Digitizing Physical Assets on Blockchain 2.0: A Smart Contract Approach to Land Transfer and Registry

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Abstract. The real estate market in many African countries reflects inefficiency, indiscipline, suspicion, and fraudulent activity. Beyond the direct personal and financial costs, the friction of the existing property transfer process prevents assets from being utilized and valued at their maximum utility. The frustrations and lack of trust affect most real estate markets across Africa, including Ghana, where we will focus the investigation and examples in this paper. Remarkably, the existing Ethereum blockchain platform and smart contract capabilities can be used to bring efficiency, accuracy, trust, and value to the property transfer and registration process without a significant investment in new infrastructure.

We develop a blockchain smart contract appropriate for the continent that provides transparency and traceability of digital assets from initial registration through all subsequent transfers. While blockchain-based land registration systems have been proposed and even implemented in other contexts, they are primarily for land title and deed registration. The system proposed in this paper performs these functions while also allowing the owners to trade in the tokenized assets. While we focus on the technical contribution, we also consider the infrastructure, legal, financial, and cultural factors relevant to designing a land registry solution for a developing country.

While we focus on the case of Ghana, our solution is applicable anywhere and is particularly appropriate for Africa because it does not require any new infrastructure. A similar approach may be taken for a variety of e-government services such as digital identity management and online certificate management.

Keywords: Blockchain 2.0 · Smart contract · Ethereum · Digital assets · e-infrastructure · e-government · Land title · Land registry

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1 Introduction

Holding productive assets such as properties and buildings comes with economic and societal benefits. Financially, assets contribute to a productive economy, generate revenue, and are useful as collateral for bank loans or other transactions. However, the asset benefits are only fully realizable with the details of ownership adequately documented and managed. Credible asset record management requires a system where the asset details accurately reflect the legal owner and permit an efficient and trustworthy transfer of ownership rights.

In Ghana, ownership of assets, particularly land and buildings, is acquired and transferred according to the Land Title Registration Act, 1986 (PNDCL 152), and the Land Registry Act, 1962 (Act 122) [1]. Besides these legal systems, traditional chiefs and local governments in Ghana are still active in the distribution and trading of land and buildings due to their role as the primary actors in the customary land tenure system [2,3].

Buying land in Ghana is arguably a complex and rigorous process for a buyer [3]. When buying a land or a building in Ghana, one local authority has cautioned that an investor or a buyer undertake at least four different levels of checks to avoid fraud [1]. Similarly, a paper on land acquisition in Ghana exposes the indiscipline, lack of trustworthy registration authority, and attendant insecurities in buying land, highlighting that it is common to sell a single property to more than one buyer [4]. According to the World Bank, several African countries besides Ghana have inadequate asset management systems [5]. Irregularities aside, even more highly developed countries such as the Republic of Georgia and Sweden are exploring how blockchain technology is useful for greater efficiency, transparency, and accuracy when validating property-related transactions [6].

1.1 The Paper-Based Land Registration System in Ghana

Ghana's asset registration and management process is primarily a paper-based, not digital, system [7]. Paper records, also known as land certificates, are issued to any citizen who registers his or her property with the Lands Commission. This certificate bears the name of the current owner, the date of registration, the buyer, and the Commission's office's official details.

Storage of all registered land information is in a centralized database within the Lands Commission and subsidiary offices. This centralization of land records and issuance of paper-based land certificates has several implications. It makes it difficult for buyers and investors to track the historical records of a property. Also, financial institutions, particularly banks and insurance companies, cannot verify the validity of a land certificate used as collateral security or an asset to be insured. Additionally, a problem in the paper-based system is the ease of fabrication and tampering with the original ownership document, often with the intent to defraud a buyer. As a result of the ease of fabrication of ownership certificates, it is often possible to sell the same asset to more than one buyer, leading to crime, lack of trust in the real estate market, and inefficient use and transfer of assets.

The main problem to be addressed in this project is the issue of preventing illegal selling of the same land or building to more than one person at a time. This problem is akin to preventing *double spending* on a cryptocurrency platform, which is the primary problem solved by the creation of the original blockchain.

1.2 Project Objectives

The objective of this project is to answer the question, "How can we implement a blockchain smart contract solution to bring greater trust, transparency and efficiency to Ghana's land registration system?" This goal is to create a blockchain-enabled smart contract platform that allows users to register, track, and verify a property on a public ledger, achieving provenance and transparency.

Actors involved in this ecosystem include the Lands Commission officials (to register lands officially on decentralized servers), buyers and sellers, the Ethereum blockchain network (to maintain records and verify that a record is unaltered), and third parties like banks and insurance companies (to verify the authenticity of any asset used as collateral security or insurance). Records of physical assets are stored on the blockchain platform, making it easy for the public to verify and validate the authenticity of property ownership. Additionally, there will be a complete history of asset ownership from creation to depletion.

By connecting the Lands Commission, banks, and other financial institutions to a blockchain network, assets more reliably tracked, and transparency and efficiency are improved. The goals of the project are:

- Improve transparency in buying and selling assets.
- Eliminate dependence on middlemen such as brokers and agents, who add cost and friction to the transaction process.
- Protect buyers from being defrauded.

1.3 Scope

This project focuses primarily on the technical implementation of a proposed solution to the issues identified. However, delivery is within the context of Africa's social, regulatory, and economic conditions as a developing continent. In particular, it relies upon the use of the existing Ethereum blockchain infrastructure with services that can be affordably purchased as needed and requiring little additional investment beyond a computer or smartphone and an Internet connection.

2 Background and Other Work

Having a database or platform that keeps track of property ownership would not only provide transparency for government institutions and business organizations but may also have the potential to unlock economic opportunities for citizens [8]. Several countries have developed technological and legal systems to register properties. However, there remain inefficiencies in the registration of assets, especially in the less developed countries. According to the World Bank's Ease of Doing Business score, it takes approximately 51, 107, and 71 days to register a property in sub-Saharan Africa, South Asia, and East Asia, respectively [5]. These statistics highlight the bureaucracies that exist in these economies. Blockchain technologies are emerging as an alternative to traditional methods for the provenance of assets.

Blockchain, which was introduced in 2008 by the pseudonymous Satoshi Nakamoto, is defined as a chain of blocks of transactions stored on a distributed ledger using a peer-to-peer network to provide a tamper-proof history of transactions [9]. Variations of the original blockchain have been created. For instance, the original peer-to-peer network was public and open, but private or permissioned blockchains have emerged where participation in the network is limited to selected or known entities. Cryptocurrencies, such as Bitcoin, are one of the earliest applications of blockchain technology. The invention of Bitcoin created a revolutionary system for digital cash and payments, allowing two or more parties to make transactions without a centralized authority or trusted third party such as a bank or credit card company [10]. The original blockchain, designed to support Bitcoin, allowed a relatively limited set of functions, while some newer blockchains are fully programmable. We base this work on the Ethereum platform, a so-called *blockchain 2.0* application that is Turing-complete and, therefore, able to support any computable function. Blockchain technology is now applicable to a range of disciplines.

One of the most exciting uses of new blockchain technologies is for *smart contracts*. A smart contract, being programmable, can automate and automatically enforce contract provisions. The supply chain industry has made significant efforts to utilize smart contract technology to enable the transfer of digital assets to a recipient upon the fulfillment of the stated contract [11]. For instance, a buyer and seller can electronically sign a smart contract that automatically releases payment to the seller for goods once they are delivered and accepted at the buyer's warehouse. Blockchain technology, and smart contracts, can be used in a wide range of e-governance tasks, such as digital identity management and secure document handling [10]. The implications for transparency and efficiency in e-government provide compelling reasons to continue exploring blockchain applications.

Blockchain applications have been proposed in the land registration system to improve the transfer and registration process. In 2015, the government of Honduras partnered with Factom, a startup company based in Texas, to develop a permanent and verifiable land title using blockchain technology [12]. The goal of this pilot project was to address the poor record-keeping of the Honduran land registration system. In this implementation, a public blockchain ledger remains updated and secure based on traditional blockchain techniques, where the majority of nodes on the network verify transactions and maintain consensus on the state of the ledger [13]. A similar solution has been implemented in India to address what has been called incoherent and inconsistent land title records in the government institutions [14]. Another project was undertaken in the Republic of Georgia. In the early 2000s, buying and selling land in Georgia was not only a long process but also prone to bribery [15]. In April 2016, the government of Georgia piloted with BitFury, a blockchain firm based in San Francisco, to fight corruption and develop a private permissioned blockchain platform that would improve transparency in property-related government transactions [15]. Despite some success, the project has limitations as the blockchain is not integrated with the country's official land title registration application, but rather is an "add-on" service [16].

Early efforts at registering property on a blockchain often used the original Bitcoin blockchain because of its widespread use and large community. However, because the original blockchain was only designed to register Bitcoin transactions, property registration solutions were limited and required creativity. Bitland, based in Ghana and started in 2016, was an early entrant into the blockchain land registration space. They used the original Bitcoin blockchain and a concept called *colored coins* [17]. The Bitcoin blockchain, while limited, allowed small bits of metadata such as title, GPS coordinates, size, and contact address to be encrypted and attached as metadata to Bitcoin digital tokens [17]. Because each Bitcoin digital token is unique, and unique users can use their private key to encrypt the digital token, only users with the private key had access permissions to perform transactions related to a unique digital token [18]. This process is no different from the control and transfer of a Bitcoin. To expand the metaphor, tokens (or coins) were the same in the way that a US dollar bill has the same value as any other dollar bill, but they were unique (or colored, compared to other coins) in that they were identified by a unique token/metadata combination, much like each US dollar bill has a unique serial number. By associating unique property data with a unique token, possession (or private key cryptographic control) of the token represents possession of the physical land or building. However, any user on the Internet can view and track the ownership history of an asset. As with any asset that is not natively digital, this scheme relied on a trusted third party (Bitland) to verify the correspondence between a digital token and a physical property. Bitland has gone on to develop their own Bitshares blockchain network using similar principles and has had some success partnering with the government of Ghana to digitize and record property deeds while also expanding to other countries [19].

Despite having a goal similar to this project and being based in Ghana, our solution takes a different approach by using the Ethereum platform. This approach is cost-effective from an infrastructure standpoint, compared to developing a custom solution due to economies of scale. Bitland issued a custom digital currency (colored coin) called Cadastrals to facilitate transactions on its blockchain platform. Cadastrals are a new digital currency and require the public to subscribe via initial coin offering (ICO). The value of a digital currency is largely dependent on people's trust in the system and is difficult to bootstrap for a newer and relatively under-subscribed coin. Given that blockchains are not well known in Ghana, any complex solution that does not leverage existing infrastructure will face more significant challenges to acceptance, adoption, and credibility. Our solution, rather than creating a new coin infrastructure, leverages Ethereum's blockchain and Ether to facilitate the transfer of digitized assets. The platform is widely used in the blockchain community, tested, and has more comprehensive support and adoption than a proprietary solution.

Bitland has also come to focus more on related services such as drone mapping and ownership verification, and the details of their blockchain implementation are not open.

Many African countries have yet to adopt blockchain technology, despite the benefits that could come with implementing a blockchain-based asset registration system. The work reviewed in this section highlights certain system features that could make adoption more feasible. As mentioned in the Republic of Georgia implementation, they have a standalone application that does not integrate into the national land title registration system. A successful solution must itself be sufficiently understood, transparent, and reliable to integrate with or replace existing systems. Proprietary or boutique solutions, therefore, are less likely to be accepted. The solutions proposed in [12–14,19] are limited to land deeds and titles registration only. Stated differently, they do not support the trading and transfer of ownership from one user to another directly on their blockchain platform. In *The Mystery of Capital*, Hernando de Soto emphasizes the importance of converting dead assets into live capital [20]. It is only by allowing owners to trade in their digitized assets that the economic value of their assets is fully realized and that these assets can easily move to their highest and best value, uninhibited by the friction and uncertainty of the current system. Lack of a native payment system was identified as a drawback to some existing proposals [15].

Recognizing these gaps, we propose a land transfer, payment, and registration solution that allows users to not only register their physical assets on the worldwide Ethereum platform but also to facilitate trading and transfer of ownership using smart contracts and Ethereum's native digital currency, Ether.

3 Methodology

This section highlights the approach or methodology followed to build the asset-based transaction blockchain system.

3.1 System Design Process

The system design is categorized into two processes: the asset digitization process and the asset transaction process. Explanations of each follow.

Asset Digitization Process. To register an asset on the blockchain, a user submits a valid land certificate or building document to the Lands Commission of Ghana for verification. Since the Lands Commission is the only institution mandated to issue land title certificates in Ghana, no user can submit invalid or fabricated land certificates as the office can easily detect modifications to the original certificate. After successful verification, the asset details are recorded and tokenized on the blockchain as follows.

A new piece of land, a building, or other asset is represented as a digital token on the smart contract. Each token is given a unique address and tagged with metadata such as the GPS of the land or building, size of the property, year built or owned, and other relevant information. The details of the legitimate owner are encrypted using public key infrastructure to provide anonymity. This information is written to the Ethereum blockchain through a smart contract and appended to the previous blocks of transactions. Since the Ethereum blockchain uses a secure hashing algorithm (SHA) to keep track of block pointers and transactions, it is infeasible to fabricate a certificate on the smart contract. This series of activities is shown in Fig. 1.

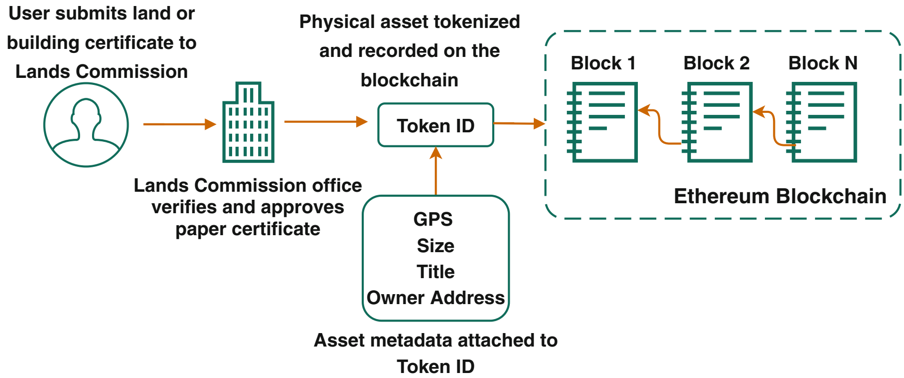


Fig. 1. Tokenization of physical assets on a blockchain.

Asset Transaction Process. After the physical asset is digitally tokenized and published on the blockchain network, the asset owner (or a knowledgeable agent acting on their behalf) can perform future transactions directly on the blockchain. When selling an asset, the smart contract verifies the user is the legitimate owner of the asset through their knowledge of their cryptographic private key. Upon meeting this condition, the owner can securely transfer ownership to a buyer using the buyer's public key. This system is akin to how an email account functions. Anyone can send to an email address because it is (relatively) public, but only the account owner can send from the account because only they know the password.

Upon confirmation of payment from the buyer, ownership details of a token are transferred automatically to the buyer. Payment can take place through the smart contract on the blockchain using Ethereum, again, possibly with the assistance of a knowledgeable agent. Alternatively, the buyer and seller can use traditional payment arrangements, with the seller confirming to the smart contract that payment is satisfactorily received. In the event a user needs a loan from a bank, the blockchain solution will help banks to verify the authenticity and ownership right of the digital asset.

Achieving Consensus. Since our solution leverages the existing Ethereum blockchain infrastructure, our consensus algorithm is the consensus algorithm implemented on Ethereum—Proof of Work (PoW). In the PoW approach, a node competes to be the first to validate transactions on the network and solve a related cryptographic puzzle. The first node to solve the puzzle broadcasts its solution to the other nodes and collects a reward once the other nodes validate the solution. This node subsequently writes the next block of transactions into the blockchain ledger.

There is growing concern regarding the amount of energy expended by nodes to solve the cryptographic puzzle. There is also concern that the massive computing power required compete on the network concentrates the verification and reward, or mining, process, in the hands of a relatively few mining pools. Ethereum is responding to this concern by making a gradual shift from PoW to a newer consensus algorithm called Proof of Stake (PoS). Our solution will take advantage of future developments in the consensus algorithm process without the cost or risk of trying to independently develop an alternative.

Storage of Metadata Chaining Mechanism. We also considered the tradeoffs between on-chain and off-chain storage of information, including the limitations of data stored on the blockchain and the cost of executing or committing a transaction. As we aim to develop a cost-effective solution, off-chain storage is the more economical approach given the current capabilities of the Ethereum ecosystem. Instead of converting a hard copy land certificate into a digital copy and saving it directly on to the blockchain, we instead transfer only the essential details that guarantee proof or identification of an asset. These details, such as a hash of the actual document contents, are entered into a smart contract, bundled into a data type, and hashed and stored on the Ethereum blockchain. This approach is cost-effective as it requires less on-chain storage that must be replicated to all nodes participating in the network. Ethereum developers are actively pursuing more economical methods of Ethereum data storage, and we expect to be able to take advantage of future progress.

4 Implementation

This section discusses the implementation of the proposed blockchain digital asset registration system. The architecture of the blockchain system is modelled using the concept of a private permissioned blockchain, where anyone can freely participate on the platform, but only selected nodes are granted the privilege to verify transactions and write them into the ledger. Public blockchains are more common on the Ethereum platform, but permissioned blockchains are supported. Either approach would work from a technical standpoint, but we model a permissioned chain because it is likely more palatable to regulatory authorities.

4.1 The Nodes

The nodes are the actors who are directly or indirectly involved in a blockchain transaction. The identified nodes in the project include:

- Lands Commission: The Lands Commission is the government agency responsible for issuing land certificates to the public. These nodes are given the privilege to validate and verify land certificates presented for registration.
- Buyers and Sellers: These are the direct actors of the platform. The seller can transfer his or her property to the buyer. Also, the buyer can buy an asset and make payment using digital currency.
- Banks: The banks are given permission to deny or approve digital asset transactions in which they have an interest once an asset is created on the blockchain platform. Banks, therefore, have information about the status of assets and their ownership.

4.2 Smart Contracts

The back end code of the blockchain is developed using the Solidity programming language as it supports the creation of smart contracts. The contract classes are as follows.

User Account Contract. This contract contains information about all the buyers and sellers on the blockchain. The properties of this contract are shown in a class diagram in Fig. 2.

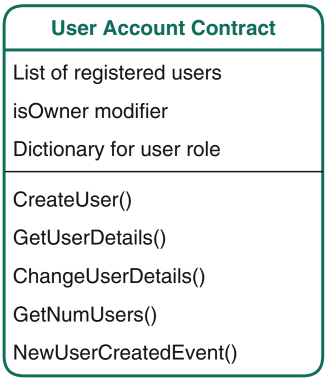


Fig. 2. User account class diagram.

In addition to the user account class diagram, below is a code snippet showing the details of the contract in Solidity.

Listing 1.1. User Account Contract

```
contract UserAccount {

        enum Role {User, Institution, LandOfficial}
        event newUserAdded(uint id, address user_address);

        //creates a structure for a user object
        struct User{
                string username;
                address owner;
                Role userRole;
        }
}
```

Asset Contract. This contract will handle all new property registrations. It has the properties and operations shown in Fig. 3.

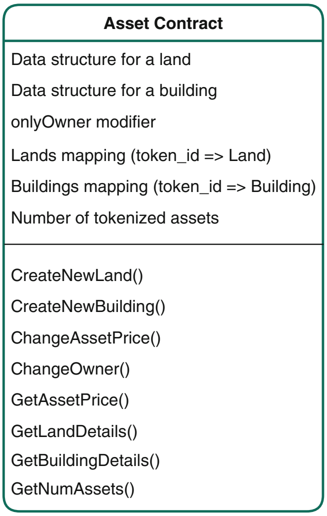


Fig. 3. Asset class diagram.

Similarly, we show the data structure for the building object in the below code snippet.

Listing 1.2. Asset Contract

```
//structure for a building
            struct Building {
                string size;
                address owner;
                uint token_id;
                uint price;
                string gps;
                string details;
                uint num_rooms;
                uint date_created;
            }
```

Transaction Contract. This contract is the main entry point of interaction between all the nodes identified above. This contract allows users to transfer ownership from one person to another upon confirmation of successful payment, or direct payment in Ether in the Ethereum network, Fig. 4. Likewise, we show a snippet of a constraint that permits digitized assets to be transferred only after receiving the full payment.

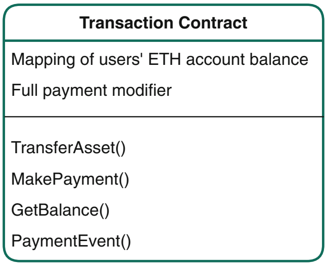


Fig. 4. Transaction class diagram.

Listing 1.3. Full Payment Modifier

```
contract Transaction is Asset{

    //track of the amount of money (Ether) a user has
    mapping(address => uint) private userBalanceMap;

    //a modifier to ensure buyer has made full payment
    modifier fullPayment(uint token_id, uint asset_type,
    uint price)

    {
    uint asset_price = getPrice(token_id, asset_type);
    require( asset_price <= price);
    _;
    }
```

List of Tools and Technologies. The following tools, frameworks and programming language were used to develop the platform:

- MetaMask Ethereum Wallet: This add-in was installed on Google Chrome to allow our web browser to connect to a blockchain network.
- Remix: This is an online editor for writing and managing smart contracts using Solidity.
- Solidity: The programming language used to develop a smart contract. Our Solidity code is available at https://github.com/PeyGis/LandReco.

Simulation Environment. We conducted our simulations on Remix, an online Ethereum and smart contract management platform that enables blockchain developers to develop, test, and deploy smart contract solution on the Ethereum network. We also used the smart contract programming language Solidity to implement our land registry and transfer smart contract solution.

Our simulations used the native Ether payment module available in Solidity. Another option is to explore the use of ERC-721 third-party payment tokens. Unlike most cryptocurrencies, each ERC-721 token is unique and is valued based upon the uniqueness or rarity. Interestingly, they have been used to own and transfer virtual land in the Decentraland virtual world and the related integration of crypto-collectibles in the integration of Cryptokitties and Decentraland.

5 Results and Discussion

We proposed using a blockchain-based asset registration system in Ghana to bring trust and transparency to the system. This section shows how it was implemented.

5.1 How Has the Project Addressed the Problem?

Asset Tokenization. Using public key infrastructure and smart contracts, we found that we could digitize physical assets on a blockchain using a unique token for each asset. Physical assets, ownership, and mapping between physical and digital are verified by integrating a trusted third party into the ecosystem. In this case, Ghana's Lands Commission office. The involvement of a trusted third party helps to validate and verify any document or asset. The asset tokenizing process for registering a land or building on the blockchain network is shown in Fig. 5.

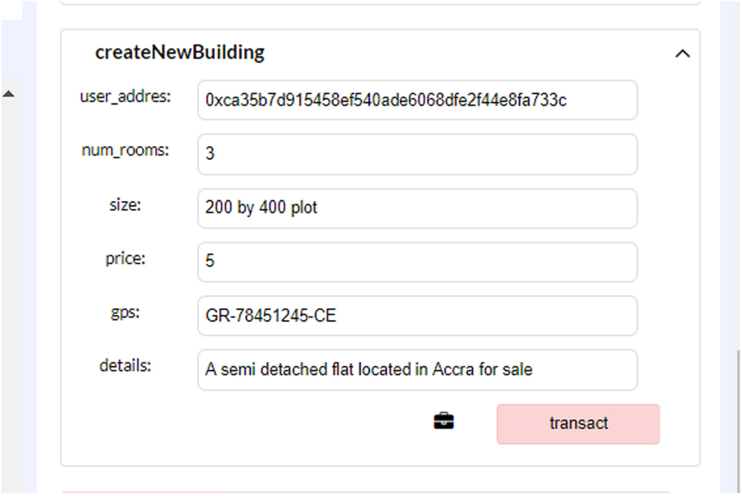


Fig. 5. Creating a new building user interface.

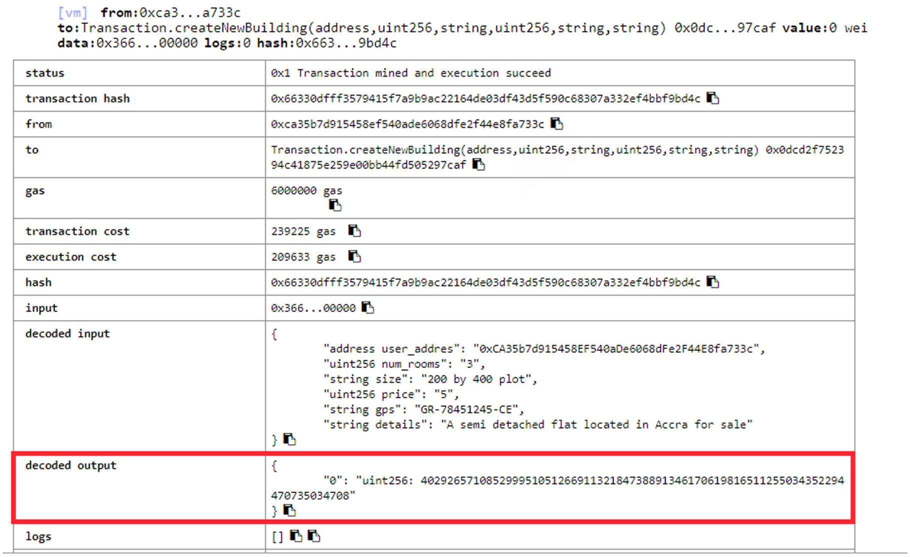
After the property has been created, a unique token is generated for the asset with its associated metadata. This result is shown in Fig. 6.

Asset Transaction. Our simulations show that by digitizing or tokenizing physical assets, a seller cannot sell the same property to more than one buyer, addressing the issue of double selling of an asset. Thus, after a buyer makes a payment for an asset, the asset's ownership details are transferred to the buyer's public key, preventing the seller from selling the same property to a different buyer. Figure 7 shows a simulation of a buyer purchasing an asset and making a payment with Ether cryptocurrency.

The result of this operation is shown in Fig. 8. This operation demonstrates that we could trade or transfer ownership from one user to another on a blockchain platform.

Since the smart contract dynamically transfers ownership rights from one user to another, we mitigate the issue of an asset owner selling the same property to more than one buyer. Figure 9 shows the details of the asset after the `makePayment()` transaction.

As shown in Fig. 9, the details of the asset (especially the owner's address) have been changed from `0xCA...733c` to `0x4B...D2dB`. As a result of this oper-


[vm] from:0xca3...a733c
to:Transaction.createNewBuilding(address,uint256,string,uint256,string,string) 0x0dc...97caf value:0 wei
data:0x366...00000 logs:0 hash:0x663...9bd4c

status	0x1 Transaction mined and execution succeed
transaction hash	0x66330dfff3579415f7a9b9ac22164de03df43d5f590c68307a332ef4bbf9bd4c
from	0xca35b7d915458ef540ade6068dfe2f44e8fa733c
to	Transaction.createNewBuilding(address,uint256,string,uint256,string,string) 0x0dcd2f752394c41875e259e00bb44fd505297caf
gas	6000000 gas
transaction cost	239225 gas
execution cost	209633 gas
hash	0x66330dfff3579415f7a9b9ac22164de03df43d5f590c68307a332ef4bbf9bd4c
input	0x366...00000
decoded input	{ "address user_addres": "0xCA35b7d915458EF540aDe6068dFe2F44E8fa733c", "uint256 num_rooms": "3", "string size": "200 by 400 plot", "uint256 price": "5", "string gps": "GR-78451245-CE", "string details": "A semi detached flat located in Accra for sale" }
decoded output	{ "0": "uint256: 402926571085299951051266911321847388913461706198165112550343522944707350 34708" }
logs	[]

Fig. 6. Asset token successfully generated.

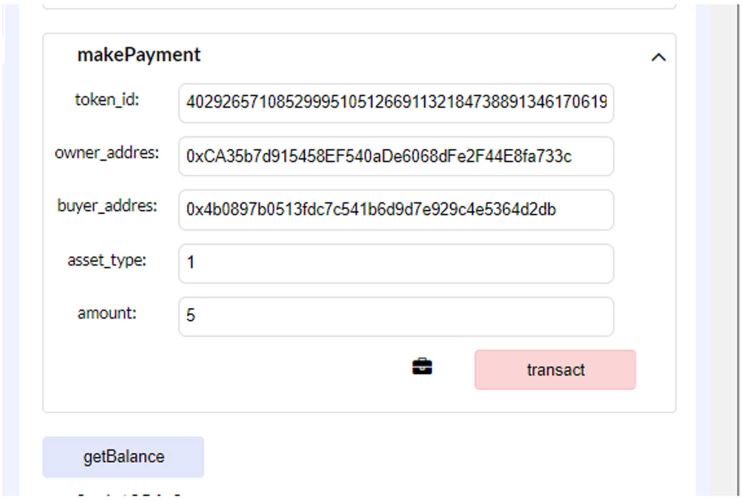


Fig. 7. User making payment for an asset.

status	0x1 Transaction mined and execution succeed
transaction hash	0x89d8b0e4d7a7b328e497fb460248360f6b2f29f93d898b4dfee9e56ae1f0dae9
from	0x4b0897b0513fdc7c541b6d9d7e929c4e5364d2db
to	Transaction.makePayment(uint256,address,address,uint256,uint256) 0x0dcd2f752394c41875e259e00bb44fd505297caf
gas	6000000 gas
transaction cost	73442 gas
execution cost	46794 gas
hash	0x89d8b0e4d7a7b328e497fb460248360f6b2f29f93d898b4dfee9e56ae1f0dae9
input	0x67f...00005
decoded input	{ "uint256 token_id": "40292657108529995105126691132184738891346170619816511255034352294470735034708", "address owner_addres": "0xCA35b7d915458EF540aDe6068dFe2F44E8fa733c", "address buyer_addres": "0x4B0897b0513fdC7C541B6d9D7E929C4e5364D2dB", "uint256 asset_type": "1", "uint256 amount": "5" }
decoded output	{ "0": "bool: true" }
logs	[{ "from": "0x0dcd2f752394c41875e259e00bb44fd505297caf", "topic": "0x05666d9673471b289a16b2df77f162a627749ed621e9b78ffedcb38884f464db", "event": "PaymentEvent",

Fig. 8. Successful payment receipt.

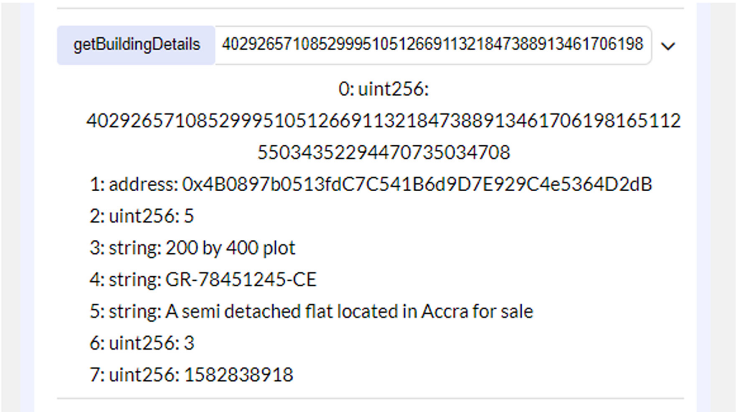


Fig. 9. Property details after payment.

[vm] **from:**0x583...40225 **to:**Transaction.makePayment(uint256,address,address,uint256,uint256) 0x0dc...97
value:0 wei **data:**0x67f...00005 **logs:**0 **hash:**0xd47...8106d

status	0x1 Transaction mined and execution succeed
transaction hash	0xd478eca0dc9a7b85ecc6c7df7ba7df8327a4fcd887f36c2fba99d42fb768106d
from	0x583031d1113ad414f02576bd6afabfb302140225
to	Transaction.makePayment(uint256,address,address,uint256,uint256) 0x0dcd2f752394c41875e259e00bb44fd505297caf
gas	6000000 gas
transaction cost	36707 gas
execution cost	10059 gas
hash	0xd478eca0dc9a7b85ecc6c7df7ba7df8327a4fcd887f36c2fba99d42fb768106d
input	0x67f...00005
decoded input	{ "uint256 token_id": "40292657108529995105126691132184738891346170619816511255034352294470735034708", "address owner_addres": "0xCA35b7d915458EF540aDe6068dFe2F44E8fa733c", "address buyer_addres": "0x583031D1113aD414F02576BD6afaBfb302140225", "uint256 asset_type": "1", "uint256 amount": "5" }
decoded output	{ "0": "bool: false" }
logs	[]

Fig. 10. Unsuccessful payment request.

ation, `0xCA...733c` can no longer sell or receive payment from this asset. The function above is also made available for banking institutions to validate assets.

The simulation in Fig. 10 shows an unsuccessful transaction for a payment made from `0x58...0225` to `0xCA...733c`. This is because `0xCA...733c` no longer has control over the asset.

From these simulations, we show that by digitizing physical assets on a blockchain network, we can transfer ownership from one user to another and prevent double-selling of the asset.

5.2 Non-technical Considerations

Legal System. Although proponents of blockchain and smart contracts envision a world where the "code is the law" [12], this requires an evolution of the legal landscape. In the event of a breach of contract, the smart contract must have a mechanism that addresses disputes. It is unlikely that all matters can be settled automatically by the contract, however, and at some point, adjudication of a dispute is likely to enter the traditional legal system. Therefore, legal policies will need to be amended to resolve conflicts and misunderstandings that may arise from a smart contract. "Code as law" may require "coders as lawyers."

Ghana's Data Privacy Act. Given that our proof-of-concept solution is based in Ghana, we considered the laws that govern data access and treatment. In 2012, the Parliament of the Republic of Ghana enacted The Data Protection Act 2012 to protect the privacy of individual's data. One of the critical principles enlisted in this Act is accountability and data security safeguards. Since our proposed solution integrates the land commission to verify paper certificates, we trust that the data provided on our platform is accurate and authentic. The smart contract solution, built on top of the blockchain infrastructure, can provide the level of consistency, security, and privacy required by the Act.

Mapping of Physical Property to Digital Property. The digitalization of physical assets is one means to prevent selling the same asset to unwitting third parties. This correspondence requires accurate mapping of physical assets to digital tokens through a trusted third party. There must also be a mechanism to identify and correct discrepancies or deal with the destruction of an asset.

Context and Practical Concerns. Users will be unfamiliar with Ethereum, blockchain, cryptocurrencies, and the complexity of their functioning and transfer. Use of the Ethereum platform for transactions also requires some minimal fees. A knowledgeable agent will likely be required to assist in facilitating transactions. Many aspects of the traditional property transfer process are complicated and unfamiliar to buyers and sellers, however, and the use of specialized escrow or transfer agents is a well-established custom.

The primary payment method proposed is Ethereum's native Ether cryptocurrency. This method integrates well with the platform and smart contracts. Cryptocurrency payments can be another function undertaken by the escrow agent, as well as transfers that involve traditional payment methods. Ethereum fees can be collected as part of the usual transfer process, similar to fees paid for other services such as notarization. Ethereum fees may also reduce or replace other property registration fees.

Use of the Ethereum platform also depends upon a stable Internet connection, which is not available to many individuals in developing countries. Again, this is an area where an escrow agent can be useful. Many African countries also have district offices where people can conduct government and e-government business in person.

Security of Ethereum and Smart Contracts. The Bitcoin and Ethereum blockchain platforms are grounded on decentralization and the premise that no one entity, or node, can exercise full control over the network. Nodes maximize their chance of earning a reward by participating correctly in verifying transactions, attempting to solve the cryptographic puzzle, and verifying the work of their peers. As there are no shortcuts to solving the cryptographic puzzle and all solutions are peer-verified, there is little incentive to attack the network or propose illegitimate transactions or solutions. Doing so successfully is computationally infeasible unless a malicious entity controls more than 51% of the computing power on the network. Given the decentralized design of the Ethereum network, this is also considered infeasible.

Besides the Ethereum platform's overall security, decentralized apps (DApps) such as smart contracts provide internal security mechanisms. For instance, while developing our smart contract in Solidity, we undertook programming practices to deter successful DApp attacks. Some of the design considerations included using private versus public access, internal versus external, using modifiers to restrict access to a function, and using read-only decorators to prevent unauthorized users from writing or hijacking the contract. These practices enhance the security of the smart contract.

6 Conclusion

Our simulation shows that it is possible to use a well-established open blockchain platform, Ethereum, to create a land transfer, payment, and registration system. Our approach requires little in the way of new blockchain infrastructure beyond writing the appropriate smart contract code. The use of smart contracts creates trust in the transfer process, is efficient, and helps to reduce fraud and corruption.

While we focus on the case of Ghana for details of their current process, our solution is applicable anywhere and is particularly appropriate for Africa because it does not require any new infrastructure. A similar approach may be taken for a variety of e-government services beyond land registration.

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