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Blockchain-Enabled Hybrid Auction System for State-Owned Tangible Assets

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Abstract

Centralized online auctions for state-owned tangible assets suffer from human intervention, high fees, and opaque bid handling. We design and field-test a blockchain-enabled hybrid architecture that records bids, audit logs, and asset transfers on-chain while maintaining off-chain Know-Your-Customer (KYC), deposit, and appraisal workflows required by Vietnam's 2016 Law on Property Auction. A prototype on Binance Smart Chain(BSC) supported government auctions with a median 100 qualified bids each, confirmed within 7.5 seconds and at 84.9 % lower operating cost than the incumbent web platform. All respondents (n = 78) perceived the new process as fair and transparent. These results provide the first empirical evidence that a regulatory-aware hybrid design can meet both legal and transparency requirements for public-sector disposals, and they offer a replicable blueprint for other high-value asset auctions.

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Keywords: Hybrid auction system; Blockchain-based bidding; Smart contracts; Public asset auction; Regulatory compliance; On-chain transparency; NFT

1. Introduction

Online auctions for state-owned tangible assets are still dominated by centralized Web-2 architectures, where auctioneers act as trusted intermediaries and exercise full control over bid handling, fee schedules, and data visibility. This model exposes participants to human intervention, single-point-of-failure risks, and opaque server-side edits that

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encourage shill bidding and bid sniping. This ultimately erodes bidder trust and perceived fairness [1, 2]. To overcome these shortcomings, the research community has proposed a variety of decentralized auction protocols. These include sealed-bid commit-reveal schemes, zk-SNARK/zk-STARK designs, and non-malleable timed commitments for NFTs, cloud resources, and other digital or intangible assets [3, 4, 5]. While these solutions remove the trusted intermediary and record bids immutably on-chain, they generally ignore the statutory KYC, appraisal, and treasury workflows that remain mandatory when the asset being sold is a physical object owned by the public sector.

Recognising this regulatory constraint, several authors have explored hybrid on-/off-chain architectures that retain off-chain components for identity checks or metadata storage yet anchor key auction events to smart contracts [6, 7, 8, 9]. However, most of these hybrids stop short of offering an end-to-end design that satisfies (i) the disclosure, timestamping, and record-retention rules that govern state-owned property and (ii) the usability expectations of non-crypto-native bidders. These compliance requirements are codified in multiple jurisdictions—for example, Directive 2014/24/EU on public procurement, the EU MiCA Regulation 2023/1114, Vietnam's Law on Property Auction 2016, and its implementing decrees [10, 11, 12, 13, 14] - and together they mandate immutable bid logs, rigorous AML(Anti-Money Laundering)/KYC checks, and verifiable audit trails.

Meanwhile, the industry landscape has demonstrated a growing appetite for blockchain-based auctions. Industry leading auction organizers such as Christie's, Sotheby's and Millon have tokenised artwork and conducted digital- asset auctions on public blockchains [15, 16, 17, 18, 19]. Energy, data-market, and spectrum-trading platforms have adopted similar mechanics for intangible goods [20, 21, 22, 23, 24]. Vietnam's National Digital Transformation Programme also identifies online auction services as a priority sector [25]. These advances underscore that decentralized technology and innovations like tokenisation are likely to shape the future of public-sector disposals, yet they also highlight a gap between experimental protocols for digital assets and legally compliant solutions for tangible property. Against this backdrop, fraud and manipulation (e.g., shill bidding, phantom bids, and algorithmic bid sniping) remain pressing concerns [26], and existing centralized systems provide limited transparency. Consequently, two un- resolved challenges persist: (1) designing a regulatory-aware hybrid architecture that combines on-chain transparency with off-chain compliance and (2) supplying comprehensive empirical evidence: throughput, latency, cost, and user experience, under real-world workloads involving non-crypto-native bidders.

This study addresses two main research questions:

1. Can a regulatory-aware hybrid architecture achieve on-chain-grade transparency while fulfilling legal and usability requirements for auctions of tangible state assets?
2. What performance and cost trade-offs arise when such a system is deployed in live government auctions?

To answer these questions, this paper contributes the following:

1. A compliance-centric hybrid design that records bids and asset transfers on-chain while keeping KYC, deposit, and appraisal workflows off-chain under Vietnam's Law 01/2016/QH14.
2. The first field data set from government auctions showing 7.5 seconds bid finality and an 84.9 % reduction in operating costs compared with our existing centralized platform.
3. Smart-contract templates and deployment workflow that other jurisdictions can adapt for high-value public-asset disposals.

This paper is structured as follows: Section 2 details the system architecture. Section 3 presents the field results. Section 4 discusses key findings, limitations, and future research directions. Finally, Section 5 concludes the paper.

2. Proposed Method

The auction of public assets in Vietnam is governed by a robust legal framework, primarily the Law on Property Auction 2016 (Law No. 01/2016/QH14), supplemented by recent regulations such as Decree 172/2024/ND-CP (detailed guidance on online auction procedures) and Decree 50/2025/ND-CP (further amendments on public asset auction procedures). The auction process must comply with these laws to ensure transparency, fair valuation, and efficient management of public assets, especially for online auctions. To address challenges in both the auction service industry and regulatory compliance, we propose a hybrid approach in which core auction functionalities (such as NFT minting, smart contract execution, bidding procedures, and auction logic) are implemented on a blockchain network (on-chain). Other processes, such as interactions between the State Agency and the Auction Organizer, Know Your Customer (KYC) procedures, asset legality verification, and legal contract signing, remain off-chain. This creates a

secure, automated, transparent, and trustworthy environment for auction interactions while maintaining compliance with auction laws and regulations (see Fig. 1).

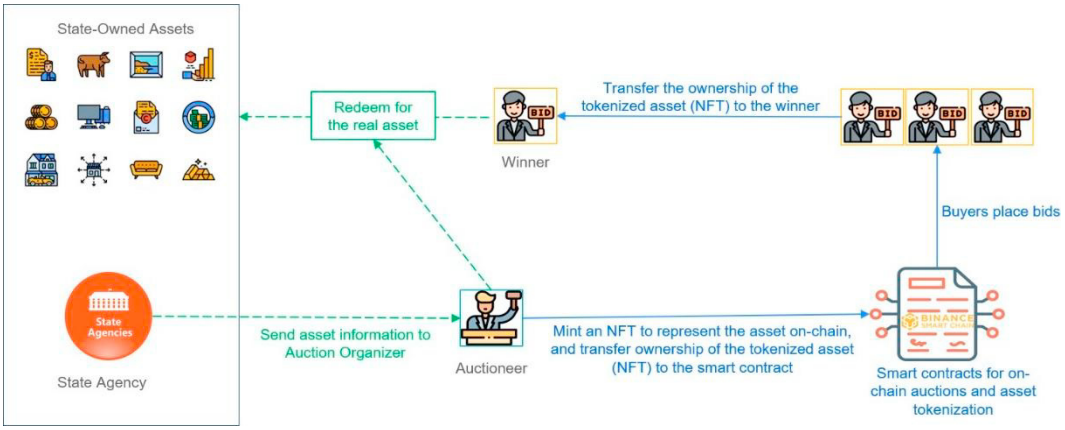


Fig. 1. Overview of the hybrid auction model for tangible state-owned assets (Green: Off-Chain, Blue: On-Chain).

We proposed a multi-component system by integrating front ends, blockchain smart contracts, decentralized storage, and oracle network (see Fig. 2).

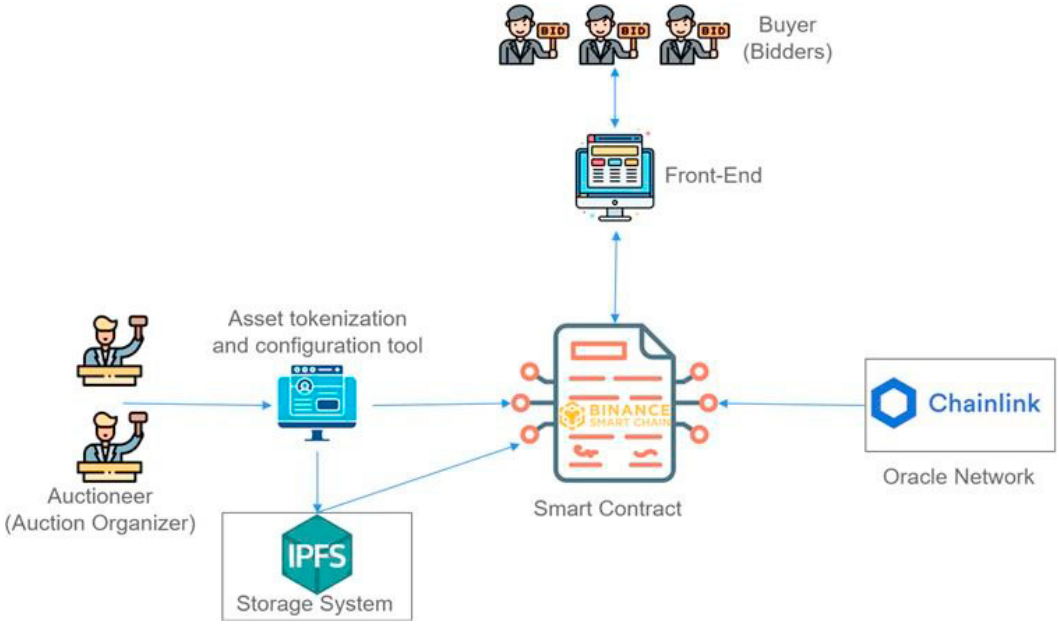


Fig. 2. Detailed system architecture for the hybrid blockchain auction platform. The architecture integrates smart contracts, IPFS, oracles, front ends, and role-based actors (e.g., Auction Organizer, State Agency, Bidder) to ensure secure and compliant interactions.

It operates on a blockchain that supports smart contracts and NFTs for on-chain functionality, with IPFS for off-chain data storage, oracles for external data verification. The front-end, where the bidder and the auctioneer can view and interact with smart contracts, is developed using technologies such as HTML, CSS, and JavaScript. There are seven primary roles in the approach: (1) Auction Organizer (AO, also known as Auctioneer): Entity managing auction. (2) State Agency (SA): State asset owner representative who delegates sales function to the AO. (3) Bidders (B):

Participants submitting bids. (4) Winner (W): Successful bidder acquiring the asset. (5) Storage System (SS): Decentralized storage for asset metadata. (6) Oracle Network (OR): External data verifiers for real-world parameters and (7) Smart contracts: Code for auctions is automatically executed on-chain. Fig. 3 shows a detailed sequence diagram that illustrates how these components work together.

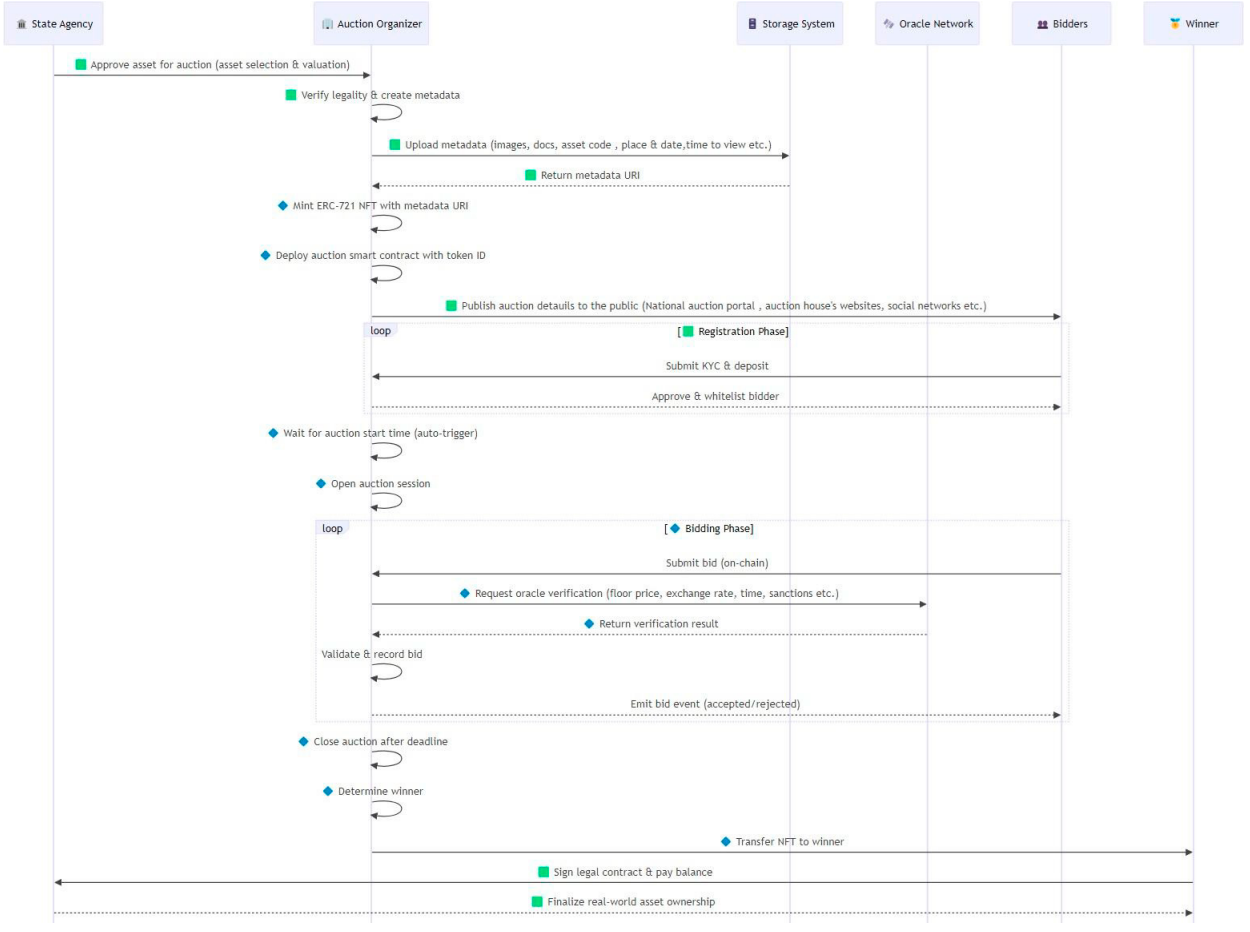


Fig. 3. End-to-end sequence of events in hybrid auctioning of state-owned assets. Green represents off-chain activities (e.g., registration, KYC, legal verification), and blue denotes on-chain logic (bid handling, NFT issuance, and smart contract events).

3. Results

3.1. Implementation

The smart contracts for tokenizing real-world assets into NFTs, conducting on-chain bidding, and transferring NFT ownership to winners are written in Solidity language. Public assets in the real world (such as cars and apartment units) are unique. Therefore, each asset is digitized as an NFT that complies with the ERC-721 standard, is described in Algorithm 1. The token's metadata is hosted on Pinata Cloud, and a representative JSON payload is provided in Fig 4.

Algorithm 1. Smart contract pseudocode for tokenizing real-world assets into NFTs.

Contract *StateOwnedAssetNFT* inherits ERC721, Ownable *Extends the ERC-721 standard and grants owner-only minting privileges.*
Variable: tokenCounter ← 0 *ID counter tracking the number of minted NFTs.*
function CONSTRUCTOR
    Set the token's name and symbol. *Branding: NFT name and symbol.*
    tokenCounter ← 0. *Initialize counter for extra safety.*
end function
function MINTNFT(to, tokenURI)
    tokenId ← tokenCounter. *Assign next available ID.*
    _ mint(to, tokenId). *Create the NFT.*
    _ setTokenURI(tokenId, tokenURI). *Attach metadata URI.*
    tokenCounter++. *Increment counter for next mint.*
    return tokenId. *Return the newly minted token's ID.*
end function
function _BaseURI
    return default base URI. *Root path for token metadata.*
end function


```
{
  "name": "QSH Căn hộ 1904A - HH02 - Eco Lakeview",
  "description": "Tokenized apartment for ownership transfer - QSH 1904A - HH02 - Eco Lakeview",
  "assetType": "Apartment",
  "image": "ipfs://bafybeigmi44cjvxys7yr7r7qgq5c4z7uqiyb7nrjnuk33nt6kkhoaoljlu",
  "animation_url": "ipfs://bafybeieglb6yfiuewqsjae447mpiww5ezwe64mb7zjsrzczmjknyikbowy",
  "documents": {
    "notice_of_asset_auction_pdf": "ipfs://bafybeieglb6yfiuewqsjae447mpiww5ezwe64mb7zjsrzczmjknyikbowy",
    "asset_auction_regulations_pdf": "ipfs://bafybeicwijycks5llhmzbs5rdbnoslqew3zd7prkqunxxebrenhhflbdw4"
  },
  "attributes": [
    { "trait_type": "Starting price", "value": "2.490.840.000 VNĐ" },
    { "trait_type": "Property code", "value": "MTS-9Z950B" },
    { "trait_type": "Property owner", "value": "TỔNG CÔNG TY LÂM NGHIỆP VIỆT NAM" },
    { "trait_type": "Viewing location", "value": "HH02 & HH03, Eco Lakeview, 32 Đại Từ, Đại Kim, Hoàng Mai, Hà Nội" },
    { "trait_type": "Viewing time", "value": "01/08/2023 - 02/08/2023" },
    { "trait_type": "Room", "value": "1904A" },
    { "trait_type": "Building", "value": "HH02" },
    { "trait_type": "Project", "value": "Eco Lakeview" },
    { "trait_type": "Auction organizer", "value": "Lac Viet Auction Partnership Company" },
    { "trait_type": "Auctioneer", "value": "Do Thi Hong Hanh" },
    { "trait_type": "Address", "value": "No. 49 Van Cao, Lieu Giai, Ba Dinh, Hanoi, Vietnam" },
    { "trait_type": "Created by", "value": "KOET" }
  ]
}
```


Fig. 4. Example metadata payload (ERC-721 standard) hosted on Pinata Cloud. Demonstrates key-value pairs defining tokenized apartment asset attributes (e.g., starting price, legal documents, property photos) linked via IPFS.

Smart contracts form the system's core and were developed using Solidity 0.8.17 via Remix, an online IDE that allows coding, debugging, testing, and deploying EVM-compatible smart contracts on BSC. These on-chain smart contracts are open-source and automatically self-execute to determine the winning bid, ensuring fair auction results, is described in Algorithm 2.

Algorithm 2. Smart contract pseudocode for on-chain bidding and NFT transfer to the winner.

```
Variables:
nft : ERC721; tokenId : uint256;                          The NFT being auctioned.
startingPrice, bidIncrement : uint256;                    Minimum price and step size between bids.
startTime, endTime : uint256;                             Auction opening and closing time.
highestBid ← 0; highestBidder ← address(0);               Tracks the top bid and who placed it.
isOpen ← false;                                           Flag to check if auction is live.
whitelist : mapping(address → bool);                      Stores verified users from off-chain KYC.
function startAuction
        require(now ≥ startTime);                         Only open if current time meets start time.
        isOpen ← true;                                    Mark the auction as active.
        emit AuctionStarted();                            Notify off-chain systems the auction is live.
end function
function Bid(amount)
        require(isOpen and now < endTime);                Auction must be open and not expired.
        require(whitelist[msg.sender]);                   Only users approved off-chain can bid.
 require(amount ≥ startingPrice);                         Bid must meet or exceed the reserve price.
 require(amount ≥ highestBid + bidIncrement);             Bid must exceed the current highest by the minimum step.
 highestBid ← amount; highestBidder ← msg.sender;         Update the highest bid and the current top bidder.
    emit BidAccepted(msg.sender, amount);                 Emit event to log the accepted bid.
end function
function closeAuction
        require(isOpen and now ≥ endTime);                Can only close after auction ends.
        isOpen ← false;                                   Mark the auction as closed.
        if highestBid ≥ startingPrice then
            nft.safeTransferFrom(owner, highestBidder, tokenId);   Send NFT to winner if reserve price was met.
            emit AuctionSucceeded(highestBidder, highestBid);      Emit success event.
        else
            nft.safeTransferFrom(address(this), owner, tokenId);   Return NFT to seller if no valid bids.
            emit AuctionFailed();                         Emit failure event.
        end if
end function
```

3.2. Results

A prototype smart contract was developed and deployed on BSC. Successfully used for the auction of state-owned assets, including cars and apartment units through the website https://lacvietauction.vn. Table 1 presents a comparative evaluation of centralized and hybrid on/off-chain auction systems across key metrics under real-world workloads with non-crypto-native qualified bidders. Bid confirmation latency metric is the time needed to confirm a bid on the auction platform. Auditability metric applies to the system's ability to provide verifiable, tamper-proof records of bidding activities. Single point of failure (SPoF) risk determines the likelihood that a single component failure could disrupt the entire system. The centralized auction system faces a high risk of SPoF because it relies on a single administrative back end. In contrast, the hybrid system mitigated this risk by shifting critical operations such as bid submission and auction-winner determination to decentralized smart contracts. Scalability captures the system's capacity to handle increased bidder activity without performance degradation, it is limited by BSC throughput. Transparency reflects the extent to which system operations, rules, and outcomes are visible and verifiable to all participants.

We conducted a follow-up survey via Microsoft 365 Forms to rate two metrics: bidder's perceived fairness and bidding experience. The bidder' perception of fairness is defined as each bidder's assessment of the auction process's

procedural fairness and legitimacy. The bidding experience reflects the system's ease of use, efficiency, and overall user satisfaction. We invited a group of 78 bidders who had passed KYC and placed at least one bid to complete a comparative experience survey. The survey prompted participants to rate aspects of the new system on a 5-point Likert scale (from "strongly disagree" to "strongly agree") and to provide a direct comparison against their experience with the legacy centralized platform. Among them, 64 (approximately 82%) reported a positive experience, and all respondents agreed on the fairness and legitimacy of the auction process. These results show that the hybrid system meets legal transparency requirements and keeps user satisfaction over legacy platforms. Table 2 presents the gas cost in USD for smart contract deployment and the median gas cost in USD for the main transaction within the contracts.

Table 1. Comparative evaluation of centralized and hybrid auction systems across key bidding metrics.

Metric	**Centralized auction**	**Hybrid on/off-chain auction**
Bid confirmation latency	Near-instant (≪ 1 s), mutable	~ 3 seconds to appear, ~ 7.5 seconds final & immutable (after FastFinality: ~ 2.5 blocks to finalize)
Auditability	Only top bids shown; server-side edits possible	All bid events immutably on-chain
Single point of failure risk	High	Low
Scalability	High	Limited by blockchain throughput
Transparency	Limited, auctioneer controls data visibility	High, all transactions recorded on blockchain
Bidder-perceived fairness	Often questioned; no immutable record	100% confident in fairness and legitimacy
Bidding experience	~ 80% positive	~ 82% positive

Table 2. Comparative cost breakdown per auction session between centralized and proposed hybrid blockchain-enabled platforms.

Operation	**Centralized auction system**	**Proposed auction system**
IT/platform license	~$80 (fixed)	Pay per operation
Median qualified bids per auction session	~100	~100
Deploy auction smart contract	-	$3.46
Avg. NFT mint	-	~$0.6
Bidding	-	~$0.1
Bid opening	-	~$0.77
Randomness / Anti sniping	-	~$0.4
Bid closing	-	~$0.05
NFT ownership transfer	-	~$0.24
Total cost per auction session	**~$80**	**~$12.06**

Circular 20/2024/TT-BTP, issued by the Ministry of Justice on 31 December 2024, establishes the fee schedule for online auctions: a fixed fee of 2,000,000 VND per auction (~$80), which is reduced to 1,000,000 VND (~$40) if no bidders register. By contrast, fees in a blockchain-enabled auction system are not fixed as in a centralized platform.

Every transaction executed by the smart contracts incurs a separate gas cost. Elevated transaction fees can erode the proceeds of both the auctioneer and the seller and may also degrade the overall bidding experience. The implemented auction contract was first deployed on Mar 07, 2023, and used 0.0053 BNB (approximately $3.46). This one-time deployment fee is the most expensive because it covers the contract's complex initialization operations. The prototype processed 14 successful pilot auctions, each with up to 100 qualified bids per auction session. The gas cost per auction session is estimated using Equation 1, was approximately ~$12.06. It represents an 84.9% reduction relative to the fixed per-auction fee in the centralized system.

$$C_{\text{auction}} = C_{\text{mint}} + n_{\text{bid}} \times C_{\text{bid}} + C_{\text{open}} + C_{\text{rand}} + C_{\text{close}} + C_{\text{transfer}}. \quad (1)$$

where:

C_{mint}	average NFT-minting cost
C_{bid}	gas fee per bid
n_{bid}	number of bids submitted in the auction session
C_{open}	cost of opening the auction
C_{rand}	randomness/anti-sniping fee
C_{close}	cost of closing the auction
C_{transfer}	NFT ownership-transfer fee

4. Discussion

4.1. User Experience Considerations in the Bidding Process

Binance Smart Chain (BSC) has an average block time of roughly 3 seconds, and transactions achieve finality after about 2.5 blocks, approximately 7.5 seconds in total [27]. Bid confirmation therefore depends on this latency, which directly affects the user's bidding experience by slowing down the bidding rhythm. In contrast, a centralized auction platform records and displays bids almost instantaneously. As of May 2025, BSC has reduced its block time from 3 to 1.5 seconds. This change, implemented under BEP-520, results in a bid-confirmation latency of 3.75 seconds (BSC finality ~2.5 blocks) in our recent experiment. Such latency is acceptable for auctions of high-value, state-owned tangible assets with large bid increments, where the rhythm and enjoyment of bidding are less critical than in auctions of low-value digital assets.

4.2. Bid Sniping Risk and Mitigation

Bid sniping is a timing attack method where a bidder waits until the last seconds of an auction to submit a winning bid. The implemented smart contract is sensitive to bid sniping due to its use of a blockchain timestamp to determine the auction's end time. The best practices to defend against bid sniping are using a trusted external time source and implementing a commit-reveal scheme in an auction smart contract. For this prototype, we focused on keeping the system simple and cost-effective. We left out complex anti-sniping features like commit-reveal schemes for now. Since high-value assets usually have longer auctions, we think the risk is lower, but we know this is an important area to improve in the future.

4.3. Blockchain Network Consideration

This prototype was deployed on a monolithic Layer-1 network (BSC) because of its Ethereum Virtual Machine (EVM) compatibility and mature development tooling. The empirical evaluation, however, was limited to moderate bid volumes and an auction format, which constitutes the primary limitation of this study. Even within that scope, our findings indicate that the platform's scalability is strongly determined by the chosen network and ultimately bounded by the performance envelope of the underlying blockchain. Consequently, future work should explore building and

testing the system on Layer-2 roll-ups or higher-throughput Layer-1 networks to mitigate these scalability constraints and sustain reliable performance at larger scales.

4.4. Limitations and Future Work

This study focused on one auction format and a limited bid volume, which may restrict generalizability to other auc- tion types. Future work will focus on expanding the system's capabilities by integrating zero-knowledge proof mech- anisms to ensure bidder privacy. Additionally, integration with Vietnam's e-government platform, such as VNeID, could facilitate faster user onboarding. We also plan to improve the scalability by using Ethereum Layer-2 rollups or by migrating to alternative high-performance Layer-1 blockchains such as Solana, Aptos or Algorand. Another approach for achieving high-performance auctions is to build an application-specific chain on multichain Layer plat- forms, such as Cosmos, Polkadot or Avalanche.

5. Conclusion

In this paper, we present our approach to improving Vietnam's public-auction service. By integrating blockchain technology into the existing centralized system, we enhance bidder-perceived fairness and the overall bidding experience, making the service fundamentally fairer and more transparent. Our findings show that the proposed hybrid model not only complies with Vietnamese auction laws and regulations but also reduces operating costs per auction session by approximately 84.9 %. To the best of our knowledge, this study is the first blockchain-based implementation specifically designed for auctioning legally regulated, tangible state-owned assets. It offers a replicable blueprint for public-asset auctions in other countries. We identify the novel challenges that arise in this decentralized auction system, analyze their impact on participants, and propose directions for future research and development.

AI Usage Declaration

We declare that we use ChatGPT in this manuscript to check for grammar and paraphrasing. The result from AI is not used directly and is under human supervision for error checking.

Data Availability

Part of the data used in this study is publicly available on the official website of Lac Viet Auction Partnership Company at https://lacvietauction.vn. The remaining data is not publicly available due to confidentiality restrictions.

Author Contribution Statement

M.T. Le: conceptualization, methodology, original draft writing, smart contract development, system implementation. T. Dat: data curation, testing, project administration. H. Giang: stakeholder engagement, legal and regulatory analysis, survey design, funding acquisition and supervision.

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