Secure Land System Based on the Ethereum Blockchain: Benin Case Study

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Abstract. Land management in Benin is a great challenge for its administration. Due to the nonexistence of appropriated tools, land transfer cases end up in litigation. Several court judgements refer to them when the people concerned do not deliver justice.

The goal of this paper is to design a secure system for land management using Ethereum blockchain technologies. In doing so, landowners should be able to visualize information about the areas and locate them through a web mapping application by using LeafLet library.

The solution we propose is mainly usable by notaries and landowners. Nevertheless, all citizens can visualize on an online map, all the lands of the system. This way of doing so, we have a secured land solution based on Ethereum blockchain which is accessible to all.

Thus, our solution will be associated with the current land management process and land fraud will be reduced consequently since we cut out the middlemen.

Keywords: Land management · Blockchain technology · Ethereum · Smart contracts · Web mapping

1 Introduction

After colonization, several African countries found themselves with diverse land tenure systems. This is not without drawbacks. The independence acquired by the countries of West Africa did not really solve the problems. Bernard Georges Gbago states in the book *Le foncier au Bénin - Droit béninois n° 3*, that there are two modes of land acquisition based on the coexistence of two different legal regimes in Benin [7]. These are the customary rules and the civil code. In rural areas where a large amount of land is still held in common, ignorance of the

Y. H. Sheikh et al. (Eds.): AFRICOMM 2021, LNICST 443, pp. 93–106, 2022.
https://doi.org/10.1007/978-3-031-06374-9_7

new land tenure system to the detriment of verbal agreements leads to conflicts. What can be called the land mafia is also a phenomenon that rages in certain town halls in Benin. The evil has intensified with the subdivision operations in the concerned town halls. We can understand that land conflicts are recurrent in some urban and peri-urban areas. Places, where subdivision operations are underway, are also targets for the sale of state-owned land. Land disputes do not only involve the illiterate population, but also land specialists such as surveyors, land surveyors, and other specialists in the field of land tenure.

As part of improving land governance, the Government of Benin has implemented several projects. In 1993, these were the Natural Resource Management Project, funded by the World Bank, the French Development Agency (AFD) and the German Technical Cooperation (GTZ), and the Land and Natural Resource Management Project, funded by the AFD and GTZ [6]. In 2005, the Millennium Challenge Account and the Government of Benin launched a project to modernize and standardize the frameworks [6]. These various actions have made it possible to achieve considerable progress in the field of land tenure security. Today, land tenure security and management in Benin is carried out by the National Agency for Domain and Land Tenure (ANDF). It has set up and manages the digital cadastre in Benin. It should also be noted that notaries have a platform dedicated to land transactions to facilitate transfers. Despite the efforts made, several land disputes are brought before a court when the protagonists do not receive justice. The sources of conflicts are multiple, but the main ones are land sharing on the one hand and sale on the other. Faced with this observation, our research aims to use blockchain technologies, specifically smart contracts, in order to implement a digital solution to secure state administration through disintermediation.

The paper is organized as follows. In the second section, we will present the usefulness of blockchain in land management and discuss in section three the related work. In the fourth section, we will describe the materials and methods used. We will present the different results we have achieved in section five. We will conclude this paper with remarks in section six.

2 Usefulness of Blockchain in Land Management

Our society is increasingly faced with the constraints related to litigation, intermediaries and mainly trusted third parties which affect the implementation of optimal land transactions. Intending to secure land tenure and speed up the procedures for transferring lands, considerable efforts characterized by solutions already in use are notable. For instance, the provision of a digital cadastre accessible to all by the National Agency for Domain and Land Tenure (ANDF) and the implementation of the e-notary platform.

These solutions are based on computer technologies except the Blockchain technology. The drawbacks of such solutions are as follows:

- online cadastre only concerns Cotonou, Porto-Novo and Lokossa which are not the only town halls in Benin;

– several levels of human intervention are required before the information is made available;
– information may not be accessible because of its non-fault tolerance; and
– technologies used for the deployment of this cadastre do not guarantee the data inalterability.

The use of the Blockchain would improve land management since it is:

– transparent: anyone can follow the data;
– immutable: no one can modify the data inside any transaction; and
– decentralized: it does not belong to a single entity.

These characteristics of the blockchain enable it to provide a little more security in land management, as is the case with the solutions implemented in Ghana [4] and Honduras [5]. Therefore, blockchain can be used as a preventive or a consultative tool in the management of land conflicts.
Indeed, blockchain technology can provide the same functionalities as a land registry system, namely:

– registering a land;
– knowing a land owner at a real time;
– ensuring unique ownership;
– tracking transactions; and
– monitoring the transaction history of a land.

Beyond these aforementioned features, blockchain can provide additional functionalities. Thanks to its shared database, it offers secure backups.

Trust is added by its cryptography and security mechanisms. Because of the private key, it is not possible for a non-owner to make transactions within it [12]. All these potentialities make the blockchain a trusted tool for securing land and make it a safe alternative to conventional land registers for the time being.

In literature, we note that only the Ghana initiative with bitland uses the end-to-end blockchain for the prevention and management of social conflicts. Honduras uses it only for conflict management and auditing purposes. The potential of the blockchain characterized by transparency, security and disintermediation makes it possible to implement various applications. Thus, we no longer speak about the blockchain only for electronic money. We also have applications adapted to the following fields such as: banking, insurance, real estate, energy, transportation, health, online voting, etc. [17]. The blockchain aims to replace centralized *trusted third party* businesses with distributed computer systems. Our proposed solution aims to avoid intermediaries such as canvassers during land transfer operations between two people, to prevent land fraud as much as possible and to limit human intervention in land management as much as possible.

3 Related Work

In 2016, Avi Spielman in "Blockchain: digitally rebuilding the real estate industry" worked on blockchain technology for a digital reconstruction of the real estate sector [15]. He explored the aspect of title registration by comparing the advantages and limitations of the blockchain with those of the existing record-keeping system. He presents two probable ways in which the blockchain might work in the real estate management of an American city. His approaches focused on the colored coin of Bitcoin and on a hybrid approach. Indeed, in his first solution approach, a person who wishes to register his property would present himself at the registry with all the required documents proving that he is the current legitimate owner (e.g. deeds, etc.). The registry office would record the information and share it with the tax assessor's office. In turn, it would determine that the information provided is correct and would create a colored coin (which would result in an initial transaction) in which all relevant information would be incorporated and represent the property. This transaction would be digitally authorized using the appraiser's public key as a signature, after which the appraiser would transfer the coin to the Bitcoin address of the current owner, thus establishing this transaction point as the open or unspent transaction and the person at that address as the owner of the property. Once this information in the blockchain, the owner can transfer the property without further interaction with the registry. In the future, each new transfer of ownership will constitute the chain of title on the blockchain.

His second approach to introducing the blockchain into the land registration process is to work within the existing system by combining elements of the current model with elements of the blockchain. For example, once the tax assessor has confirmed that the new information is accurate and has been entered into his database, this information can also be chopped into the blockchain using existing services, such as http://proofofexistence.com/, which essentially allows documents to be saved into the blockchain (the process is similar to downloading a file to a cloud drive such as Dropbox or Google Drive). The hash, which represents a title or deed associated with a particular piece of land or property, is time-stamped when it is submitted.

Like all technologies in the world, the colored coin has advantages but also disadvantages. Indeed, the colored coin [3,9,14]:

- is very complex to implement and develop;
- puts more pressure on the blockchain because its creation increases the size of transactions and this affects the network's ability to process transactions. All of this results in a decrease in the number of transactions that can be processed, increases the cost of mining commissions, and greatly increases the size of the blockchain;
- discourages miners because of the low commissions. This can lead to a loss of computing power for the network due to the low profits of the miners, who will then prefer to exploit more profitable crypto-currencies;
- can be lost if the appropriate software is not used.

In 2018, Karamitsos et al. presented in "Design of the Blockchain smart contract": A Use Case for Real Estate, the blockchain and the smart contract in real estate [8]. Specifically, they presented the process of setting up a smart contract followed by an application for the rental of residential and commercial buildings. For this use case, the Ethereum blockchain was selected. The real estate agency acts as the owner of the properties (residential and commercial properties) that require renting using the blockchain. The smart contract is concluded between a property owner and tenants. The purpose of the contract is to ensure that the rental agreement is signed, that the rent is paid on time, and that the termination of the contract is properly executed. The implementation of the smart contract is done with the solidity language. It is then deployed on the Ethereum blockchain and users will be able to interact with the contract through their browsers.

In 2020, Vinay Thakur et al. presented a paper entitled "Land records on Blockchain for implementation of Land Titling in India" [16]. They are exploring the use of blockchain technology for land records management in India. This has been done by highlighting issues such as minimal transparency, accountability, inconsistent data sets with different ministries regarding the same piece of land, and delays in their current land records management process. The paper illustrates the design of a system using blockchain technology for the implementation of the Land Titles Registration System in India so that land titles are inviolable and confer genuine and conclusive property rights [16]. Note that their work stopped at the design phase while we went through the implementation and conducted usability testing.

4 Materials and Methods

To implement our solution, we made several technical choices presented below.

4.1 Materials

Ethereum Blockchain. It is an open blockchain for the development and deployment of Decentralized Applications (see Fig. 1). A Decentralized Application is an application friendly user interface based on smart contracts. Thanks to smart contracts written in solidity programming language, a computer code can facilitate the exchange of money, content, property, shares, or any object of value. Simply deploy the smart contract on the Ethereum Virtual Machine (EVM) and it will run automatically when specific conditions are met [13].

EVM has allowed the Ethereum blockchain to go beyond the primary purpose of blockchains, which is to offer only a crypto-money service. EVM makes the process of creating applications based on the simpler blockchain. We do not need to create a blockchain entirely for each new application. Ethereum allows the development of thousands of different applications on a single platform [13].

We write the smart contracts thanks to the OpenZeppelin library [11]. It provides tools to write, deploy and operate decentralized applications. It includes the most widely used implementation of the *ERC-721*[1] standard. It allows the

[1] Consensus adopted within the community of Ethereum which is characterized by its ownership not fungible.

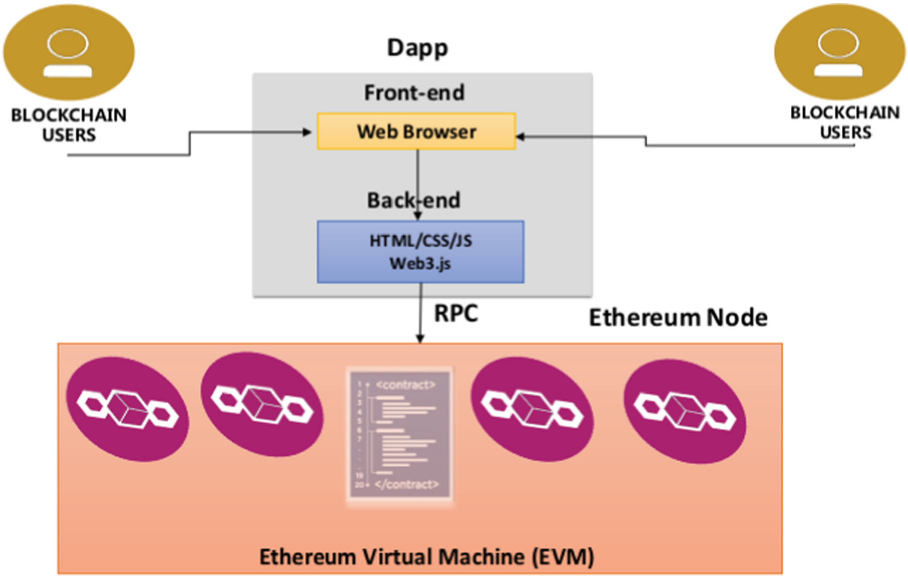

Fig. 1. DApp structure [8].

creation of single identity tokens. In other words, these are tokens that cannot be replaced by other tokens during an exchange because they do not have the same value and characteristics. According to the requirements of this standard and depending on the type of data we have to handle in our solution we used *Uniform Resource Identifier* (URI). In our solution, a URI represents a JSON type file stored on our server that characterizes a land. It includes the GPS coordinates of the various markers, the land title number, a descriptive text, and a link to an image. All this was done in the Truffle development environment [10].

Spatial Data Server. Spatial Database Management Systems are engines for managing databases of data that incorporate spatial components. They offer the ability to store and manage spatial data such as points, lines, surfaces, and volumes [1].

We are interested in a comparative study of three database management systems that integrate space cartridges. These are: MySQL (MyGIS), Oracle (Oracle Spatial, Oracle Locator) and PostgreSQL (PostGIS). This study was carried out by LINAGORA and CampToCamp for the Centre National d'Etudes Spatiales (CNES) [2].

According to the set of functionalities (geometric objects, spatial indexes, spatial predicates, spatial functions, and supported spatial reference systems) offered by the studied DBMS, Oracle Spatial would come first followed by PostgreSQL/PostGIS. However, we choose PostgreSQL/PostGIS because it is a free and open source, and almost as powerful as Oracle Locator which is a proprietary product and not free.

Webmapping. For online mapping, we had the choice between OpenLayers and Leaflet. Table 1 presents the results of a comparative study conducted between these two libraries.

Table 1. Comparison between OpenLayers and LeafLet [a].

	LeafLet	OpenLayers
Getting started	Fast	Slow
Maintenance	Every 6 months	Every 3–4 months
Documentation	Available with many examples and tutorials. Well-documented API allowing to quickly find a desired functionality	Available but most of the examples are outdated. API well documented, but dense that one could get lost in it at the beginning.
Community	More than 600 contributors	Nearly 240 contributors
Flexibility and strength	Yes by adding plugins	Yes natively
GIS format supported	GeoJSON, CSV, WKT, TopoJSON, GPX, ...	GeoJSON, TopoJSON, KML, GML, GeoRSS, ...
Code line	Fewer lines of code to get the expected result	More lines of code because it is more structured

[a]Source: https://www.geoapify.com/leaflet-vs-openlayers.

In view of this comparison, we used LeafLet to locate the different lands on the maps.

We used the GeoJSON format to provide land coordinates to LeafLet library for their displaying.

4.2 Methods

Our work was carried out according to the phases of analysis, design and implementation presented in the following subsection.

Analysis Phase. In this step, we identified the different user roles of our application and their different implications. This allowed us to establish the operating principle of our solution.

The architecture of our system in Fig. 2 is divided into several levels. A client launches a query through its web applications. These queries depend on the type of user. The different users of our system are as follows:

notary: has the possibility, based on convincing documents provided by the alleged landowners, to create an asset relating to the land in question on the block. This asset consists of the GPS coordinates of the said land and its land title (if it exists). It is automatically sent to the owner's account using his public address. When the asset is created on the blockchain, the coordinates of the land are also saved in the GeoJSON format in the database.

owner: disposes of its assets on its account. If he wishes to make a sale, he will be able to transfer the asset (the land concerned) to the account of the new owner thanks to his public address. Thanks to webmapping, he will be able to visualize on-demand on a map the information related to his land.

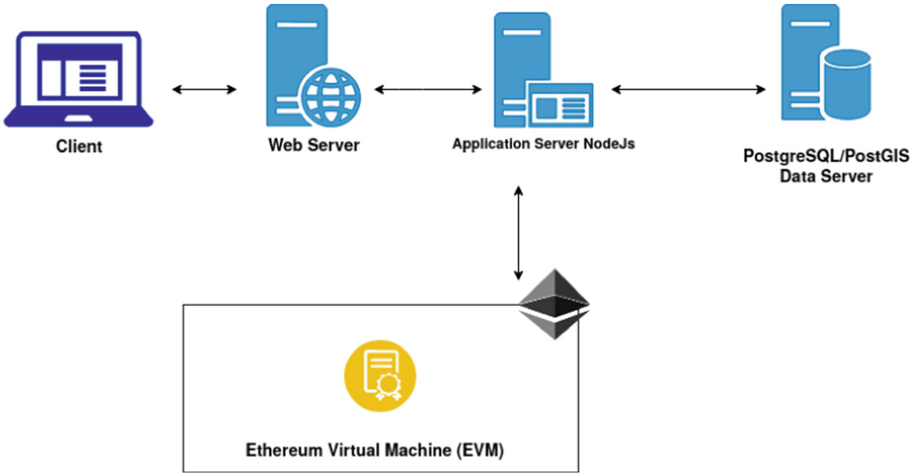

Fig. 2. System architecture.

Design Phase. The use case diagram in Fig. 3, presents the functional interactions between the actors and the studied system. It shows the system from the actors's view.

The class diagram in Fig. 4 shows the different classes of the system and the interactions between them. It describes the internal and the static structure of the system.

Implementation Phase. Table 2 provides a summary of different tools and languages used in the development of our solution.

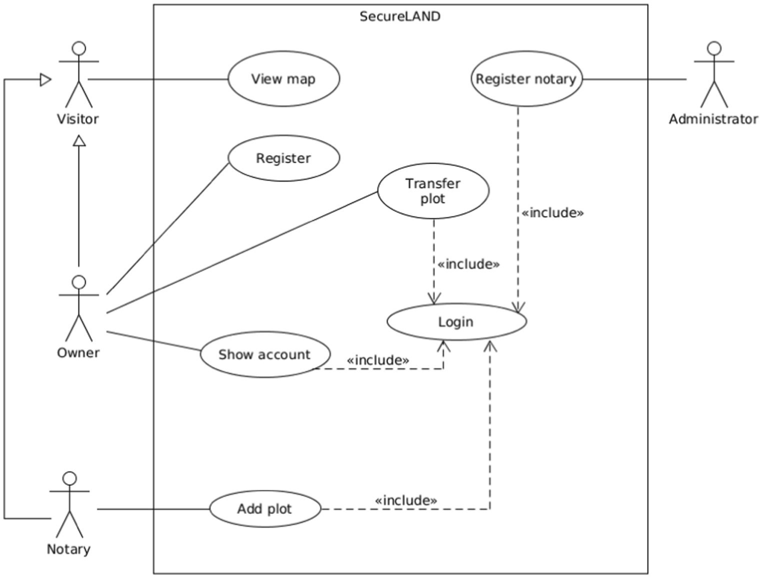

Fig. 3. Use case diagram.

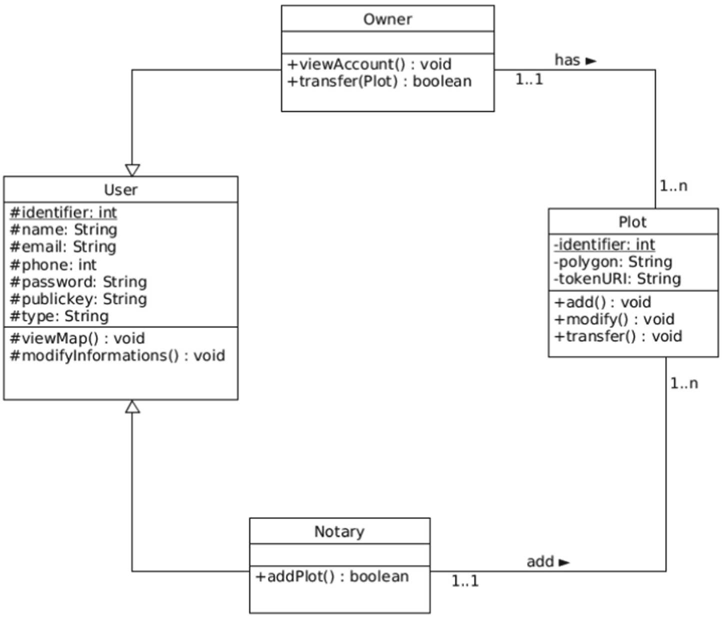

Fig. 4. Class diagram.

Table 2. Synthesis of the tools and languages used.

Programming languages	**Solidity:** For the realization of our smart contract **JavaScript:** For the realization of our API thanks to Express.js and of our interfaces thanks to Vue.js
JavaScript libraries	**Web3.js:** To interact with a node of the blockchain **LeafLet:** To manage and display the registered lands on a map
Development interfaces	**Visual Studio Code 1.46.1:** To write the codes for the realization of our solution **Ganache 2.4.0:** Ethereum local blockchain to test and deploy our smart contract
Modeling language	Unified Modeling Language (UML)
Database management system	PostgreSQL with its PostGIS extension for the manipulation of geographic information

5 Results and Discussion

5.1 Presentation of Results

In addition to the functions of the OpenZeppelin library [11], we have written our own functions that are adapted to the assets we handle. To do this, we have:

– a function for creating a new token based on the owner's public address and the URI token whose prototype is as follows:

```
function safeMint(address, string memory)
    public
    returns (uint256)
```

– a function to perform the transfer of ownership between two owners based on their public addresses and the token identifier. Its prototype is as follows:

```
function safeTransfer(
    address, address, uint256
) public
```

– a function to check the existence of a property in the blockchain. Its prototype is below:

```
function tokenExist(uint256)
    public view returns (bool)
```

– a function to perform a registration modification on a token. We first delete the property before recreating it with the modified information. Here is its prototype:

```
function resetToken(
    uint256, address, string memory
) public
```

We illustrated below some screenshots of the results we achieved. The Fig. 5 presented some lands (in red) registered in the system. Indeed, when a land is registered by the notary, its coordinates are retrieved and transformed into the GeoJSON format.

The owner can view all the lands belonging to him, as illustrated in the Fig. 6 and can perform different operations (display a location and perform a transfer) on his properties.

Fig. 5. Visualization of lands.

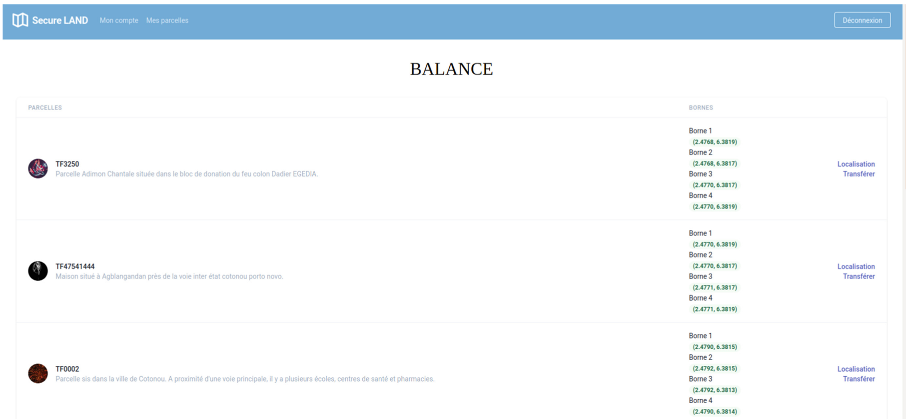

Fig. 6. List of an owner's lands.

Fig. 7. Land transfer.

We have also implemented a transfer property feature as showed in Fig. 7. To transfer a land, after selecting the transfer option the current owner must fill in the public address of the new owner.

The whole project is available at https://gitlab.com/liooonel/landsecure.git.

5.2 Discussion

Thanks to the solution we propose and in comparison to the technological and traditional land management made in Benin, we note that:

- intermediaries are eliminated in the operations of land transfer;
- the responsibilities can be easily located thanks to the reduced number of users and to the computerization of the solution;
- the possession of a land is no longer questionable;
- the registration and deletion of lands without any control of the system is not possible.

This work consists in the implementation of an application to secure land in Benin thanks to the blockchain technology. This application is associated with webmapping technologies. Our researches allowed us to realize that there are existing solutions and works carried out in the same field in Benin. But all of them used intermediaries. Then, land security is not guaranteed. Our solution brings a plus to land management in Benin more precisely thanks to the blockchain technologies we have associated with it. It allows us to cut out the intermediaries during the operations of transfer or acquisition of lands. In spite of the problem solved, our application also has shortcomings. Thus, we have noticed that our solution will be difficult to access for rural populations, most of whom are illiterate.

6 Concluding Remarks

Our society is more and more confronted with the constraints related to litigation, intermediaries and mainly to trusted third parties that affect the implementation of optimal land transactions. In a view of securing the land and accelerating the procedures for land transfers, considerable efforts characterized by solutions already in use are notable. For example, the provision of the digital cadastre accessible to all by the ANDF and the implementation of the e-notaire platform.

We have implemented a smart contract for land management in Benin. Thus, a land added to the system would no longer be subject to any suspicion for a presumed owner. In the same way and for security reasons a transfer of ownership could be concluded by a transfer into our system. Users can visualize on an online map all the registered lands.

Although our solution meets the stated need, we are thinking of simplifying the solution so that it is accessible to rural populations, most of whom are illiterate. In addition, it would also be interesting to explore the possibility of setting up a stand-alone solution based on the authentication of ownership documents. In this way, the role of notaries would be eliminated and the documents attesting to ownership would be directly processed by the system.

References

1. Akakpo, A.: Prototype d'un système de Webmapping interactif avec les JSP et les Servlets. Master's thesis, Institut de Mathématiques et de Sciences Physiques: IMSP, Dangbo, Bénin (2011)
2. Baldé, I.: Mise en place d'une plateforme de cartographie dynamique. Master's thesis, Ecole Supérieure Polytechnique de Dakar, Dakar, Sénégal (2008)
3. Bit2Me Academy: What is a colored coin? (2020). https://academy.bit2me.com/en/what-is-a-colored-coin, Accessed 01 Feb 2021
4. Bitland Ghana: Our mission (2020). https://www.bitlandghana.org/blog/our-mission, Accessed 01 Feb 2021
5. Blockchain France: Blockchain: Honduras 1-france 0? (2016). https://blockchainfrance.net/2015/09/16/le-honduras-adopte-la-blockchain, Accessed 05 Feb 2021
6. Byamugisha, F.F.K.: Securing Africa's Land for Shared Prosperity. The World Bank (2013)
7. Gbago, B.G., Devaux, O.: Le foncier au Bénin - Droit béninois n° 3. Presses de L'Université Toulouse 1 Capitole, Geneviève, Dahan (2014). https://www.ut-capitole.fr/le-foncier-au-benin-droit-beninois-n-3-revue-dirigee-par-barnabe-georges-gbago-et-olivier-devaux-481111.kjsp. ISBN: 978-2-36170-080-5
8. Karamitsos, I., Papadaki, M., Al Barghuthi, N.B., et al.: Design of the blockchain smart contract: a use case for real estate. J. Inf. Secur. **9**(03), 177 (2018)
9. Lars, L.: Des jetons sur bitcoin: colored coins et autres procédés (2020). https://journalducoin.com/bitcoin/actualites-bitcoin/jetons-bitcoin-colored-coins-autres-procedes, Accessed 01 Feb 2021
10. Mohanty, D.: Deploying smart contracts. In: Ethereum for Architects and Developers, pp. 105–138. Springer, Heidelberg (2018). https://doi.org/10.1007/978-1-4842-4075-5_4
11. OpenZeppelin: Openzeppelin (2018). https://github.com/OpenZeppelin/openzeppelin-contracts
12. Pal, O., Alam, B., Thakur, V., Singh, S.: Key management for blockchain technology. ICT Express (2019)

13. Mitra, R.: Qu'est-ce qu'ethereum? le guide le plus complet de tous les temps! (2019). https://blockgeeks.com/guides/fr/quest-ce-qu-ethereum, Accessed 17 May 2020
14. Rosenfeld, M.: Overview of colored coins. White paper, bitcoil. co. il 41, 94 (2012)
15. Spielman, A.: Blockchain: digitally rebuilding the real estate industry. Ph.D. thesis, Massachusetts Institute of Technology (2016)
16. Thakur, V., Doja, M., Dwivedi, Y.K., Ahmad, T., Khadanga, G.: Land records on blockchain for implementation of land titling in India. Int. J. Inf. Manag. **52**, 101940 (2020)
17. Treiblmaier, H., Rejeb, A., Strebinger, A.: Blockchain as a driver for smart city development: application fields and a comprehensive research agenda. Smart Cities **3**(3), 853–872 (2020)