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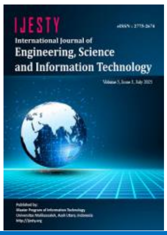

Blockchain Technology Model on Virtual Museum as an Effort to Enchance Balinese Cultural Metaverse

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Abstract

The preservation of cultural heritage in the digital era faces numerous challenges, particularly in securing authenticity, ownership, and preventing damage or loss of digital assets. This study explores the implementation of blockchain technology within a virtual museum dedicated to Balinese culture as part of the broader metaverse environment. Blockchain provides a decentralized and immutable system to record and manage digital cultural assets, ensuring transparency and security in their provenance and ownership. This paper presents a blockchain model for a virtual museum that includes features such as digital tokens and smart contracts, enabling automated processes such as the lending, licensing, and sale of digital artifacts. The integration of this model with metaverse technology creates an interactive and immersive environment for users to explore Balinese culture virtually, while simultaneously ensuring the preservation of its digital representations. The model is developed using the Rapid Application Development (RAD) methodology, enabling quick prototyping and system adjustments based on user requirements. Testing results demonstrate the system's functional success in terms of blockchain transactions and user interaction in the virtual environment. Despite challenges such as regulatory and infrastructural constraints, the findings indicate that the blockchain model has strong potential for application in digital heritage preservation. This study concludes by highlighting the benefits of blockchain in securing cultural assets and its role in promoting the Balinese digital economy through cultural tourism and virtual experiences.

Keywords: *Blockchain Technology, Virtual Museum. Balinese Culture, Metaverse, Digital Heritage Preservation*.

1. Introduction

Blockchain technology has shown tremendous potential in various fields, including the preservation of cultural assets and the strengthening of the digital economy. Virtual museums are one of the innovative forms that allow users to access and experience art and cultural collections in the world and especially in Indonesia, without the need to be physically present at the museum location. However, just like physical collections, digital assets in virtual museums also require proper protection and preservation [1]–[4]. The preservation of digital cultural assets is becoming increasingly important given the risk of loss, damage, or even forgery that can occur in a digital environment.

Blockchain technology offers an attractive solution in this regard, as it is capable of providing a secure, transparent, and verifiable system for recording and tracking digital cultural assets in an irreversible way . The application of blockchain technology in virtual museums can provide several significant benefits. First, by storing metadata about each digital cultural asset on the blockchain, information about history, provenance, and ownership can be better preserved. Second, blockchain can be used to secure copyrights and licenses of digital artworks, providing fair recognition and rewards to creators. Third, by utilizing smart contracts in blockchain, virtual museums can automate processes such as lending digital artworks or selling artworks, increasing efficiency and transparency [5]–[7].

However, the application of blockchain technology in virtual museums also faces several challenges, including the availability of technical infrastructure, implementation costs, and regulatory and legal issues related to copyright and ownership of digital assets [8]–[10]. Considering these potentials and challenges, research on the application of blockchain technology in virtual museums as an effort to preserve digital cultural assets is highly relevant to be developed and implemented [11]–[13].

The research objective is to develop a model that utilizes the potential of blockchain technology in protecting and preserving digital cultural heritage for future generations. Blockchain technology can enable interoperability between virtual worlds, eliminating the need for intermediaries in the metaverse and improving the smooth flow of assets and information [14]–[16]. Moreover, technological advances make it possible to integrate the physical and virtual worlds, expanding interactions and experiences in the metaverse [17]–[21]. Blockchain is a digital distributed ledger that stores data in the form of blocks linked together using cryptographic functions. The metaverse, a virtual world that incorporates various digital technologies such as video conferencing, virtual reality, social media, and artificial intelligence, offers a multifaceted environment with diverse applications and implications [22]–[24]. This environment provides unique features that can benefit the supply chain through technologies such as virtual reality, blockchain, and artificial intelligence, contributing to sustainability and ecological considerations [25], [26].

The implications of the research by implementing and developing a Blockchain technology model on the metaverse so that it can support the digital economy and also the preservation of Balinese culture and can understand how Blockchain works on the metaverse platform. The use of blockchain technology in virtual museums brings significant benefits, especially in terms of data security and transparency. Each Balinese cultural artifact entered into the virtual museum platform will be assigned a unique token recorded in the blockchain, making it possible to verify the authenticity of the artifact, know the history of ownership, and ensure data integrity in a decentralized manner. Incorporating the concept of the metaverse, users can experience Balinese culture firsthand and can explore the virtual museum space, interact with artifacts, and even participate in cultural events and activities organized in the metaverse. This opens up new opportunities to increase awareness and understanding of Bali's cultural heritage on a global level. The development of a blockchain model in a virtual museum, with the integration of the metaverse, is a revolutionary step in the effort to preserve Balinese culture and boost the digital economy. By utilizing the collaboration between technology and culture [27]–[29], it can create an inclusive, interactive, and safe environment for cultural heritage to be explored and keep this precious heritage alive in an ever-evolving digital world.

The problem-solving approach by providing solutions to existing problems is to build and develop a blockchain technology model in the Virtual Museum to test in the protection of digital cultural assets, support for the digital economy, and performance of valid blackbox testing scenarios for system functionality and successful smart contract testing with produce a blue print of the blockchain model in the Balinese cultural metaverse.

2. Literature Review

The convergence between blockchain technology and cultural heritage preservation has become an emerging field of study, particularly as digital transformation reshapes how heritage is stored, accessed, and interpreted. Blockchain, as a decentralized and immutable ledger, offers significant advantages for securing ownership, authenticity, and traceability of digital cultural assets. [1] emphasize the synergy between blockchain, virtual reality, and the metaverse in enabling trustworthy digital ecosystems. These technologies are particularly relevant to museums and cultural institutions seeking to digitize and protect their collections. Several studies have explored blockchain's role in the context of cultural heritage and museums. For example, [5] argue that blockchain can enhance museum transparency and object provenance, while [6] demonstrated its use in managing object loans and transactions. Blockchain also plays a role in copyright protection and monetization, notably through smart contracts and NFTs [8], enabling artists and cultural institutions to retain control over digital reproductions and rights management. In the context of the metaverse, scholars such as [12], [13] highlight the potential of immersive platforms to host virtual exhibitions, learning environments, and cultural events, thus broadening access and engagement.

However, technological adoption is not without challenges. [9] outline legal and regulatory barriers, especially concerning intellectual property rights and cross-border interoperability of systems. Further notes that blockchain's economic model may introduce new forms of digital exclusion if access to platforms and infrastructure is not equitably distributed [10]. In terms of educational applications, researchers like [11] have pointed out the pedagogical value of combining blockchain and virtual environments, leading to immersive learning experiences that also preserve historical narratives. In relation to Balinese cultural preservation, prior research by [24] on augmented reality applications for Lontar Prasi has laid groundwork for using digital tools to revitalize indigenous knowledge. This current study builds upon such work by proposing a more robust model integrating blockchain and the metaverse, aiming to secure digital artifacts while allowing global audiences to interact with Balinese culture in a dynamic, virtual setting.

This review confirms a knowledge gap at the intersection of blockchain-enabled digital heritage systems and metaverse platforms, particularly in the Indonesian context. Therefore, the model proposed in this study contributes to both theory and practice by offering a replicable framework for secure, immersive cultural preservation.

3. Method

In this research for the convergence approach between Metaverse and Blockchain using RAD. (Rapid Application Development) RAD is a system development model that adapts the waterfall model with fast processing time. In previous studies, the RAD method was used in model design [30]–[33]. The following is an overview of the RAD method.

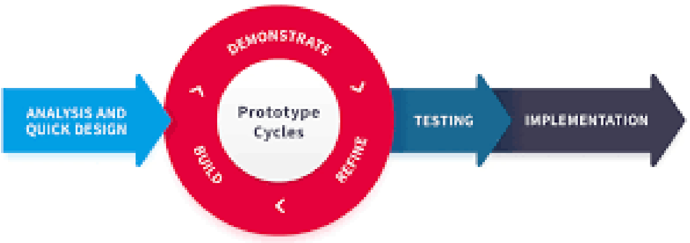

Fig 1. RAD (Rapid Application Development) Method

In the first stage, an analysis and data mining study related to Balinese cultural metadata, namely Balinese masks and Balinese lontar prasi, was conducted. Needs analysis and data identification are carried out in accordance with the activity schedule. Furthermore, researchers design user needs in blockchain-based virtual museums. In this research for the convergence approach between Metaverse and Blockchain using RAD. RAD is a system development model that adapts the waterfall model with fast processing time. In previous studies, the RAD method was used in model design. The following is an overview of the RAD method. At the requirement planning stage begins with identifying the research objectives, namely to create a virtual museum blockchain model in order to develop the digitization of Balinese culture, such as statues, inscriptions, and Balinese Lontar Prasi. At stage 1. Requirement Planing researchers identify the metadata that can then be integrated into the metaverse and blockchain by utilizing smart contracts and digital tokens. The Design Workshop stage is aimed at designing a virtual museum blockchain model. In the flowchart above the user will be directed to create an account on the e-wallet and verify so that the login to the virtual museum can be accessed. Then the verification is processed, if it is successful it will enter the wallet account and the user chooses the token that has been prepared. The user will enter the token and if successful, the user will be able to access and explore the virtual museum.

The next stage of research activities is to design the Blockchain model and blueprint for the Virtual Museum. logical architecture of the virtual museum blockchain model to determine the functionality of the virtual museum web application and data communication with the polygon matic network can be connected. The implementation stage is to build a virtual reality-based museum web application equipped with 3D assets from Balinese statues, inscriptions, and Lontar Prasi that have been stored in the master database.

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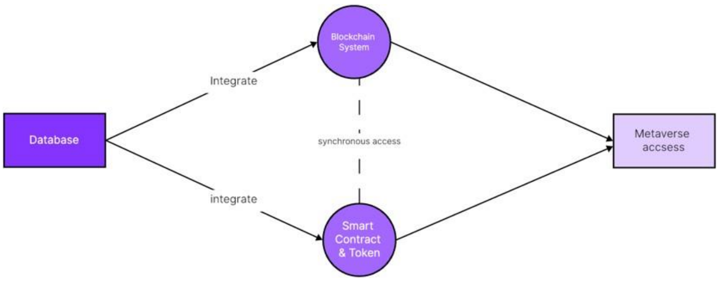

Fig 2. Flow Requirement Planing

Furthermore, the Workshop Design stage is aimed at designing a virtual museum blockchain model which can be described in the flowchart in Figure 3 below.

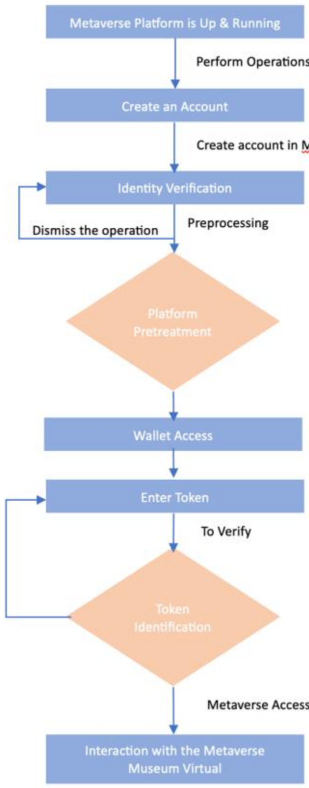

Fig 3. Flowchart of the Blockchain Model in the Virtual Museum

Based on Figure 3, it can be explained that in the flowchart above the user will be directed to create an account on the e-wallet and verify so that the login to the virtual museum can be accessed. Then the verification is processed, if it is successful it will enter the wallet account and the user chooses the token that has been prepared. The user will enter the token and if successful, the user will be able to access and explore the virtual museum. To make transactions, the web application will direct to the Polygon Matic Virtual Machine which is already connected to a digital wallet, namely the metamask wallet. In this system, the metamask wallet is connected to the Ganache application to obtain Polygon Matic Coin. Metamask and Ganache are third-party applications that are connected to the Ethereum network and have been used by many users.

The Ethereum gate in this application consists of Web3.JS which connects the web application to connect to the Polygon Matic Network which includes smart contracts and also the local Polygon Matic blockchain which records all processes carried out by users in the virtual museum web application. To be able to continue at the implementation stage, it is necessary to have a logical architecture of the virtual museum blockchain model to determine the functionality of the virtual museum web application and data communication with the Polygon Matic network can be connected. The implementation stage is to build a virtual reality-based museum web application equipped with 3D assets from Balinese statues, inscriptions, and Lontar Prasi that have been stored in the master database.

4.1. Data Analysis

In the first stage, an analysis and data mining study related to Balinese cultural metadata, namely Balinese masks and Balinese lontar prasi, was conducted. Needs analysis and data identification are carried out in accordance with the activity schedule, which is for two months. Can be seen in the figure below.

Fig 4. Balinese Mask 3D Asset

In the virtual museum there are several Balinese masks as assets that can be seen by visitors to the virtual museum, by utilizing AR / VR technology in visualizing 3D from mask objects, so that visitors can see every detail of the Balinese mask assets.

4.2. Virtual Museum Implementation

The implementation of the virtual museum can be done in the polygon matic network, and there is a connection process with the metamask wallet. successfully connected, the user can select the menu displayed, and can choose sign in & pay so that the user can explore the virtual museum. users can access and explore the virtual museum, by viewing existing collections according to the metadata obtained.

(a)

(b)

Fig 5. (a) and (b). Virtual Museum Display

4.3. Testing the Blockhain Network Model Smart Contract

The next stage is testing the virtual museum blockchain model by conducting blackbox testing and successful transactions with the "Amoy" token. Website for checking amoy token transactions, 0xE7690bef4931bAB9afD98605004e2CD643094855 is a metamask wallet for the wallet that is transferred.

This section is block data that has successfully made a transaction. There is Txn hash for blockchain hash data, method for the type of blockchain usage, block for block numbering data in the transaction, date time for date and time, from for the wallet of the sender's wallet address, to for the wallet of the destination wallet address, amount is the amount of tokens transferred and Txn fee is the commission/gas fee that must be paid for transactions outside of the transaction amount.

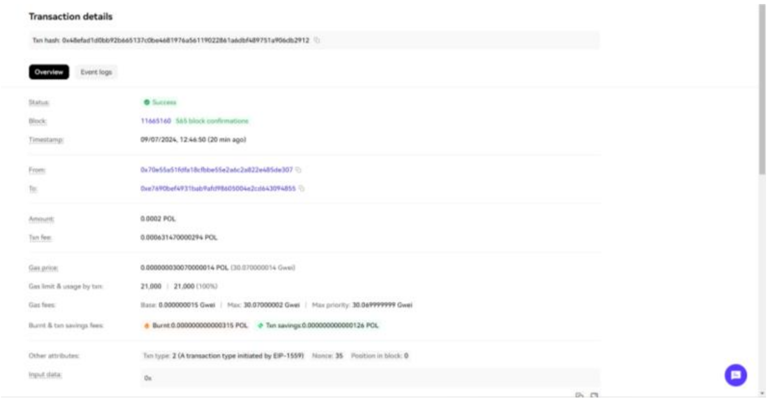

Fig 6. Transaction status block

Here is the data from one of the Txn hashes, which displays the status of the transaction, block for the block numbering data in the transaction, timestamp for the date and time, from for the wallet of the sender's wallet address, to for the wallet of the destination wallet address, amount is the amount of tokens transferred and Txn fee is the commission/gas fee that must be paid for transactions outside of the transaction amount, gas price for the service fee on the transaction, gas limit for the gas limit used in the transaction, gas fees fees from the gas price Gwei is the unit used to measure the gas price on the Ethereum network. Burnt & txn saving is the total tokens burned for the transaction.

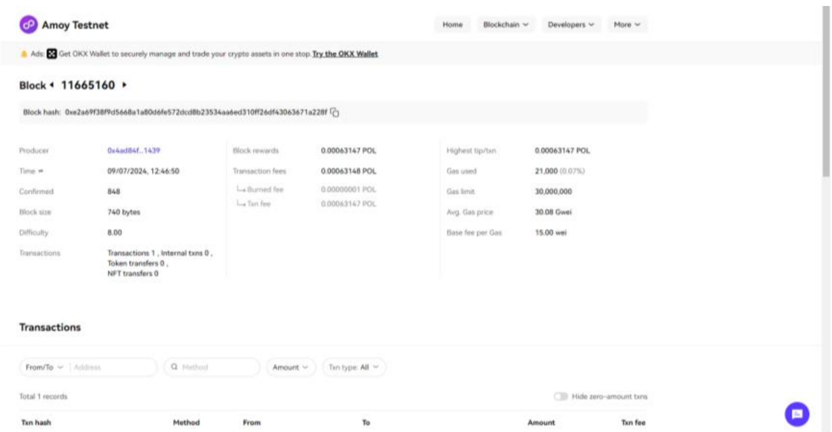

Fig 7. Transaction Producer

Here is the Block data on one of the transactions. Producer is the address of the miner/validator that validates the transaction created. Confirmed is how many blocks from the transaction network are created after the user makes a transaction on the network, block size is the size of the block data used for the transaction. Difficulty is the level of difficulty of completing the transaction, the greater the transaction nominal, the greater the level of difficulty itself (based on the gas fee).

4.4. Device Connectivity Performance Testing

In the process of testing device connectivity performance, there are 4 devices used in accessing from the virtual museum. The results of this performance test, in the form of how long it takes to make each transaction to the blockchain system. The unit used in this performance test is seconds.

Table 1. Device specifications

No.	Device Name	Specification
1	Device 1	2.3 GHz Quad-Core Intel Core i7 Processor
		Graphics Intel Iris Plus Graphics 1536 MB
		16 GB 3733 MHz LPDDR4X Memory
		Mac OS Sonoma 14.2.1
2	Device 2	16GB RTX 4060Ti VGA
		Processor Intel(R) Core(TM) i5-14400 2.50 GHz
		Installed RAM32 .0 GB (31.6 GB usable)
		System type 64-bit Windows 11 Pro operating system, x64-based processor
3	Device 3	Processor 11th Gen Intel(R) Core(TM) i5-11400H @2.70 GHz 2.69 GHz
		24.0 GB installed RAM (23.8 GB usable)
		System Type 64-bit operating system x64-based processor
		Windows 11 Home Single Language
4	Device 4	Processor 11th Gen Intel(R) Core(TM) i7-1165G7 @2.80 GHz (8 CPUs), ~2.8 GHZ
		Memory 16384 MB RAM
		Operating System Windows 11 Pro 64-bit (10.0, Build 22631)

Based on the 4 devices, 4 performance testing scenarios were carried out to determine the time required to access and perform each process on the virtual museum blockchain system.

Table 2. Performance Testing Results

No.	Testing	Results (in Seconds)			
		Device 1	Device 2	Device 3	Device 4
1	Opening the Virtual Museum website	19s	10s	15s	25s
2	Connecting Wallet to Metamask	30s	26s	29s	40s
3	Display the Virtual Museum Main Menu	15s	8s	10s	18s
4	Displaying Virtual Text and Audio Guide	15s	10s	15s	17s

Based on the table above, it can be explained that testing was carried out using 4 devices with different specifications and operating systems but connected to the same internet network. The test results show that the Virtual Museum Site can be accessed with various operating system platforms, namely Windows and Mac OS. From the results of device performance testing, it can be concluded that Device 2 gets the fastest time when accessing virtual museums and Device with the longest access time is device 4. So that in addition to internet connection, differences in specifications ranging from processor, memory to VGA affect the fast or slow device in accessing virtual museums.

4.5. Virtual Museum Blackbox Testing

Blackbox testing is intended to test system functionality for all features using blackbox testing, this test aims to determine the level of conformity of system features without system bugs and errors. Blackbox testing is done to test the system is running according to the features and flow that is done. The following are the test results from Blackbox testing.

Table 3. Blackbox Testing

No	Scenarios	Expected Outcome	Testing Results
1.	Opening the Virtual Museum website	The Virtual Museum site can be run on a browser	Success
2.	Pressing the Connect Wallet Button	Connecting Museum with Token Wallet and Connecting into Metamask	Success
3.	Display the Virtual Museum Main Menu	Displays 3 main menus of the Virtual Museum: - Sign in and pay - About Virtual Museum - Add Polygon Network to Wallet	Success
4	Press the sign in and pay buttons	Login to enter the Virtual Museum and Make Token Payment	Success
5.	Pressing the About Virtual Museum Button	Display the Visit Museum button to enter the museum	Success
6.	Pressing Add Polygon Network	Select the token network to use	Success

	to Wallet Button		
7.	Making Payments Using Tokens	Making Payments Using Tokens	Success
8.	Pressing Button Visit Here	Enter the Virtual Museum	Success
9	Displaying Guide Virtual	Displaying 3D Human Objects as Virtual Guides	Success
10.	Virtual Guide outputs audio and text	Display sound and text	Success
11.	Displaying the Virtual Mask on the Museum	Displaying Virtual Mask 3D Objects	Success
12.	Display information about the content of Lontar Prasi	Display information about the content of Lontar Prasi	Success

5. Conclusion

The development of a blockchain-based virtual museum model, integrated into the metaverse, offers significant advancements in preserving and promoting Balinese cultural heritage in the digital age. By implementing blockchain, the authenticity, ownership, and provenance of digital cultural assets are safeguarded, ensuring transparency and security. The use of smart contracts further enhances the automation of processes such as digital artwork transactions, lending, and rights management. Through this integration, the project contributes not only to the protection of cultural assets but also to the growth of the digital economy. Despite challenges such as technical infrastructure and legal considerations, the successful implementation of this model demonstrates the feasibility of blockchain in cultural heritage preservation. Future research should focus on refining the technical aspects and addressing regulatory frameworks to ensure broader adoption.

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