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INTEGRATION OF BLOCKCHAIN TECHNOLOGY IN DIGITAL LIBRARIES: A SOFTWARE ENGINEERING DESIGN

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Abstract—*This research aims to design software engineering that integrates blockchain technology in digital libraries to improve system security and reliability. This integration is expected to overcome challenges related to data security, service reliability, and efficiency in digital library management. The research methodology involves collecting data through literature, expert interviews, and observations, on the implementation of blockchain technology in digital libraries, then analyzing data to support data design such as etherum, smart contracts, address, node.js, solidity, metamask, and sublime text, then using the Agile Extreme Programming (XP) method for software development. The research results include the design of a decentralized blockchain architecture, the use of smart contracts, and the application of cryptographic techniques to enhance security. Immutability testing in the context of blockchain involves verifying data consistency, validating the process of adding data, testing the ability to delete data, testing against attacks, and activities on immutable data. These tests were conducted using the Truffle framework. The results show that the system is able to maintain data integrity well.*

Keywords*: blockchain, digital libraries, integration, security, software engineering.*

Intisari—*Penelitian ini bertujuan untuk merancang rekayasa perangkat lunak yang mengintegrasikan teknologi blockchain dalam perpustakaan digital guna meningkatkan keamanan dan keandalan sistem. Integrasi ini diharapkan dapat mengatasi tantangan terkait keamanan data, keandalan layanan, dan efisiensi dalam pengelolaan perpustakaan digital. Metodologi penelitian melibatkan pengumpulan data melalui literatur, wawancara dengan ahli, dan observasi, terhadap implementasi teknologi blockchain dalam perpustakaan digital, kemudian analisis data untuk mendukung perancangan data seperti etherum, smart contract, address, node.js, solidity, metamask, dan sublime text, kemudian menggunakan metode Agile Extreme Programming (XP) untuk pengembangan perangkat lunak. Hasil penelitian mencakup desain arsitektur blockchain terdesentralisasi, penggunaan kontrak pintar, dan penerapan teknik kriptografi untuk meningkatkan keamanan. Pengujian Immutability dalam konteks blockchain melibatkan verifikasi konsistensi data, validasi proses penambahan data, uji kemampuan menghapus data, uji terhadap serangan, dan aktivitas pada data yang tidak dapat diubah. Pengujian ini dilakukan dengan menggunakan kerangka kerja Truffle. Hasilnya menunjukkan bahwa sistem ini mampu menjaga integritas data dengan baik.*

Kata Kunci*: blockchain, perpustakaan digital, integrasi, keamanan, rekayasa perangkat lunak.*

INTRODUCTION

The incorporation of advanced technology in today's digital era has brought about a significant transformation in numerous industries and sectors, including libraries. The increasing need for safe and dependable digital platforms has led to the emergence of blockchain technology as a possible option in digital libraries. Blockchain serves as the foundational technology for digital currencies like Bitcoin. Nevertheless, the scope of blockchain extends beyond financial transactions and can be effectively utilized in other domains, such as digital libraries. Blockchain provides robust security and data integrity by utilizing a decentralized peer-to-peer network that is publicly distributed, transparent, and resistant to tampering [1]. The evolution of blockchain technology may be divided

into three distinct stages: the first 1.0 stage focused on the introduction of digital currencies, the subsequent 2.0 stage centered around the deployment of smart contracts, and the current 3.0 stage characterized by programmable blockchains [2, 3]. Presently, blockchain is in the second phase of its development, primarily utilized in limited-scale local applications, with minimal implementation in industrial-grade or neighborhood-level contexts. However, the distinctive characteristics of blockchain technology have begun to permeate numerous industries [4].

Blockchain provides robust security and data integrity by utilizing a decentralized peer-to-peer network that is publicly distributed, transparent, and resistant to tampering [5]. Blockchain is categorized into three types: public blockchain, alliance blockchain, and private blockchain, based on the perspective of specific applications and system design. A private blockchain is a closed version of blockchain designed for internal information exchange [6].

The assimilation of digital information and the extensive utilization of the internet have altered the manner in which individuals obtain and consume knowledge. Digital libraries have become an indispensable asset for scholars, students, and the general public. Nevertheless, the current digital library architecture has obstacles concerning security and dependability, including data tampering, unauthorized entry, and vulnerabilities to system failures.

Blockchain technology, initially created for digital currencies like Bitcoin, offers a decentralized and unchangeable means of recording transactions that can effectively tackle these difficulties. Through the incorporation of blockchain technology into digital libraries, we can create a clear and secure environment that guarantees the reliability and genuineness of digital assets.

The software engineering architecture will incorporate distinct components and functionalities tailored exclusively for digital libraries. Initially, a network of nodes will be created in a decentralized manner, guaranteeing the spread of data and removing the need for reliance on a central governing body. The implementation of this decentralized architecture will mitigate the risks associated with singular points of failure, hence enhancing the overall reliability of the system. The design will integrate smart contracts, which are programmable agreements that autonomously perform pre-established activities according to specific situations.

Blockchain technology has led to a high demand for smart contracts. A smart contract is an innovative technology that enables autonomous negotiation, execution, and enforcement of agreement conditions within a blockchain ecosystem [2]. Smart contracts offer several advantages over traditional contracts, including risk reduction, decreased administrative and service expenses, and enhanced efficiency in company processes [7]. Significantly, smart contracts possess the ability to establish confidence among participants inside a contract setting that does not rely on trust [8]. It will significantly alter business operations and may disrupt traditional methods [9].

Sinha et al. [10] introduced a technique utilizing smart contracts to enhance the efficiency of delivery management. Lawton et al. [11] demonstrated the applicability of smart contracts to the management system. Khatoon [12] discussed the tangible advantages of utilizing smart contracts in the administration of healthcare. Wang et al. [13] outlined some common application scenarios of smart contracts and deliberated on forthcoming trends in their development. The utilization of smart contracts is essential for enhancing and revolutionizing conventional procurement practices [14, 15].

This technology is essentially a decentralized database based on the underlying bitcoin technology. It offers a novel technical solution that eliminates the need for a third party to store, validate, transmit, and communicate network data. This is achieved through its own distributed nodes. Furthermore, it is regarded as the most revolutionary technological advancement since the creation of the Internet [16].

Smart contracts enable the implementation of safe transactions, copyright management, and access control inside the digital library ecosystem. By implementing this measure, it guarantees that only persons with proper authorization can gain access to and utilize digital assets, hence minimizing the possibility of unauthorized tampering or plagiarism [17][18].

Implementing cryptographic techniques in the proposed design will bolster the security of the digital library. Encryption methods will be employed to safeguard sensitive user data and guarantee confidentiality. Utilizing digital signatures will ensure the legitimacy of digital assets and deter unwanted alterations. Implementing these cryptographic methods will enhance the overall security stance of the digital library system.

The incorporation of blockchain technology in digital libraries holds significant promise for augmenting the security and dependability of these platforms. To establish a robust and reliable digital library ecosystem, we can implement a software engineering architecture that incorporates decentralization, smart contracts, and cryptographic approaches. The objective of this

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research is to enhance current understanding and offer practical guidance for the integration of blockchain technology in digital libraries.

When incorporating blockchain technology into digital libraries, the primary obstacles that must be tackled encompass data security, service reliability, scalability and performance, regulatory compliance, and user acceptance.

Data security is a key concern in digital libraries, and the utilization of blockchain technology is regarded as a promising remedy. Libraries can enhance data security and safeguard the integrity and confidentiality of stored material by utilizing the decentralized and encrypted features inherent in blockchain technology.

The introduction of blockchain technology places significant emphasis on ensuring the dependability of digital library services. Through the utilization of blockchain technology, the efficiency of automation operations such as loans and returns can be enhanced, leading to a decrease in the likelihood of mistakes caused by human intervention and ultimately enhancing the dependability of the system. However, it is imperative to take into account technical and policy limitations that could impact the accessibility of these services.

Scalability and performance concerns are crucial factors to address, particularly when workloads in digital libraries grow. Approaches to tackle this issue revolve around creating a system design that can easily adapt to changes in scale and constantly optimizing it to ensure high performance while yet maintaining efficiency.

Blockchain technology can aid in achieving compliance and adhering to regulations within a digital library setting. Nevertheless, the implementation of this initiative may encounter legal and policy obstacles, necessitating the modification of current legislation to ensure proper and legitimate execution.

Ultimately, the approval and adoption of blockchain technology integration by users is a crucial determinant of success. Enhancing comprehension of users' apprehensions and anticipations, as well as actively engaging them in the process of change, might amplify the acceptance and utilization of novel technology. Providing education about the advantages and management of utilizing blockchain technology can influence digital library users to develop favorable opinions.

This research seeks to enhance security, efficiency, and user acceptance in digital library management by integrating blockchain technology. Additionally, it aims to optimize the loan and return process by implementing smart contracts on the blockchain.

MATERIALS AND METHODS

The research methodology employed in this study is qualitative research, specifically utilizing an exploratory approach. Qualitative research is a type of research that places importance on comprehending and interpreting the phenomenon being studied. An exploratory approach refers to the method used to investigate and examine a phenomenon that is not yet commonly understood or recognized.

The following procedures will be taken in order to undertake this research:

1. Data collection stage
   Data collection is done at this stage using a variety of sources, such as:
   a. Literacy
      Data on literature will be gathered from a variety of sources, including books, articles, and journals. The fundamental ideas of blockchain, security, dependability, and software engineering will be studied using literature data.
   b. Interview
      Subject matter experts in software engineering, security, blockchain, and dependability will be interviewed. To learn more in-depth details about the blockchain's application in digital libraries, interviews will be held.
   c. Observation
      Digital libraries that have adopted blockchain technology will be the subject of observations. The use of blockchain technology in digital libraries will be observed firsthand.
2. Data analysis stage
   In order to create an appropriate software engineering design, the data collected will be analyzed [19, 20]. In order to integrate blockchain technology into the current system architecture, the following supporting materials are needed:
   a. Ethereum is a decentralized software platform that makes it possible to create and operate Distributed Applications (DApps) and Smart Contracts without interruption, fraud, outside control, or interference.
   b. A smart contract is an agreement that is converted into digital form so that it is difficult to perform [21].
   c. Address, a means of establishing a distinct identity within the Ethereum network.
   d. Using the open-source program Node.Js, one can create solidity contracts right in the browser.

e. Solidity is a language for object programming used to create blockchain smart contracts.
f. Metamask is a web browser that facilitates communication with Ethereum-based websites.

3. The software engineering design stage
Furthermore, the author employs the Agile Extreme Programming (XP) approach for software development, alongside data collection and data analysis techniques. Extreme programming (XP) is an agile software development paradigm that emphasizes coding as the primary activity throughout all phases of the software development cycle [22]. The XP technique is a highly adaptable approach [23]. XP allows for the execution of iterations in a repetitive manner as required. XP provides rapid and iterative stages that are tailored to specific areas of attention in order to accomplish desired outcomes. The software development process in XP consists of four stages: planning, designing, coding, and testing [24], as seen in Figure 1.

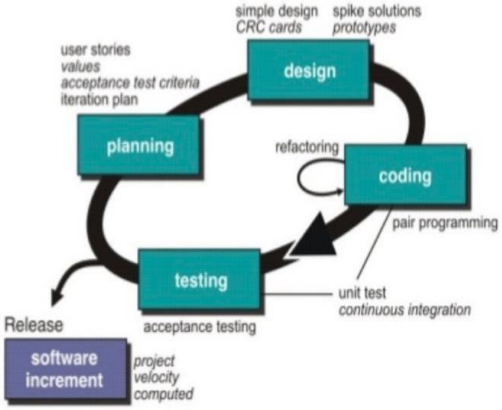

Figure 1. Extreme programming methodology

There are multiple steps to this method, specifically:

a. Planning
During this phase, planning for software development and gathering user requirements are done. To comprehend the needs and create a development plan, the user team and the development team collaborate.
b. Design
Following the planning stage, the software's structure is designed during the design phase. After determining the necessary entities and functions, the development team produces a basic design.
c. Coding
The coding step is completed after the design is finished. Once the design has been converted into program code, the development team puts it into practice.
d. Testing
To make sure the software meets user needs and operates as intended, testing is done after coding. This test examines the software's performance, security, and functionality.

RESULTS AND DISCUSSION

1. Interview

Before getting into planning, researchers conducted interviews with various parties related to digital libraries, be it digital library users, digital library managers, or blockchain experts. The purpose of the interviews was to collect data and information needed to produce a blockchain-based digital library software engineering design. The data and information collected can be: the needs and goals of digital library users, the needs and goals of digital library managers, the advantages and disadvantages of blockchain technology, and how to utilize blockchain for digital libraries.

The results of the interviews conducted, namely researchers can: understand the needs and goals of digital library users, understand the needs and goals of digital library managers, understand the advantages and disadvantages of blockchain technology, and understand how to utilize blockchain for digital libraries.

2. The Planning Stage

The development team worked together with the customer of the digital library to start planning. Stakeholders are actively involved in defining the requirements and prioritizing the functionality to be integrated using blockchain technology. These stakeholders include representatives from libraries and end users. The development team collaborated extensively with security specialists to identify the most effective methods for data security in a distributed setting. The design incorporates the necessary validation and encryption mechanisms to guarantee the highest level of security. Together, the customer and the team decide which essential features should be integrated using blockchain technology.

3. The Design Stage

The following are included in software design:

a. The system architecture known as blockchain architecture describes the layout and functionality of a blockchain network. Blockchain is a distributed technology that

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allows parties to exchange value and information without depending on a single authority. As seen in Figure 2, the blockchain architecture is made up of a number of essential components that cooperate to guarantee the system's security, consistency, and transparency.

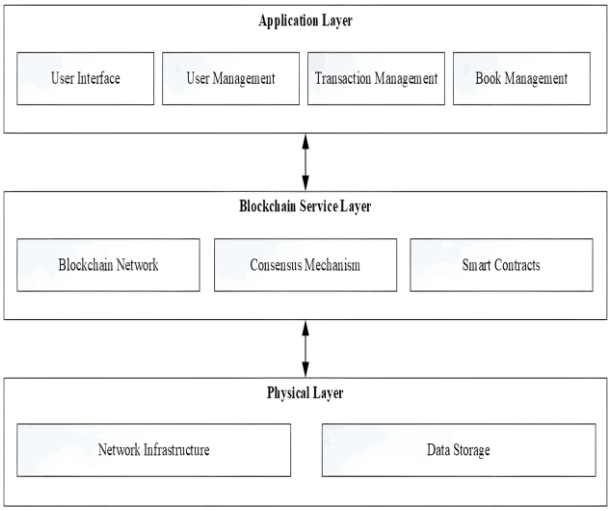

Figure 2. Blockchain Architecture

1) The topmost layer that communicates directly with users of digital libraries is called the application layer. It includes the applications and user interface (UI/UX) that let users interact with the blockchain system. These include:
   a) User Interface: This is the user interface that allows digital library users to interact with the system. The user interface should be well-designed, intuitive and easy to use to facilitate searching, borrowing, returning books and other interactions within the digital library.
   b) User Management: This layer serves to manage user information such as personal data, borrowing history, and membership status. It includes features such as member registration, authentication, and authorization of users to utilize the digital library.
   c) Book Management: This layer manages information about books including title, author, publisher, description, and other attributes. It allows users to search and learn more about the books available in the digital library.
   d) Transaction Management: This layer is responsible for handling transactions such as borrowing and returning books. It will communicate with the blockchain layer to record and confirm valid transactions.
2) The central component of the blockchain architecture, the Blockchain Service Layer manages decentralized data storage, transaction validation, and business logic. It is made up of the following components:
   a) Blockchain Network: This layer is a distributed network consisting of nodes that communicate with each other and exchange information. Data in the blockchain is replicated across every node in the network to achieve consensus and high security.
   b) Consensus Mechanism: This layer defines the rules and protocols used to achieve consensus among the nodes in the network. Consensus methods such as Proof of Work (PoW) or Proof of Stake (PoS) are used for transaction validation and the creation of new blocks.
   c) Smart Contracts: This layer contains the code used to define the business logic that enables automation in digital libraries, such as the validation of borrowing and returning books. Smart contracts run on the blockchain and are executed automatically according to specified conditions.
3) The physical layer involves the physical infrastructure that supports blockchain operations, including network nodes, servers, and other hardware. Responsible for the availability and connectivity of the blockchain network, it consists of:
   a) Network Infrastructure: This layer deals with the physical network infrastructure that supports connectivity between blockchain nodes. This includes components such as servers, routers, switches, and cables needed to ensure stable and secure connections.
   b) Data Storage: This layer serves to store and access data-book information, users, transactions-of the digital library. This data can be stored in the library's data center or using relevant storage technologies, such as distributed databases or cloud-based storage technologies.

Planning and arranging the database structure is known as database design. An effective database design will guarantee that the database can be efficiently accessed, managed, and meet user needs [25].

Book-related data, such as the title, author, genre, and ISBN for unique identification, are stored in Table 1.

Table 1. Book Table Chart

Columns	Data Types	Description
BookID	INT	Primary Key, Unique Identification of Books
Title	VARCHAR	Title of the Book
Author	VARCHAR	Author of the Book
Genre	VARCHAR	Genre of Books
ISBN	VARCHAR	International Identification Numbers

Table 2 includes details about the book's author, such as name and birthdate.

Table 2. Author Table Chart

Columns	Data Types	Description
AuthorID	INT	Primary Key, Author Unique Identification
FirstName	VARCHAR	First Name of the Author
LastName	VARCHAR	Last Name of Author
BirthDate	DATE	Date of Birth of Author

Every transaction, including the borrowing and returning of books, is tracked in Table 3 with reference to the book and the member in question.

Table 3. Publisher Table Chart

Columns	Data Types	Description
PublisherID	INT	Primary Key, Publisher Unique Identification
Name	VARCHAR	Name of Publisher
Address	VARCHAR	Publisher's Address
Email	DATE	Email Address of the Publisher

Details about library users, including name, phone number, and email address, are listed in Table 4.

Table 4. Member Table Chart

Columns	Data Types	Description
MemberID	INT	Primary Key, Member Unique Identification
FirstName	VARCHAR	First Name of Member
LastName	VARCHAR	Last Name of Member
Email	VARCHAR	Email Address of Member
PhoneNumber	VARCHAR	Member's Telephone Number

Every transaction that takes place, including loans and returns of books, is noted in Table 5 along with the book and the member that took part.

Table 5. Transaction Table Chart

Columns	Data Types	Description
TransactionID	INT	Primary Key, Transaction Unique Identification
BookID	INT	Foreign Key of the Book Table
MemberID	INT	Foreign Key of the Members Table
TransactionType	VARCHAR	Transaction Type (Borrowing/Returning)
TransactionDate	DATETIME	Date and Time of Transaction

Blockchain-related data, such as block details, related transactions, block hash, and formation time, are kept in Table 6.

Table 6. Blockchain Data Table Chart

Columns	Data Types	Description
BlockID	INT	Primary Key, Unique Identification Block
PreviousBlockID	INT	Foreign Key to Connect the Previous Block
TransactionID	INT	Foreign Key of Transaction Table
BlockHash	VARCHAR	Hash of Blocks for Security Verification
Timestamp	DATETIME	Block Formation Time

Table 7 is used to record each copy of a book, along with its status (available/borrowed).

Table 7. BookCopy Table Chart

Columns	Data Types	Description
CopyID	INT	Primary Key, Unique Identification of Book Copies
BookID	INT	Foreign Key of Book Table
Status	VARCHAR	Book Copy Status (Available/Borrowed)

Table 8 is used to record each book order by members.

Table 8. Reservation Table Chart

Columns	Data Types	Description
ReservationID	INT	Primary Key, Booking Unique Identification
BookID	INT	Foreign Key of Book Table
MemberID	INT	Foreign Key of Member Table
ReservationDate	DATETIME	Booking Date and Time

b. The process of designing how a user interacts with a computer system is known as user interface design. The goal of user interface design is to simplify the use and comprehension of computer systems for users.

1) Design of Home interface, displays all menus in the application system, which consist of Home, Catalog, Repository, About Us, Contact, and Login, as well as search and logo. The appearance of the Home interface design can be seen in Figure 3.

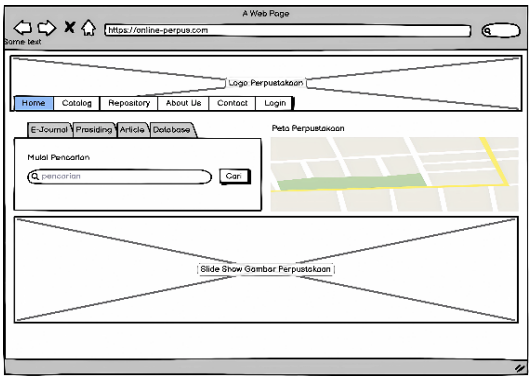

Figure 3. Home Page

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2) The catalog interface design displays a book catalog search consisting of title columns, book types, author names, and locations. The appearance of the catalog interface design can be seen in Figure 4.

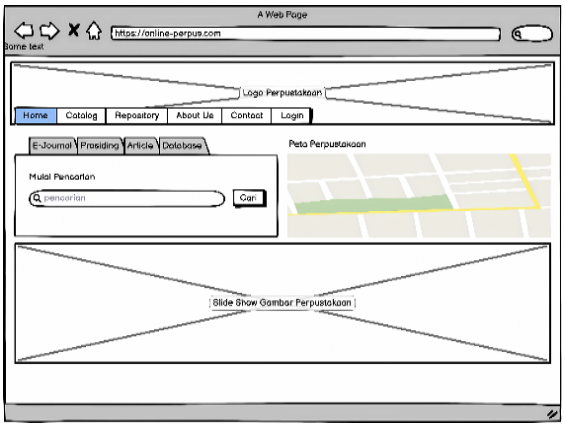

Figure 4. Catalog Page

3) The Repository interface design displays a repository page containing final project documents, such as theses, theses, and dissertations. The appearance of the repository interface design can be seen in Figure 5.

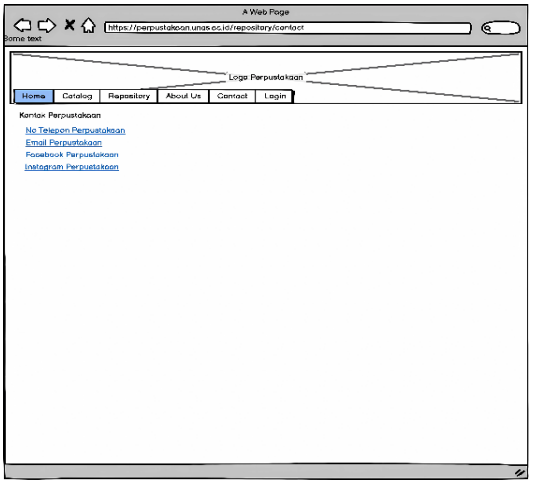

Figure 5. Repository page

c. UML diagram is a graphical modeling language used to design and document software systems [26]. UML is often used by software developers to visualize, document, and understand the design of software systems to be built. In this research, case diagrams, sequence diagrams, and activity diagrams are used.

1) One kind of diagram used in UML (Unified Modeling Language) to depict how a system and user interact is a use case diagram. Figure 6 shows the format of the use case diagram that was employed in this investigation.

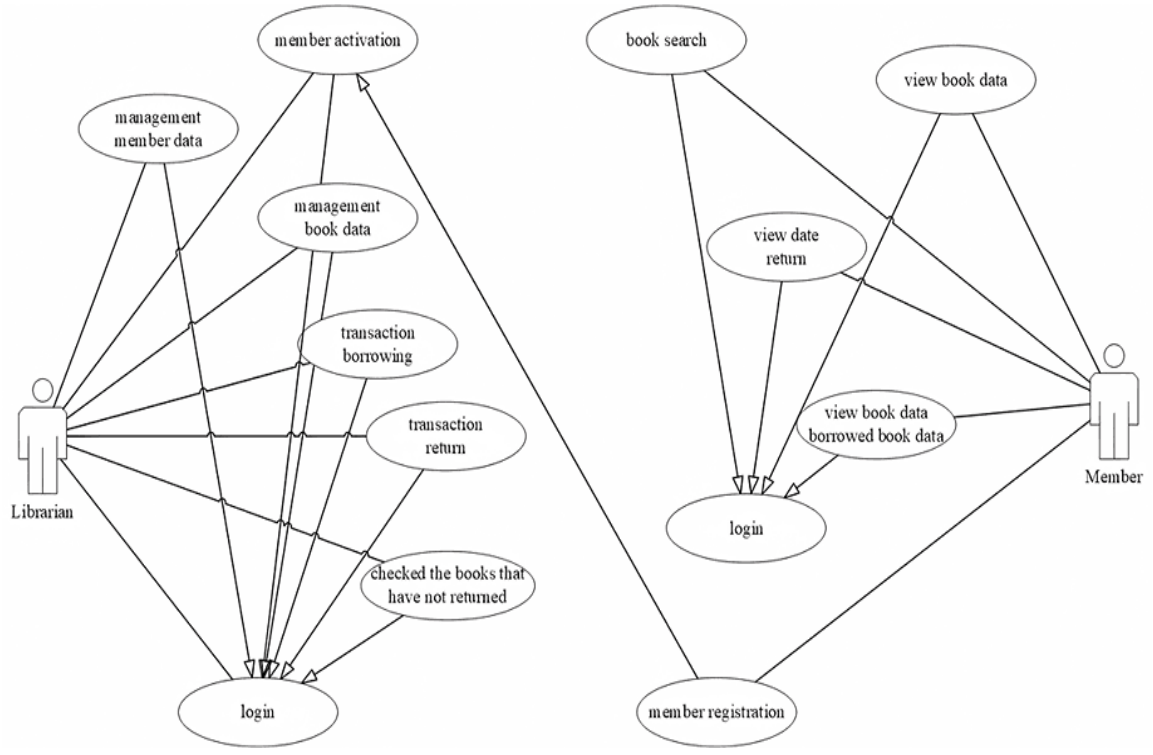

Figure 6. Use Case Diagram

2) In UML (Unified Modeling Language), a sequence diagram is a kind of interaction diagram that shows how objects interact in a specific situation. The sequence diagram shows a succession of messages exchanged between entities at a specific point in time. Figure 7 displays the format of the sequence diagram that was used in this investigation.

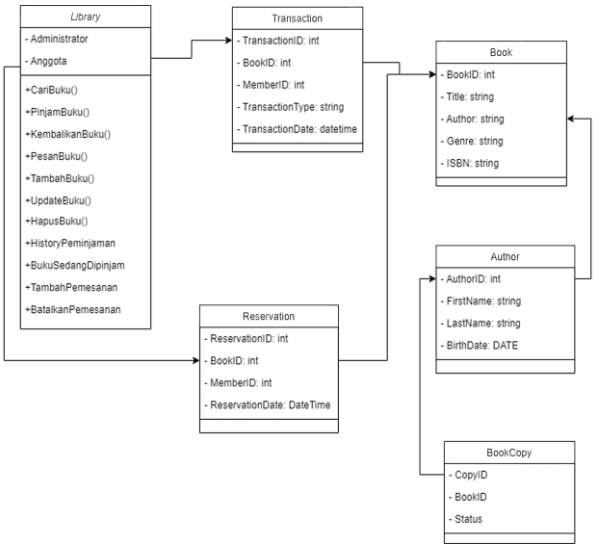

Figure 7. Sequence Diagram

3) A type of diagram used in UML to depict workflows or activities in a system or business process is called an activity diagram. Two activity diagrams are used in this study: the book loan activity diagram (Figure 8) and the book return activity diagram (Figure 9).

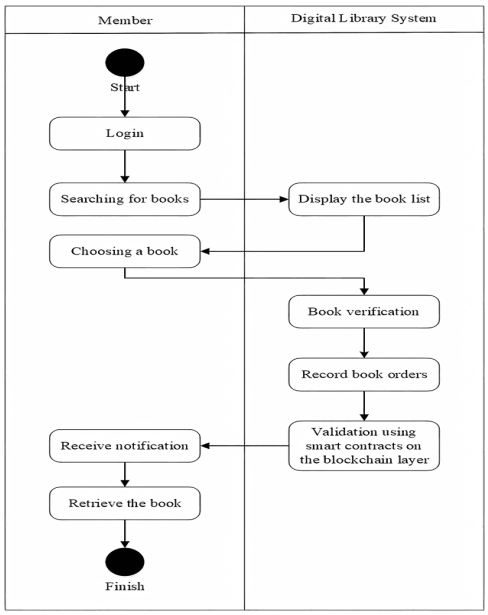

Figure 8. Book Lending Activity Diagram

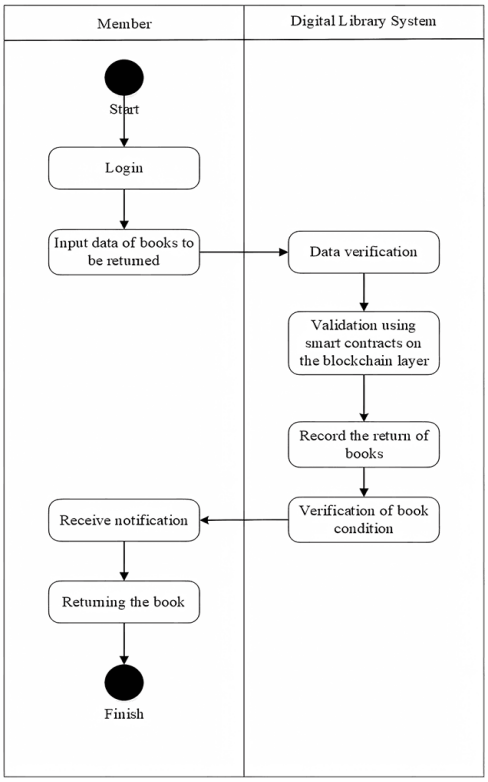

Figure 9. Book Return Activity Diagram

4. The coding stage

The previous system design will be used as the basis for implementation at this point.

a. Home interface appearance
The home page display can be seen in Figure 10, which is the initial display when accessing the application system.

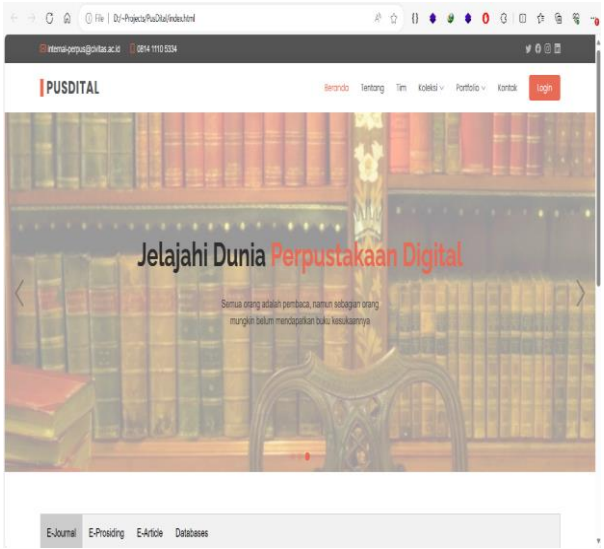

Figure 10. Home Page

b. Search interface display
The display of the Search page, as seen in Figure 11, is a display for searching the book catalog

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along with e-journals, e-proceedings, e-articles, and databases.

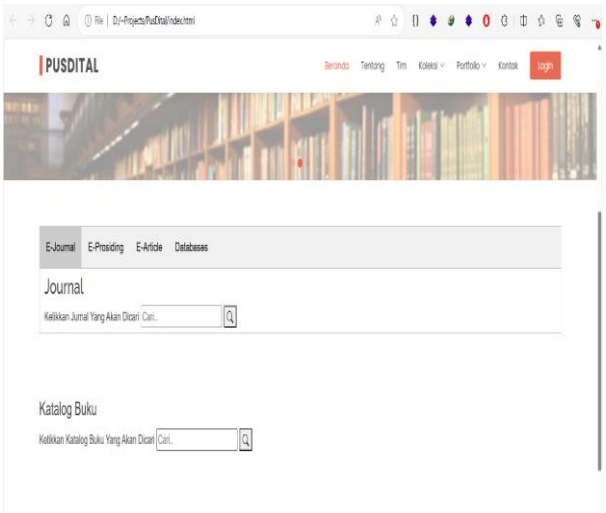

Figure 11. The Search Page

c. Display of the Contact interface
The Contact page can be seen in Figure 12, which contains the address, email, contact number, and map.

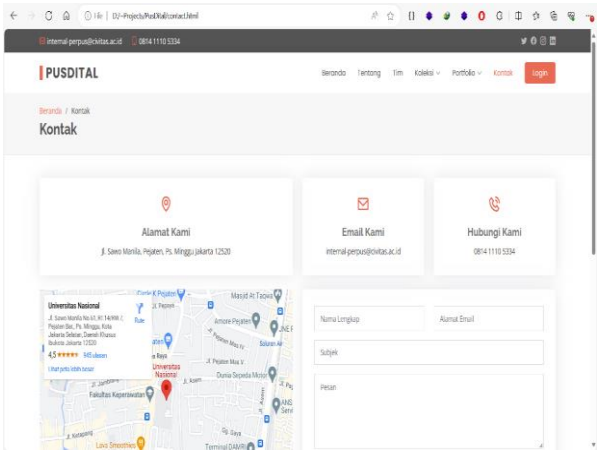

Figure 12. Contact Page

5. The testing page

When incorporating blockchain technology into digital libraries, immutability testing is crucial to guaranteeing the security and integrity of the data stored in the block chain. Some testing procedures that can be used to determine immutability are as follows:

a. Data Consistency Verification: This test aims to check if the data stored in the block chain remains consistent and unchanged over time. You can use blockchain monitoring tools to monitor and compare library data at multiple points in time. This comparison will help identify if any unauthorized changes or manipulations have occurred in the data.
b. Validate the Data Addition Process: It is important to test the process of adding new data into the block chain. In this test, you can simulate the addition of new data into the digital library and verify if the data is successfully added and remains unchanged once it is recorded in the block chain.
c. Test the Ability to Delete Data: In a digital library, sometimes outdated or unnecessary information needs to be deleted. Immutability testing should also include a test of the ability to remove data from the block chain. This will test whether the deleted data can actually no longer be accessed or reconstructed by other parties.
d. Test Against Attacks: Immutability is one of the important advantages offered by blockchain technology, as any alteration or manipulation of data will be visible and easily detectable. In this test, you can try to perform attacks to see if the system is able to detect changes or manipulations and trigger warning signals.
e. Activity on Immutable Data: In this test, you can test the policies and restrictions applied to data that is already recorded in the block chain and cannot be changed, whether the system actually allows or restricts changes to that data. For example, test trying to edit or delete data that is already recorded and see how the system responds.

Testing uses truffle, a blockchain development framework that also provides powerful testing tools. Truffle can be used to build, manage, and test smart contracts in a local development environment.

At this stage, digital library users will test the blockchain-based digital library software engineering design. This testing is done to ensure that the software engineering design meets the needs and expectations of users.

In this testing, researchers involve digital library users to test the user interface, search functionality, the process of borrowing and returning books, and other crucial aspects. Users will be asked to use the software engineering design and provide feedback. This feedback will be used to improve the software engineering design before it is implemented.

User acceptance testing is an important stage in the development of a blockchain-based digital library. This test ensures that the resulting digital library meets the needs and expectations of users. The parties who approve user acceptance testing are digital library users, such as the head of the library, library staff, and users. The results of acceptance testing have been successfully carried out in accordance with the functions and scenarios presented in Table 9.

Table 9: Acceptability testing results

Actor	Function	Scenario	Test Results
User	Book Searching	Users search books by title or author.	Successfully
User	Book Borrowing	The user tries to perform the book borrowing process.	Successfully
User	Book Ordering	The user tries to add a book to the order list.	Successfully
User	Blockchain Transaction Verification	Users verify that transactions on the blockchain are immutable.	Successfully
Admin	Catalog Management	Admin adds or removes books from the catalog.	Successfully
Admin	Member Management	Admin manages member information, such as adding or deleting members.	Successfully
Admin	Smart Contract Verification	The admin verifies that the smart contract remains unmodifiable.	Successfully
System	Security and Authorization	Verifying that only authorized parties can access the system through testing.	Successfully
System	Availability and Durability	Check the system's ability to withstand load and interruptions.	Successfully

CONCLUSION

Security, effectiveness, and user acceptability could all be greatly enhanced by integrating blockchain technology into digital libraries. Digital libraries can create a robust and reliable ecosystem by planning software engineering that takes advantage of blockchain features like decentralization, smart contracts, and cryptography. The results of the immutability test demonstrate that the system has been successful in preserving its immutability, guaranteeing the integrity of the data in the block chain. In terms of security, strong security protocols are used, regular security audits are conducted, and user awareness about security is raised.

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