstan;
[2]Institute of Information and Computational Technologies, Almaty, Kazakhstan.
E-mail: olgaussatova@gmail.com

BACKEND ARCHITECTURE OF A HYBRID BLOCKCHAIN-BASED ACADEMIC CREDENTIAL VERIFICATION SYSTEM

Amanzholova Saule — Candidate of technical science, Astana IT University, Astana, Kazakhstan,
E-mail: s.amanzholova@astanait.edu.kz, https://orcid.org/0000-0002-6779-9393;
Ussatova Olga — PhD, Institute of Information and Computational Technologies, Almaty, Kazakhstan,
E-mail: olgaussatova@gmail.com, https://orcid.org/0000-0002-5276-6118;
Mutanov Galimkair — Doctor of technical science, Institute of Information and Computational Technologies, Almaty, Kazakhstan,
E-mail: mu-tanov@ipic.kz, https://orcid.org/0000-0002-1375-1343;
Mukhanov Samat – PhD, Astana IT University, Astana, Kazakhstan,
E-mail: s.mukhanov@astanait.edu.kz, https://orcid.org/0000-0001-8761-4272;
Aitmukash Daniyar — PhD, Institute of Information and Computational Technologies, Almaty, Kazakhstan,
E-mail: Aitmukash.Daniyar@ipic.kz, https://orcid.org/0000-0001-9904-9979.

Abstract. The rapid digitalization of higher education institutions worldwide has created a growing demand for transparent, trustworthy, and secure solutions for the storage, management, and verification of academic data. Universities are increasingly transitioning to electronic document management systems for transcripts, diplomas, and other educational records. However, traditional centralized information systems used in educational institutions remain vulnerable to significant security and integrity issues, including unauthorized access to academic records, lack of transparent audit mechanisms, risks of transcript forgery, and limited trust in cross-institutional verification procedures. To address these challenges, this paper proposes a hybrid architecture that combines OffChain storage with a consortium blockchain-based OnChain verification layer. In the proposed model, the OffChain component is responsible for bulk data storage, metadata processing, and efficient management of educational records, while the

OnChain component stores cryptographic hashes of transcripts and immutable verification metadata. Such a design makes it possible to preserve the performance and scalability of conventional systems while simultaneously leveraging the decentralization, immutability, and trust guarantees provided by blockchain technology. The implemented architecture follows Clean Architecture principles and consists of multiple interconnected layers, including role-based access control, a secure API gateway for service orchestration, an authentication mechanism based on asymmetric cryptography, and a hybrid data dispersal module. In addition, smart contracts are designed to automate the verification and validation of transcripts and diplomas, thereby reducing the need for manual checks and minimizing the risk of tampering. The proposed solution improves data integrity, strengthens institutional trust, and enhances the efficiency of academic credential verification for employers, government agencies, and foreign universities. The research demonstrates that the integration of blockchain with existing educational information systems can provide a practical and scalable foundation for secure digital academic services.

Keywords: Blockchain, Academic Data Verification, Backend Architecture, Hybrid Data Storage, Smart Contracts, Data Security, API Integration

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[1]Астана IT Университеті, Астана, Қазақстан;

[2] Ақпараттық және есептеу технологиялары институты, Алматы, Қазақстан.

E-mail: olgaussatova@gmail.com

ГИБРИДТІК БЛОКЧЕЙНГЕ НЕГІЗДЕЛГЕН АКАДЕМИЯЛЫҚ СЕНІМДІК ДЕРЕКТЕРДІ ТЕКСЕРУ ЖҮЙЕСІНІҢ БЕКЕНДІК АРХИТЕКТУРАСЫ

Аманжолова Сауле — техника ғылымдарының кандидаты, Астана IT Университеті, Астана, Қазақстан,

E-mail: s.amanzholova@astanait.edu.kz, https://orcid.org/0000-0002-6779-9393;

Усатова Ольга — PhD, Ақпараттық және есептеу технологиялары институты, Алматы, Қазақстан,
E-mail: olgaussatova@gmail.com , https://orcid.org/0000-0002-5276-6118;
Мутанов Галимкаир — техника ғылымдарының докторы, Ақпараттық және есептеу технологиялары институты, Алматы, Қазақстан,
E-mail: mu-tanov@ipic.kz, https://orcid.org/0000-0002-1375-1343;
Муханов Самат — PhD, ассистент-профессор, Астана IT Университеті, Астана, Қазақстан,
E-mail: s.mukhanov@astanait.edu.kz, https://orcid.org/0000-0001-8761-4272;
Айтмукаш Данияр — PhD, Ақпараттық және есептеу технологиялары институты, Алматы, Қазақстан,
E-mail: Aitmukash.Daniyar@ipic.kz, https://orcid.org/0000-0001-9904-9979.

Аннотация. Әлем бойынша жоғары оқу орындарындағы цифрландыру үдерісінің қарқынды дамуы академиялық деректерді сақтау, басқару және тексеру үшін ашық, сенімді және қауіпсіз шешімдерге деген сұранысты арттыруда. Университеттер транскрипттерді, дипломдарды және басқа да білім беру құжаттарын сақтау үшін электрондық құжат айналымы жүйелеріне белсенді түрде көшу үстінде. Алайда білім беру ұйымдарының дәстүрлі орталықтандырылған ақпараттық жүйелері бірқатар маңызды мәселелерге ұшырайды, оның ішінде деректерге рұқсатсыз қол жеткізу, аудиттің ашық механизмдерінің болмауы, академиялық құжаттарды қолдан жасау тәуекелдері және ұйымдар арасындағы тексеру мүмкіндіктерінің шектеулілігі бар. Осы мәселелерді шешу мақсатында зерттеуде OffChain деректерді сақтау және консорциумдық блокчейнге негізделген OnChain компонентін біріктіретін гибридті архитектура ұсынылады. Ұсынылған модельде OffChain бөлігі үлкен көлемдегі деректерді сақтау мен метадеректерді өңдеуге жауап береді, ал OnChain компоненті транскрипттердің криптографиялық хэштерін және өзгермейтін верификация деректерін сақтайды. Бұл тәсіл дәстүрлі жүйелердің өнімділігі мен ауқымдылығын сақтай отырып, блокчейн технологиясының орталықсыздандырылған, өзгермейтін және сенімді сақтау артықшылықтарын пайдалануға мүмкіндік береді. Ұсынылған архитектура Clean Architecture қағидаттарына сәйкес әзірленген және бірнеше функционалдық деңгейлерден тұрады: рөлдерге негізделген қол жеткізуді басқару, сервистердің өзара әрекеттесуіне арналған қорғалған API-шлюз, асимметриялық криптографияға негізделген аутентификация механизмі және деректерді гибридті тарату модулі. Сонымен қатар, академиялық құжаттарды тексеру және растау үдерістерін автоматтандыратын смарт-контрактілер енгізілген, бұл қолмен тексеруге тәуелділікті азайтып, деректердің бұрмалану қаупін төмендетеді. Ұсынылған шешім деректердің тұтастығын арттырады, білім беру экожүйесіндегі сенімді күшейтеді және жұмыс берушілер, мемлекеттік органдар мен шетелдік университеттер үшін академиялық жетістіктерді тексеру үдерістерінің тиімділігін жоғарылатады. Зерттеу нәтижелері блокчейн технологиясын білім беру ақпараттық жүйелерімен біріктіру қауіпсіз және ауқымды цифрлық білім беру қызметтерін құру үшін тиімді негіз бола алатынын көрсетеді.

Түйін сөздер: Блокчейн, академиялық деректерді тексеру, серверлік архитектура, гибридті деректерді сақтау, ақылды келісімшарттар, деректер қауіпсіздігі, API интеграциясы

© Аманжолова С.Т.[1,2], Усатова О.А.[1,2*], Мутанов Г.М.[2], Муханов С.Б.[1,2], Айтмукаш Д. [2], 2026.
[1]Astana IT University, Астана, Казахстан;
[2] Институт информационных и вычислительных технологий, Алматы, Казахстан.
E-mail: olgaussatova@gmail.com

БЭКЕНД-АРХИТЕКТУРА ГИБРИДНОЙ СИСТЕМЫ ПРОВЕРКИ АКАДЕМИЧЕСКИХ ДОСТИЖЕНИЙ НА ОСНОВЕ БЛОКЧЕЙНА

Аманжолова Сауле — кандидат технических наук, Астана IT Университет, Астана, Казахстан, E-mail: s.amanzholova@astanait.edu.kz, https://orcid.org/0000-0002-6779-9393;
Усатова Ольга — PhD, Институт информационных и вычислительных технологий, Алматы, Казахстан,
E-mail: olgaussatova@gmail.com , https://orcid.org/0000-0002-5276-6118;
Мутанов Галимкаир — доктор технических наук, Институт информационных и вычислительных технологий, Алматы, Казахстан,
E-mail: mu-tanov@ipic.kz, https://orcid.org/0000-0002-1375-1343;
Муханов Самат — PhD, ассистент-профессор, Астана IT Университет, Астана, Казахстан,
E-mail: s.mukhanov@astanait.edu.kz, https://orcid.org/0000-0001-8761-4272;
Айтмукаш Данияр — PhD, Институт информационных и вычислительных технологий, Алматы, Казахстан,
E-mail: Aitmukash.Daniyar@ipic.kz, https://orcid.org/0000-0001-9904-9979.

Аннотация: Быстрые темпы цифровизации высших учебных заведений во всём мире обусловили рост потребности в прозрачных, надёжных и безопасных решениях для хранения, управления и верификации академических данных. Университеты всё чаще переходят к использованию электронных систем управления документами для хранения транскриптов, дипломов и других образовательных записей. Однако традиционные централизованные информационные системы образовательных организаций остаются уязвимыми к ряду существенных проблем, включая несанкционированный доступ к данным, отсутствие прозрачных механизмов аудита, риски подделки академических документов и ограниченные возможности межорганизационной проверки. Для решения указанных проблем в работе предлагается гибридная архитектура, сочетающая off-chain хранение данных и on-chain компонент на основе консорциумного блокчейна. В предложенной модели off-chain часть отвечает за хранение больших объёмов данных и обработку метаданных, тогда как on-chain компонент обеспечивает хранение криптографических хэшей транскриптов и неизменяемых данных верификации. Такой подход позволяет сохранить производительность и масштабируемость традиционных систем,

одновременно используя преимущества децентрализованного, неизменяемого и доверенного хранения данных на основе технологии блокчейн. Разработанная архитектура соответствует принципам Clean Architecture и включает несколько функциональных уровней: управление доступом на основе ролей, защищённый API-шлюз для взаимодействия сервисов, механизм аутентификации на основе асимметричной криптографии, а также модуль гибридного распределения данных. Дополнительно реализованы смарт-контракты, автоматизирующие процессы проверки и валидации академических документов, что снижает зависимость от ручных процедур и минимизирует риски подделки данных. Предложенное решение повышает целостность данных, усиливает доверие между участниками образовательной экосистемы и повышает эффективность процессов проверки академических достижений для работодателей, государственных органов и зарубежных университетов. Результаты исследования показывают, что интеграция блокчейн-технологии с существующими информационными системами образования может служить эффективной и масштабируемой основой для создания безопасных цифровых образовательных сервисов.

Ключевые слова: Блокчейн, проверка академических данных, архитектура бэкэнда, гибридное хранение данных, смарт-контракты, безопасность данных, интеграция API

Introduction. The last few years have witnessed a marked digitalization of the educational space and an intense development of national information systems with the aim of automating academic management processes, accumulating educational data, and providing public services in the electronic format. Higher education institutions produce considerable amounts of digital data, including data related to students, their performance, and academic and qualification paths. The reliability, integrity, and accessibility of such data have come to be seen as key drivers of sustainability in the digital educational space.

Despite the achieved level of digitalization, most existing educational platforms retain centralized data storage architecture. This model provides ease of administration and operational processing of information but comes with several systemic limitations. These include the risk of unauthorized modification of records, the lack of an immutable transaction history, vulnerability to internal and external intrusion, and dependence on a single storage center (Alwakid and Dahri, 2025). In the context of academic qualifications, these limitations take on special meaning, as the authenticity of diplomas and transcripts has direct implications for the trustworthiness of employers, government agencies, and international educational organizations (Alzahrani et al., 2025).

The development of academic mobility, the globalization of educational programs, and the computerization of government agencies are creating an increased need for effective means of validating educational credentials. Traditional means of qualification verification are time-consuming, involve inter-institutional

requests, and do not offer real-time verification of data authenticity (Alzhrani et al., 2023). This creates a demand for technological solutions that can guarantee the immutability of records and the transparency of their origin.

One such solution is the use of distributed ledgers based on blockchain technology. Blockchain provides decentralized data storage solutions, cryptographic protection of transactions, and immunity of recorded data against retroactive change. In the context of the education sector, it is seen as having potential for boosting trust in digital qualifications, facilitating verification processes, and preventing document forgery (Amanzholova et al., 2026).

In light of the global digitization of various countries' education systems, it is interesting to look at the experiences of various national higher education management platforms. There are various countries that have implemented centralized data storage solutions for academic qualifications and educational achievements with the aim of boosting data transparency and accessibility. Similar solutions have been implemented in various countries in Europe, the USA, South Korea, and Singapore, where various digital ecosystems in education have been integrated with government and employment services and qualification recognition systems (Amanzholova et al., 2026). However, most existing infrastructures retain a centralized storage model, which limits the ability to immutably record data and transparently audit changes.

In the Republic of Kazakhstan, the advancement of digital educational infrastructure is underway through the Unified Higher Education Platform (UHEP). The UHEP is intended to aggregate, monitor, and analyze academic data from universities (Alammary et al., 2026). It combines the educational learning management systems used by educational institutions, centralizes the storage of information on students, graduates, and educational programs, and supports government services for education. Despite the high level of digitalization and the scale of integration, the UHEP architecture maintains a centralized data storage system, which does not fully ensure the immutability of academic records, the transparency of their modifications, or the cryptographic verifiability of educational documents.

In this regard, the integration of distributed ledgers into national educational platforms is seen as a promising direction for the development of trusted digital infrastructure. The use of hybrid blockchain architecture allows for the addition of an immutable storage layer for critical data to centralized systems, ensuring a balance between operational efficiency and cryptographic protection of academic qualifications.

A pressing scientific and practical challenge in this context is the development of a backend architecture capable of ensuring secure orchestration of academic data flows, access control, cryptographic security, and subsequent verification of records in a distributed network (de Alwis et al., 2025). Particularly challenging is the construction of a hybrid storage model that combines the operational efficiency of centralized databases with the immutability of a blockchain ledger.

The purpose of this study is to develop and implement backend architecture for a hybrid blockchain platform that ensures secure verification, immutability, and scalability of academic data storage in a distributed digital educational environment. The study proposes a multi-tier server infrastructure architecture that implements Clean Architecture principles, a flexible role-based access model, a data distribution mechanism between Off-Chain and On-Chain storage, and integration with blockchain network smart contracts for transcript and diploma storage.

Literary review. The use of blockchain technologies to store and verify educational qualifications has been found to be an ongoing research trend over the years, with an increase in academic mobility and the need to digitally verify academic diplomas and transcripts. In this regard, a systematic review by de Alwis et al. (2025), which examined 63 published works on blockchain technologies applied to educational accreditation and qualifications management, found an increase in research on the use of digital records of academic diplomas and certificates and the automation of academic qualification verification processes (Dey and Shekhawat, 2021). It is argued that this would improve transparency regarding the provenance of documents and reduce the risk of document forgery during inter-institutional and international recognition.

Similar findings were made by Alammary et al. (2019) in a systematic review on various blockchain technologies applied to education, categorized by their objectives of application: integrity preservation, verification ease, and reducing intermediaries. Earlier conceptual works by Grech and Camilleri (2017) consider blockchain as an infrastructural foundation for global educational registries, while Hindarto analyze a model of distributed digital portfolios and student reputation mechanisms. These studies form a consensus: the key value of blockchain in educational systems is not related to storing a complete array of data, but to creating a trusted layer for confirming the authenticity and origin of (Hindarto, 2023).

A separate body of publications is devoted to the use of smart contracts to automate the registration and verification of qualifications. (Hindarto, 2023) demonstrate the potential of a smart contract model for recording diploma issuance events and ensuring the verifiability of records in a distributed ledger (Hindarto, 2023). The practice-oriented development of this area is reflected in the BACIP (Blockchain-Based Academic Credential Interoperability Protocol), which proposes a comprehensive framework for managing educational achievements with an emphasis on the registration, storage, and verification of qualifications in a distributed environment (Iswahyudi et al., 2023) For the purposes of this study, these works are important as confirmation of the applicability of smart contracts specifically for the proof layer, while the bulk of operational data is rationally located outside the blockchain (Iswahyudi et al., 2023).

A critical challenge for the implementation of blockchain solutions remains the limitations of throughput and storage costs in distributed networks. In the review by Zheng et al. (2018), scalability, transaction confirmation delays, and the resource intensity of operations in distributed ledgers are highlighted among the key issues,

which justify the need for architectural optimization and selective data placement (Jha et al., 2023). In practice, this leads to the spread of hybrid OnChain/OffChain architectures, in which only the minimum information sufficient for verification (e.g., hash identifiers or key attributes) is transferred to the blockchain, while metadata and documents are stored in centralized databases or external storage. Thus, the literature supports an approach in which the distributed ledger is used as an immutable confirmation mechanism, rather than as the primary storage platform for the entire lifecycle of academic data (Jha et al., 2023).

From an engineering perspective, architectural patterns in blockchain systems are of great importance. Pahl et al. (2018) describe architectural decisions regarding the allocation of responsibility between layers of applications, handling of transaction flow, and the construction of integration adapters (K et al., 2025). Architectural decisions are further linked to classes of threats, including consensus, storage, and access control, by Zhang et al. (2020), who highlight the selection of architecture and its corresponding security requirements. These results form the basis for designing server infrastructure, where security must be ensured not only by blockchain cryptography, but also by the correct organization of the API layer, access control, and data routing.

An important area is the integration of blockchain solutions with corporate and interorganizational information systems. Mendling et al. (2018) view blockchain as an infrastructure that requires alignment with existing processes and the IT landscape, including the need for intermediate layers and data synchronization mechanisms (K et al., 2025). In the context of a university, EduCTX offers a platform for the use of blockchain to record credits and verify accomplishments, demonstrating the practical use of distributed ledger systems for educational activities while highlighting the value of server-side design and integration mechanisms for implementation (Marcu et al., 2025).

Summarizing the results of the studies reviewed, two key conclusions can be identified that determine the formulation of the problem of this work. Firstly, most existing solutions and prototypes focus on the recording of final documents (diplomas, certificates) and demonstrating the advantages of immutability, while the architecture of the server circuit, providing the orchestration of academic data flows, validation and integration with existing educational systems, is not fully disclosed (Hindarto, 2023). Secondly, the literature consistently points to the feasibility of hybrid OnChain/OffChain models as the most realistic way of implementing blockchain in scalable educational platforms with limited distributed network resources (Iswahyudi et al., 2023). In this regard, the development of a backend architecture that ensures secure data processing, access control, validation and selective cryptographic recording of critical records in a consortium network is of scientific and practical interest and closes the identified architectural gap.

Materials and methods. Every operation carried out by a smart contract results in a change to the nodes of the World State tree. Ethereum State is essentially a

mapping of 160-bit address to the corresponding account state. This account state is stored in data structure called State Trie.

The account state is represented as a leaf node of which its address acts as a path from the root of trie down to that node.

Smart contracts are treated as special accounts. For each contract account, there is a distinct persistent storage data structure associated with it — Storage Trie.

The storage trie is also implemented as a Merkle Patricia Trie (MPT) (Marhoon et al., 2023).

Hence there are two levels to Ethereum World State trie hierarchy.

– Account Trie (Top Level).

– Storage Trie (Bottom Level).

Under Ethereum's current implementation, searching for/inserting a node along a path results in SHA3 () hashing followed by read / write access to levelDB. These operations take time, and the size of your new node will equate to how much data you are adding to the trie as a result of your state change. So if we can determine the current height of our new leaf node we can also determine our potential performance/storage gains. If we know how state changes are occurring in the MPT data structure we can predict transaction performance and additional storage by looking at the time it takes for world state changes to occur. We can also determine this empirically by testing smart contracts against certain business use cases. In this paper we will analyze current height of world state nodes in MPT data structure.

As described by Devroy (Iswahyudi et al., 2023), we can expect the height of an MPT to be (1):

$$H_n = \frac{2\sqrt{2log2n} + log2n}{4} \quad (1)$$

If the transactions number is n and executes another transaction, then according to Formula (2), we can calculate the average time cost for changing MPT is:

$$T_{mpt}(n) = \frac{t}{2}\log(an) \quad (2)$$

Where a represents the number of deployed smart contracts in the network, n represents the transaction volume and t represents execution time to create a node in MPT tree (including time of sha3() computation and database access time). Ethereum uses LevelDB as its key-value database. Keys used to access LevelDB are unevenly distributed due to the granularity of hashing. LevelDB has great performance for reads and writes that occur sequentially (Iswahyudi et al., 2023). However, this database suffers when confronted with random patterns of key access. As a result, t, the amount of time needed to access LevelDB, increases with

the growth of stored data. Experimental findings have demonstrated that when n is large enough, t will also rise and performance will degrade dramatically for those records that are not cached inside LevelDB.

Moving onto smart contract execution inside Ethereum Virtual Machine (EVM), after n transactions are processed we can determine average transaction execution time and the maximum transaction time using formula (3):

$$T_{avg}(n) = T_{exec} + T_{mpt}(n) \quad (3)$$

where T_{exec} – Smart contract execution time (On virtual machine)

After n transactions are executed, according to (4) formula, additional increase in storage size resulted from MPT structure change is:

$$S_{mpt}(n) = s_b\left(\frac{\log(an)}{2} - 1\right) + s_1 + s_a + s' \quad (4)$$

where s_b – size of committed transaction, s_1 – size of leaf node, s_a – space, space consumed by account state, s' – storage capacity used per account.

Including the transaction size here S_t, we can get the final formula as following (5):

$$S_{sumavg}(n) = nS_t + \sum_{i=0}^{n} S_{mpt}(n) \quad (5)$$

Authors have performed experimental validation of presented prediction method. Metrics they gathered during experiment:

– Height of State Tree in Ethereum World State;

– Transaction execution time;

– Memory usage after transaction execution.

Results. Experimental environment consisted only of test node. Single transaction was put into each block because caching systems of Ethereum could skew performance results. Empty smart contract with nearly no logic was used, 1 million transactions were sent in total.

The developed academic qualifications verification platform is implemented as a distributed ecosystem, including a web interface, a DHEP API backend service, and a blockchain infrastructure. The client-side component will operate like a web application and will interact with the server-side API, which will be responsible for the processing of the business logic, the handling of the data, and the orchestration of the write operations on the blockchain network. A schematic representation of the interaction between the components of the ecosystem is shown in Figure 1.

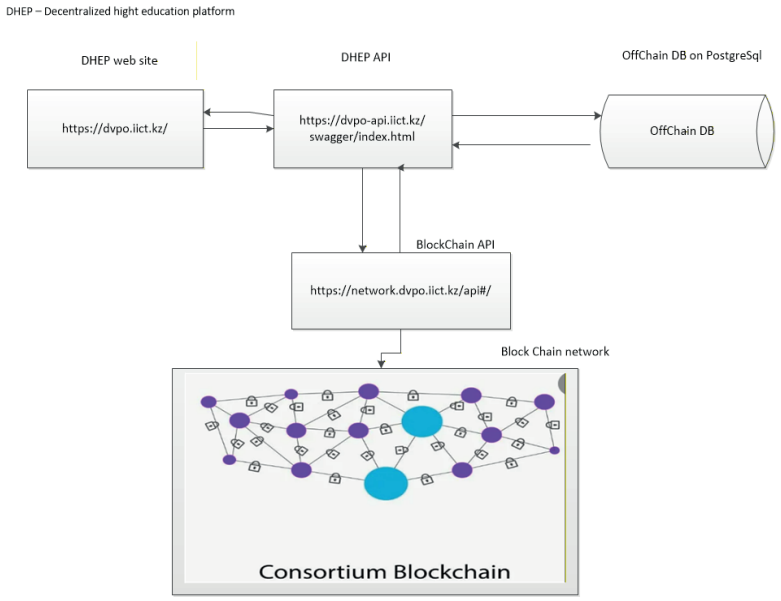

Figure 1 — General diagram of ecosystem interactions

The implementation of the backend layer is the DHEP API, and its architecture is shown in Figure 2. This layer acts as the main data processing node, which processes requests from the web interface, checks the data, manages entities in the centralized database, and interacts with the blockchain network API.

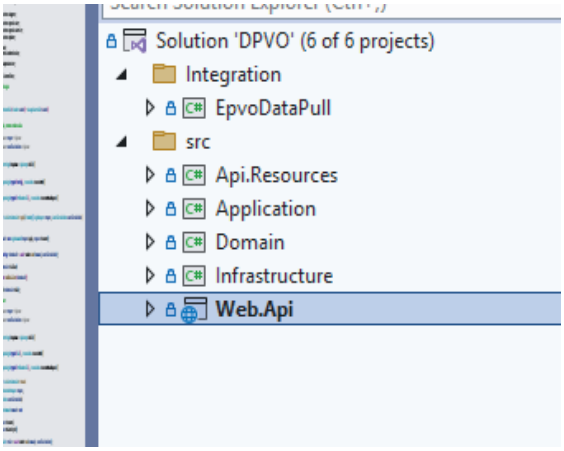

Figure 2 — DHEP API structure

The server-side architecture is based on Clean Architecture principles with the aim of separating business logic from infrastructure dependencies. This paradigm offers a layered system architecture with an application layer, a domain layer, and an infrastructure layer, where Web.Api represents the system's entry point.

The application layer is responsible for coordinating data processing scenarios, managing the life cycle of academic records, and enabling interaction between services. The domain layer includes the core system entities, which are represented by diploma, transcript, and students' data models, as well as business rules related to data processing. The infrastructure layer includes interaction with external components, represented by data sources, authentication, and blockchain nodes. The composition of Web.Api controllers and the distribution of their functional responsibilities are shown in Figure 3:

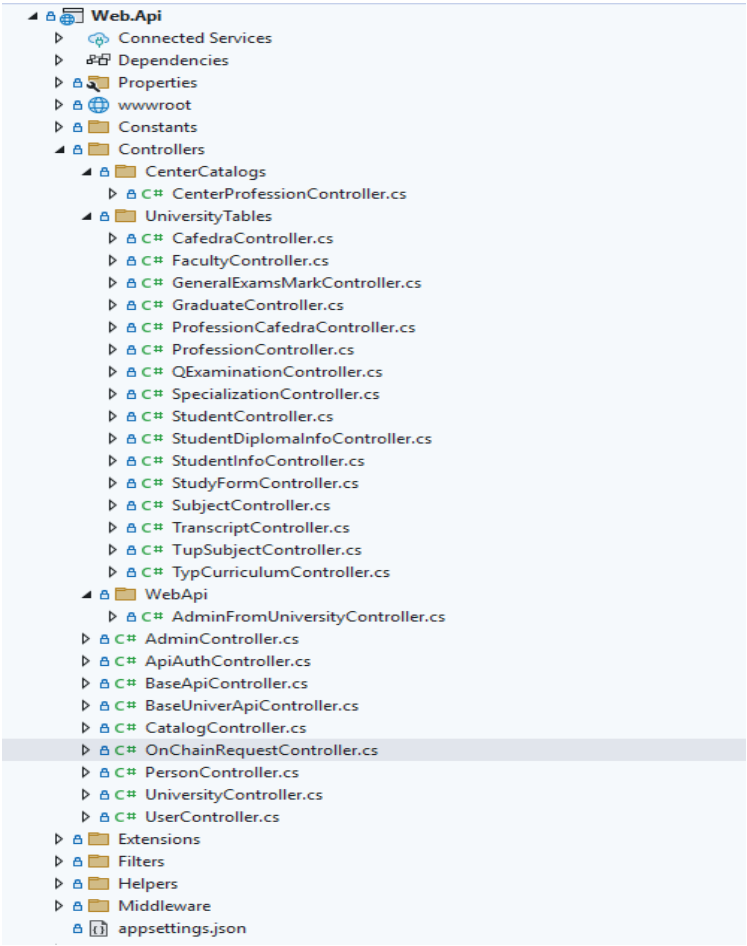

Figure 3 — Web.Api controllers

The system implements a role-based access control model, allowing users to be assigned multiple roles. Basic categories include organizational users, administrators, super administrators, and integration accounts. Access to API functionality is regulated both at the role level and through a permissions mechanism, providing flexible management of interfaces and system operations.

User authentication is implemented using JWT tokens signed with the HmacSha256 algorithm. Passwords are stored encrypted using the SHA-512 algorithm, ensuring the security of credentials.

Academic data storage is implemented using a hybrid model. The bulk of the information, including student personal data, educational program information, and administrative records, is stored in a centralized Off-Chain database built on PostgreSQL. The system utilizes central directories to ensure data consistency across various higher education institutions. Before storing records, they are validated against reference directories.

Data controllers for institutional and academic records implement a full set of CRUD operations, enabling the creation, updating, and deletion of records in the Off-Chain repository. This functional framework is shown in Figure 4:

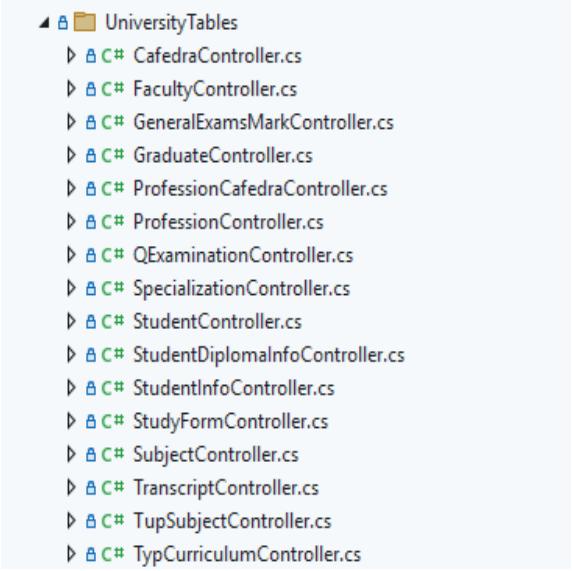

Figure 4 — CRUD controllers for managing organizational data

The process of data transfer to the blockchain network is facilitated using a specialized OnChainRequestController, the architectural role of which is presented in Figure 5:

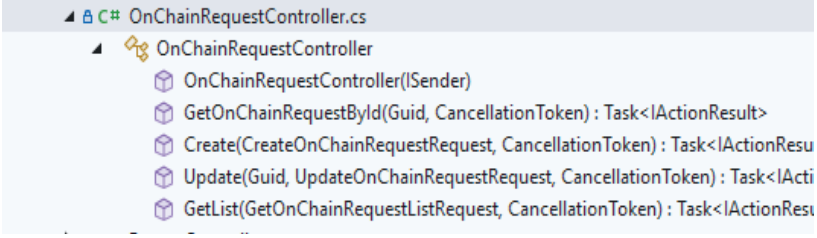

Figure 5 — OnChainRequestController

The Create method of this controller accepts the transcript model, validates the input data, and initiates a transaction on the blockchain network. In response, the system receives a transaction identifier (TransactionId), which is stored in the OnChainRequests table of the centralized database. A fragment of the implementation of this mechanism is shown in Figure 6.

```
2 references | - changes | -authors, -changes
public sealed record CreateOnChainRequestRequest(
    int UniversityId,
    long StudentId,
    long? TranscriptId,
    RequestType RequestType,
    string RequestData,
    string ResponceData,
    string TransactionId,
    DateTimeOffset CreatedAt
    );
```

Figure 6 — Excerpt from the OnChain request processing code

Considering block generation delays, a background transaction processing mechanism has been implemented. The process of transaction status interrogation is periodically carried out to check the status of previous data submissions based on TransactionId. Once the status is confirmed, the process of creating the transaction hash is initiated, ensuring the synchronization of the transcript records within the OffChain database.

Recording academic data on the blockchain network is implemented through two types of smart contracts. The initial contract has been developed for the storage of transcript grades, including course, ECTS credits, final grade, and details of the student and organization. The structural representation of this contract is presented in Figure 7.

```
{
  "transcriptId": 0,
  "memberId": 0,
  "studentId": 0,
  "totalMark": 0,
  "courseNumber": 0,
  "term": 0,
  "transcriptType": 0,
  "subjectId": 0,
  "ects": 0
}
```

Figure 7 — Transcript grade storage contract

The second contract has been designed for the storage of diploma details, including registration, number, series, issue date, and degree award date. The structure of this contract is presented in Figure 8.

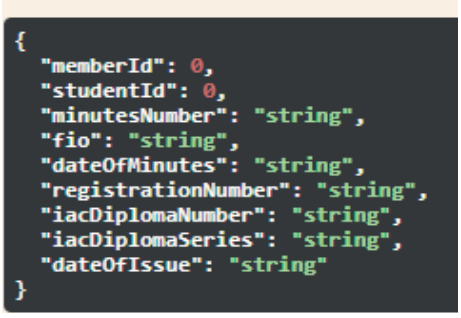

Figure 8 — Diploma data storage contract

The proposed architecture of the DHEP API backend component of the platform has ensured the entire academic data processing cycle, including centralized management, validation, and immutable storage within the distributed ledger. This has been ensured by the segregation of off-chain and on-chain components, the use of layers within the architectural structure, and the use of specialized transaction mechanisms.

Discussions. The server-side implementation of the platform has been realized within the context of the DHEP API backend application, which is responsible for handling client requests, academic data management, and integration with the blockchain infrastructure. This has been realized using the latest server-side implementation technologies, focusing on the development of distributed systems.

The ASP.NET Core framework has been employed as the backend platform, ensuring high-performance HTTP request handling, routing, and modular architecture. This has been done to realize the REST-based API, ensuring standardized interactions between clients and integration services.

The centralized academic data has been stored within the PostgreSQL relational database management system. This DBMS was selected based on requirements for transactional stability, scalability, and support for complex interrelated data structures. The database contains student records, transcripts, diplomas, reference books, and transaction tracking tables.

To work with the database, the Entity Framework Core object-relational mapping mechanism is used, which provides migration management, mapping of domain entities to the database structure, and optimization of data retrieval operations.

Integration with the blockchain network is achieved through an external application programming interface (API), which facilitates the submission of transactions and retrieval of transaction identifiers. Transaction processing is achieved through an asynchronous model, which involves the storage of transaction identifiers and subsequent verification through background checks.

Security of user interactions is achieved through a JSON Web Token (JWT)–based authentication model. Token signatures are generated through HmacSha256 hashing, and user credentials are stored through SHA-512 one-way hashing.

The backend infrastructure was deployed in a server environment with API publishing via secure network protocols. The deployment architecture ensures service availability, scalability, and transaction monitoring.

Thus, the chosen technology stack ensures stable processing of academic data, secure integration with the blockchain infrastructure, and the platform's readiness for expanding functionality.

Analysis of the effectiveness of platform architectural solutions

The developed backend platform was evaluated to analyze the impact of the adopted architectural decisions on data processing performance, data security, and system scalability. In comparison with the conventional centralized educational registries, the developed infrastructure uses the hybrid model of the management of academic information, which has several advantages.

An important factor affecting the performance of the system is the redistribution of computational tasks between the centralized and distributed circuits. The performance of primary transaction processes in the centralized infrastructure makes it possible to quickly register, update, and validate academic information, avoiding the limitations inherent in the blockchain environment.

Data storage in the distributed ledger occurs selectively, which helps to reduce the number of transactions and the time required to confirm them. This architectural model allows for the performance of centralized systems to be maintained while simultaneously implementing immutability mechanisms.

An additional optimization factor is asynchronous transaction processing, which eliminates blocking of user operations while waiting for records to be confirmed in the blockchain network. This ensures the stability of user scenarios and reduces operational latency when working with academic data.

Ensuring the integrity and security of academic records

Integrating cryptographic data capture into the platform architecture significantly increases the level of trust in educational qualifications. The use of hash identifiers ensures the detection of any attempts to modify the original records, as data changes lead to a mismatch between the control values.

The use of smart contract logic creates an immutable storage environment for critical parameters of diplomas and transcripts. Unlike centralized databases, where changes can be made by system administrators, a distributed ledger eliminates the possibility of retrospective editing of records.

An additional layer of security is provided by authentication and access control mechanisms. A multi-level authorization model reduces the likelihood of unauthorized access to registration operations and data uploads to the distributed ledger.

Scalability and resilience of infrastructure

As the participant base expands in the educational ecosystem, the architecture of

the platform is such that it supports scalability. This is achieved by the centralized server architecture, which supports horizontal scaling of computing resources to improve system throughput in line with increasing transactions due to a growing participant base.

The distributed circuit operates on a consortium model, allowing for the addition of new validation nodes. The expansion of the participant network improves the robustness of the infrastructure and reduces the threat of data loss due to unavailability of individual participants.

The separation of storage circuits also improves system robustness. This is because, in spite of a temporary shutdown of the distributed ledger system, the centralized system is always up and running, ensuring continuous recording of academic data.

Comparative analysis with centralized educational registries

In traditional data storage solutions used in the educational domain, infrastructure is largely centralized around databases and provides high processing speeds but does not ensure data immutability. Any changes can only be made with administrative privileges, which reduces the level of trust in digital qualifications.

The proposed hybrid model mitigates this drawback by recording vital parameters in a distributed ledger. This ensures transparency of record origin, independent verification, and the creation of a trusted digital environment for qualification recognition.

At the same time, having a centralized operational framework mitigates performance and storage cost constraints associated with distributed systems.

Generalized Assessment of Architectural Effectiveness

The analysis above shows that the proposed architecture for the backend of the system is effective and provides a well-balanced infrastructure for academic data management in the context of the educational domain.

The implemented solutions provide:

- Maintaining high processing speed;
- Cryptographic security of qualifications;
- Resistance to unauthorized changes;
- Scalability as the number of participants increases;
- Possibility of independent verification of educational documents.

Thus, the integration of a distributed ledger into the server infrastructure of an educational platform increases the level of trust in digital qualifications without reducing the operational efficiency of the system.

Figure 9 provides an overview of architecture for the proposed blockchain transaction processor application highlighting major components and their workflow.

The proposed architecture focuses on building highly performing blockchain-based applications that are secure and deterministic when executed on a permissioned blockchain network.

Microservice-based architecture with asynchronous communication patterns allows the solution to be efficient, scale gracefully, and support fault isolation.

To provide blockchain transaction processing services, NestJS-based OnChain API sits at the application level. The API receives the incoming requests to be executed on blockchain and is responsible for connecting to a PostgreSQL database as its persistent storage layer. The application also features a RabbitMQ-based task queue to decouple API from transaction execution logic, allowing for asynchronous and non-blocking operations.

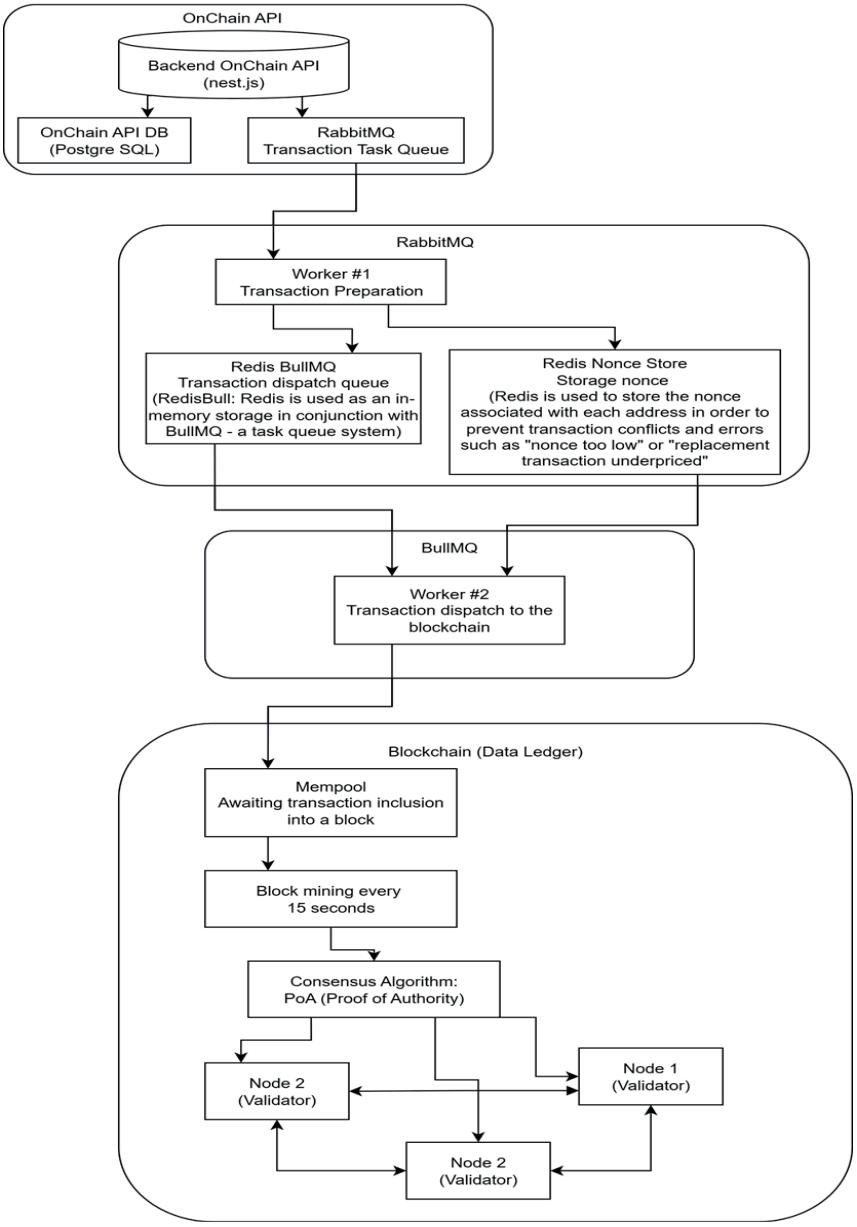

Figure 9 – Detailed architectural diagram of the blockchain-based transaction processing system

In contrast to Ethereum's public blockchain, where smart contracts can be deployed at random times in unpredictable complexity by anybody, consortium networks allow for a certain degree of estimation regarding performance and storage consumption:

- because network nodes are permissioned and access can be regulated;
- smart contracts follow a predefined structure and complexity can be controlled according to the business logic;
- transaction volume is capped by the scope of the enterprise use case at hand.

Therefore, architecture merges the deterministic behavior of a consortium blockchain with the scalability benefits of a microservice architecture.

Conclusion. This study developed and implemented a backend platform for verifying academic qualifications based on a hybrid architecture for storing and processing educational data. The proposed solution integrates a centralized server infrastructure for managing academic records with a distributed blockchain registry, ensuring the immutable recording of critical parameters of diplomas and transcripts.

The proposed architecture provides operational and cryptographic data processing paths and provides high performance for academic data while at the same time ensuring its security. An asynchronous model of transactions is used to prevent user operation blocking and ensure stability in the presence of confirmation delays in the blockchain network. Smart contract infrastructure is used to create a framework for immutable data recording of academic qualifications and enables verification of diplomas and transcripts. Cryptographic identification mechanisms ensure data immunity to retrospective modification and increase the reliability of digital academic documents.

Practical implementation of the proposed platform shows its potential for integrating with existing infrastructure in the educational domain without compromising operational efficiency of centralized systems. The hybrid data storage model ensures a balance between processing performance and record immutability, which is particularly important for scaling national educational platforms. The novelty of this study is achieved in terms of designing a backend architecture that handles academic data workflow coordination, data validation, data dissemination in Off-Chain and On-Chain circuits and subsequently performs cryptographic verification. Unlike existing studies that mostly deal with document capture, the proposed system is focused on executing the entire academic record processing lifecycle at the server infrastructure level.

The contribution of this study in terms of practical applications is achieved in terms of potential use cases in national and transnational educational qualification system development, and trusted digital registries of diplomas. Promising areas for further research include expanding the functionality of smart contracts, developing mechanisms for intersystem interoperability, and implementing analytical tools for monitoring academic data in a distributed environment.

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