DApp for Food Traceability Based on PyTeal and Algorand

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Abstract—The research area of this work is the application of blockchain technologies in tracking the authenticity of organic food. This paper discusses the influence of blockchain technology as one of the modern technologies and how it can change supply chain management. In the theoretical part of the work, the concept of supply chain management in the food industry will be explained, focusing on analysing the possible application of blockchain technology. The possibilities will be looked at in detail with applications of blockchain technologies to trace the authenticity of the food. The main goal of the research is to propose an intelligent system for tracking the origin of organic food, such as coffee, based on blockchain technology. The practical part of the paper will present the traceability of organic coffee origin by developing smart contracts. Smart contracts will be developed using PyTeal programming language and Algorand blockchain platform.

Keywords - Supply Chain Management, Organic Food Traceability, Blockchain, PyTeal, Algorand

I. INTRODUCTION

When purchasing organic food, consumers have high standards for its quality and depend on certification agencies to confirm the quality and offer details about the items' sourcing. However, there are several drawbacks to organic food traceability, including issues with organic labelling, certification fraud, and worries about the openness of food information [1]. Chain of Custody (CoC) methods based on paper are used in many certification schemes. This mandates that all businesses throughout the supply chain maintain written records of the number of certified items they acquire and sell. Additionally, it necessitates the arrival of auditors to verify those paper documents. Hence, information about the authenticity of the food is critical in the organic food supply chain, as it can show pesticide use, genetically modified organisms (GMOs), fair payments, and carbon or environmental footprint. Pesticides can be toxic to humans and have acute and chronic health effects. According to the World Health Organization, pesticide exposure's health and ecological impact remain concerning. Concerning the above observations, this study aims to investigate the possibility of using blockchain technology to track the authenticity of organic food. Blockchain enhances the sources to identify potential contamination sources and swiftly stop outbreaks. Transparency may increase brand trust by validating and authenticating food provenance when utilising the Blockchain for food traceability. Additional advantages include preventing fraud and combating attacks with preventive measures that can save costs associated with food testing and increase margins.

This paper provides a theoretical review of using blockchain technologies in supply chain management and food traceability using smart contracts and blockchain platforms. The practical part shows designing an ecosystem for tracking organic coffee origin using Blockchain. Designing and development of smart contracts for the food chain are presented. A dApp is developed using PyTeal and Algorand blockchain technologies.

II. BLOCKCHAIN IN THE SUPPLY CHAIN

A. The concept of supply chain management

The supply Chain is sources of raw materials and parts, production and assembly, warehousing and inventory tracking, order entry and order management, distribution through all channels, delivery to the customer, and the information systems required to track all of these activities are just a few of the activities involved in getting a product from the manufacturer to the customer [2]. All of these processes are coordinated and integrated by supply chain management. It connects every component in the chain, including internal organisational divisions and external partners, vendors, carriers, third-party businesses, and information technology providers. The necessity of viewing the entire procedure as a single system is a crucial component of supply chain management. To ascertain the genuine capabilities of the process, any inefficiency experienced across the supply chain (suppliers, production facilities, warehouses, customers, etc.) must be evaluated [3].

Throughout the supply chain, most traceability standards describe the capability to track the essential features of a product from its origin (including its ingredients) to the final process step. The various definitions of 'traceability' encompass two or more of the following four concepts: consistency and clarity in terminology (e.g., 'tracking' vs 'tracing'), backward follow-up of ingredients (tracing), forward follow-up of products (tracking), and product history information throughout the supply chain [4]. The definition of food traceability as a logistics management component highlights that food safety and quality are quality assurance capabilities whose efficiency and effectiveness depend heavily on logistics operations [5]. While a comprehensive collection of traceability information is necessary for this procedure, the success of the recall process is also heavily dependent on the efficiency of logistical operations and the degree of integration between the various supply chain actors [6]. While other definitions of traceability emphasise the primary functionality of tracking and tracing, Bosona and Gebresenbet's report establishes a direct connection between the purpose of traceability ("checked for safety and quality control") and the conditions of applicability ("at all stages" and "at any time required"). Forward traceability (or "tracking") is distinguished from backward traceability (or "tracing") based on the direction of information flow. The distinction is best described in the context of a product recall. The capacity to track means that products can be followed from the beginning to the conclusion of the supply chain and recognised based on recall criteria.

B. Blockchain Food Traceability System

Blockchain food traceability systems enable consumers to receive any necessary food safety and quality control checks and backup data information to serve consumers' food safety needs better. These systems are part of logistics management as an information system that captures, stores, and transmits information about the collection, rearing, and production at all stages of the food supply chain. Traceability, according to Ringsberg, is the process of figuring out how to identify the root of flaws in food safety failures throughout the supply chain [7]. The primary prevention of future food safety events is thought to be accomplished by BFTS [8]. It is seen as a critical instrument for removing information asymmetry. Barcodes have been coupled with the blockchain food traceability system (BFTS) as an identifying tool to swiftly and precisely monitor food items. The Quick Response (QR) code is always written as a two-dimensional barcode on the traceability labels [9]. A QR code has excellent readability and can hold enough info. When a piece of code is physically destroyed, it is still quite readable [10]. Because they provide more data storage and encryption capabilities and environmental protection, QR codes are viewed as improved linear bar codes in developed nations. The ability to match a variety of two-dimensional code decoding software and systems, as opposed to being restricted to reader devices, is one benefit of two-dimensional code over RFID and conventional bar codes, which can be read by a wide range of devices, including smartphones [11]. The BFTS records all types of information at all levels of the food trade chain, according to the data flow and blockchain flow definition in the logistical process. The customer may use a QR code on the product label, load the system and get critical information about food traceability.

C. Using Blockchain to Track and Trace Organic Food

The coffee industry can also utilise the Blockchain to improve supply chain traceability. This is due to the immutability, traceability, and security that define blockchain technology. Big businesses frequently use this trait to boost sales and deal with the millions of brands affected by counterfeiting difficulties. The Global Financial Integrity Organization (GFIO) has conducted studies that put the yearly cost of counterfeit or pirated goods from international trade between US$923 billion to US$1.13 trillion [12]. If the Blockchain's core features are applied to the coffee supply chain, the uniqueness of the beverage can also be preserved. Blockchain can improve coffee producers' welfare, ensure quality, and decrease fraud in the sector. Customers of coffee dealers are informed of all the participants in producing the coffee before it reaches them. Customers should be able to comprehend why the company sells coffee at the current pricing by using blockchain technology since coffee traders raise payments to farmers who adhere to the company's plantation requirements. Also, it is feasible for clients to tip farmers to improve their well-being.

Using Blockchain, enterprises in the coffee industry can record production modifications on a single shared ledger, providing comprehensive data visibility and a single source of truth. Because transactions are always timestamped and current, businesses can query the status and location of a product at any time. This aids in the fight against challenges such as counterfeit goods, compliance violations, delays, and waste. In addition, immediate action can be performed during emergencies such as product recalls, and the ledger audit trail ensures regulatory compliance. In addition, by connecting Blockchain with intelligent technologies such as the Internet of Things, supply chains may automate the tracking of manufacturing, transportation, and quality control conditions. Companies may also opt to share track-and-trace data with their customers to verify their products' legitimacy and the integrity of their supply chains.

III. DESIGNING AN ECOSYSTEM FOR FOOD TRACEABILITY BASED ON BLOCKCHAIN

A. Food Traceability Platform in Coffee Supply Chain

The applied traceability platform is based on a web application accessible to all stakeholders in the coffee supply chain (farmers, factories, roasters, consumers, and supervisory authorities) (Figure 1). It enables operators to capture information from the coffee supply chain to ensure the quality of coffee and promote its marketing. The consumer will have access to the transactions in the various levels of the supply chain.

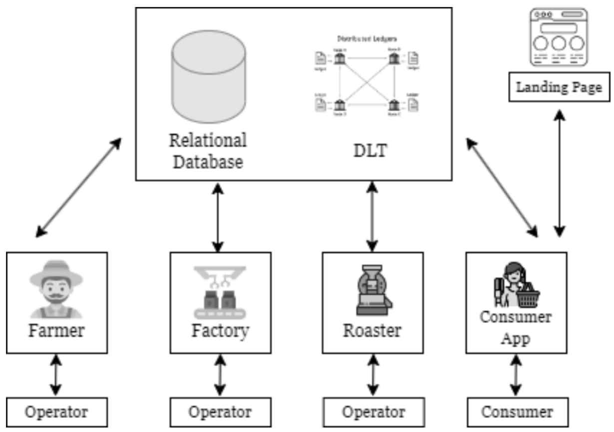

Fig 1. Traceability platform in the coffee supply chain

The key architectural components are the Backend framework, Relational Database Management System (RDBMS), and Distributed ledger technology (DLT). The development of the traceability platform is based on functional and technological needs received from Aosta valley dairy. The backend framework is the software component of the system and incorporates all the core data entry and retrieval operations [13]. The authors utilised a framework based on the Python programming language. The authors determined the required data, tables, and columns to be created in the RDBMS. MySQL is used as the database, which is hosted by Amazon Web Services (AWS). Integrating DLT and RDBMS enables the immutability of the supply chain's data by storing the required fields for identifying transactions from the relational database. The authors selected the Algorand Blockchain after analysing and evaluating several Blockchain technologies. The Algorand Blockchain is among the greenest Blockchains due to its low power consumption consensus algorithm.

In this ecosystem architecture, the various stakeholders involved in the food traceability process include:

a. Farmers and suppliers who provide the food products to be tracked
b. Regulators and certifiers who set standards and regulations for the food products and certify compliance
c. Retailers and distributors who get the food products from farmers and suppliers to consumers
d. Data analytics providers who provide insights and analysis based on the data generated by the Dapp
e. Payment providers who offer payment solutions that are integrated with the Dapp

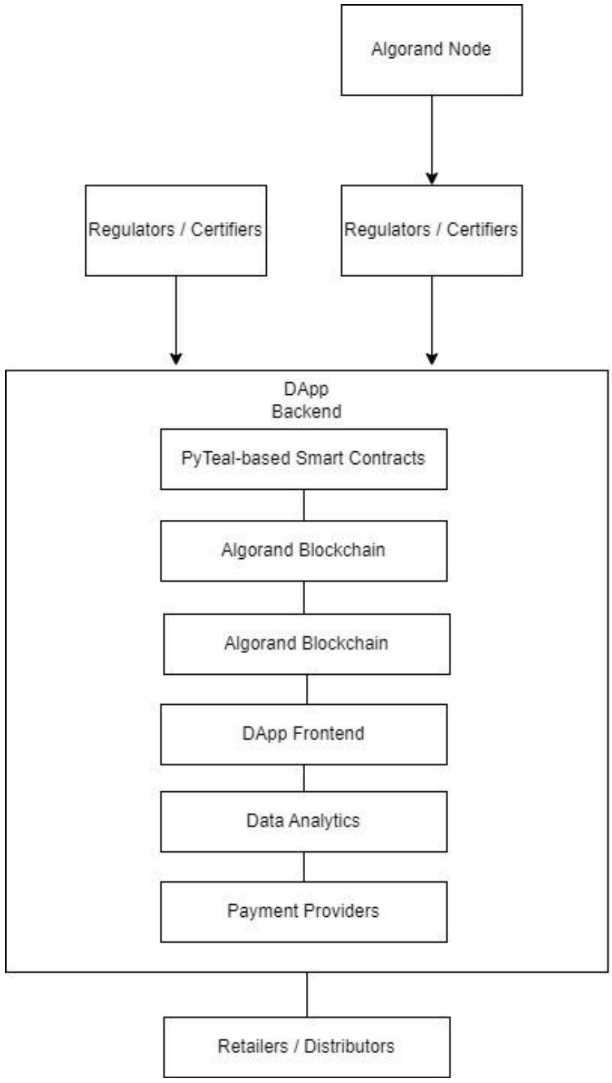

Fig 2. Ecosystem Architecture in tracking coffee

The DApp backend, which incorporates PyTeal-based smart contracts that enable food traceability on the Algorand blockchain, supports the ecosystem. The Algorand blockchain provides a secure, transparent, and immutable record of all transactions and data about tracked agricultural products. Farmers, suppliers, regulators, retailers, distributors, and consumers can interact with the DApp and access data related to the monitored food products through the DApp's frontend. The frontend is accessible via mobile and web applications. Data analytics providers have access to the data generated by the DApp to provide insights and analyses that can enhance the food traceability process. Farmers, suppliers, retailers, distributors, and other ecosystem participants can easily send and receive payments when payment providers integrate their solutions with the DApp.

B. Data Model

A data model was developed based on the organic coffee production chain, considering all supply chain phases and operators (Figure 3). The data model describes the tables and columns to be supplied with specific values in the RDBMS and DLT.

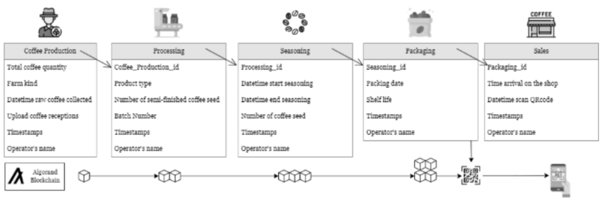

Fig 3. Principal Details recorded by operators

Automatically logged by the system are the operator's name and the transaction's timestamp. Thus, each operator must record the following data at each phase:

1. **Transporter**: The transporter begins the tour of the coffee growers and logs each quantity supplied using the existing system. The transporter arrives at the coffee producer, logs into the traceability platform, and enters the following information: the total amount of coffee collected, the type of farm (mountain pasture or valley), the date and time of raw coffee collection, and finally uploads an image containing all the quantities supplied by the farmers. The transporter sends the collected coffee to a dairy operator, who then processes it. At this step, the operator examines the most recent coffee production transactions and selects the coffee production id to handle. In addition, they describe the type of product (coffee seed or another subproduct) and the quantity of semi-finished coffee seed produced.
2. **Seasoning operator:** The semi-processed coffee seed is relocated to a unique location to mature. In this step, the seasoning operator selects the processing id containing the quantity of semi-finished coffee seeds to mature. In addition, they record the beginning and ending times of seasoning. Finally, the amount of coffee seeds labelled with CTF is recorded. The distribution operator initially selects the seasoning id and registers the packing date and shelf life. The transaction is submitted by the operator, who then obtains the QrCode. Specifically, this phase is particularly essential since the system queries and stores all associated data in the Algorand Blockchain.
3. **Sales operator or Consumer:** During this phase, the information about the shop's arrival time and the DateTime of QrCode scanning is used to determine where the coffee was purchased and to display the product's history to the final consumer on the landing page of the coffee's official website.

IV. DAPP FOR TRACKING COFFEE ORIGIN BASED ON PYTEAL AND ALGORAND

A. Business Model Canvas

Fig 4. Business Model Canvas

The Business Model Canvas DApp for food traceability based on PyTeal and Algorand is a decentralized application that leverages the Algorand blockchain and PyTeal (a Python library for writing Algorand smart contracts) to enable transparent and trustworthy food traceability. It relies on partnerships with farmers, suppliers, regulators, retailers, distributors, data analytics providers, and payment providers. The DApp's value proposition lies in transparency, increased trust, and the potential for premium pricing. Key activities include developing and maintaining the PyTeal smart contract, integrating with regulators and certifying bodies, providing user support, integrating payment solutions, and facilitating transactions within the supply chain. Customer relationships are built through transparency, feedback listening, loyalty rewards, excellent support, and collaboration with food producers.

The DApp targets farmers, suppliers, regulators, retailers, distributors, and consumers. Key resources include the Algorand blockchain, a software development team, a marketing team, and PyTeal. Channels utilized include social media, partnerships, events, academic promotion, and the Algorand blockchain platform. The cost structure includes development, maintenance, customer support, and marketing expenses. Revenue streams come from transaction fees, subscription models, advertising, and potential crowdfunding. Overall, the DApp enhances traceability, transparency, and trust in the food industry, benefiting all stakeholders involved.

In summary, the Business Model Canvas DApp for food traceability based on PyTeal and Algorand revolutionizes traceability in the food supply chain. It ensures transparency, fosters trust, and enables premium pricing. Through partnerships, key activities, customer relationships, targeted segments, key resources, channels, cost structure, and revenue streams, the DApp delivers its functionality effectively, reaching a wide user base and generating value for all stakeholders involved.

B. Smart contracts between stakeholders in the producing coffee

This sequence diagram depicts the interaction between the parties involved in coffee production and a smart contract that monitors the production procedure. The process's stakeholders include the coffee producer, the logistics company responsible for transporting the coffee, and the coffee roaster or purchaser (Figure 5).

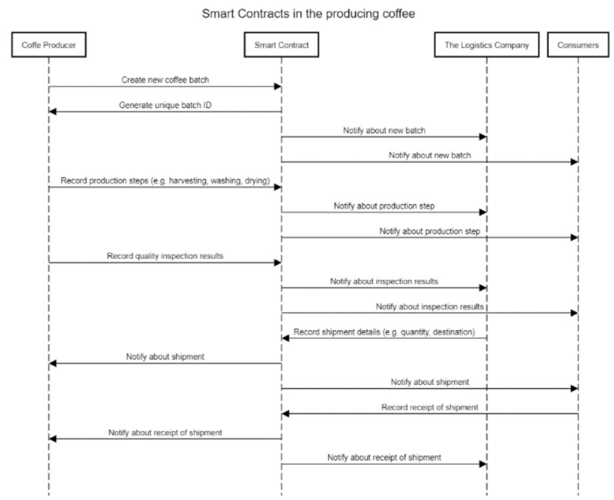

Fig 5. Sequences diagram for smart contracts between stakeholders in the producing coffee

The coffee Producer creates a new coffee batch and records the production stages using the smart contract to initiate the sequence. The smart contract generates a unique batch identifier and notifies The Logistics Company and Consumers of the new batch. The coffee Producer then continues the coffee production process while using the smart contract to capture the quality inspection results. The smart contract communicates the inspection results to The Logistics Company and Consumers.

The Logistics Company initiates the coffee shipment and documents the shipment details, including the quantity and destination, using the smart contract once the coffee production process is complete. The smart contract notifies Coffee Producers and Coffee Consumers of the cargo. Consumers receive the coffee shipment and document the receipt using the smart contract. The smart contract then alerts Coffee Producer and The Logistics Company regarding the shipment's delivery.

C. Implementation of Smart Contracts

The DApp will support two types of users: farmers and roasters. Farmers can create a new coffee batch by entering the coffee's origin, variety, and quality. Once a coffee batch is created, it will be assigned a unique identifier and added to the Algorand blockchain. Farmers can then sell their coffee to roasters by transferring the coffee batch's ownership to the roaster's address. Roasters can view the available coffee batches and choose which batches they want to buy. Once a roaster purchases a coffee batch, the ownership will be transferred to the roaster's address, and a new record will be added to the Blockchain to reflect the transaction. The smart contract defines a coffee supply chain, which allows participants to create, receive, process, pack, ship, receive at port, roast, and export coffee. The smart contract uses Algorand's stateful smart contract functionality, where participants can create and interact with a stateful application on the Algorand blockchain. The smart contract uses Algorand's PyTeal library to define subroutines for each operation. The subroutines include specific logic to check if the function is valid and the data provided is correct before approving the transaction. If the transaction is invalid, an error message is returned.

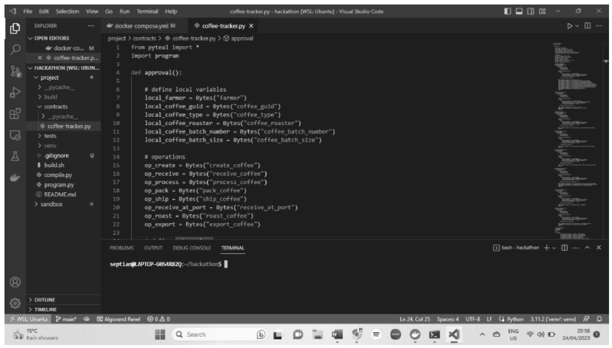

Fig 6. Smart Contracts

The program defines several constants, represented as Bytes objects, that will be used as operation codes in the Algorand smart contract. These constants include:

- create_coffee: an operation to create a new coffee batch
- receive_coffee: an operation to receive a coffee batch
- process_coffee: an operation to process a coffee batch
- pack_coffee: an operation to pack a coffee batch
- ship_coffee: an operation to ship a coffee batch
- receive_at_port: an operation to receive a coffee batch at the destination port
- roast_coffee: an operation to roast a coffee batch
- export_coffee: an operation to export a coffee batch

These operations are likely specific to the smart contract being developed and will be used in the contract's logic to determine how it interacts with the Blockchain and what actions it can perform. The local variables defined in the function, including local farmer, local coffee guid, local_coffee_type, local coffee_roaster, local_coffee batch number, and local coffee batch size, may represent data inputs or outputs for the smart contract. These variables will be used in the contract's logic to store and retrieve data related to the coffee batch.

The program module that is imported at the beginning of the code may contain additional functions and logic used in developing the smart contract. This code represents the beginning of creating an Algorand smart contract designed to manage coffee batches' creation, processing, and shipping. Overall, the contract provides a transparent and secure way of managing the coffee supply chain, ensuring that the coffee is processed, packed, shipped, and received correctly at each stage of the supply chain.

V. CONCLUSION

Creating a decentralised application (DApp) based on the PyTeal and Algorand blockchains for food tracking is a significant advancement in maintaining the safety and security of food. The DApp can successfully trace a food product's entire route from the farm to the table by utilising the transparency and immutability of blockchain technology, giving customers real-time details about its origin, quality, and safety. Using PyTeal, a smart contract language based on Python, also allowed for the user-friendly and accessible implementation of complex logic and rules. This drastically lowered the entrance hurdles for developers and made it possible for the DApp to be developed more quickly and effectively. In general, a DApp for food traceability built on the PyTeal and Algorand blockchains might revolutionise the food business and increase consumer trust and confidence in the goods they buy. It is a promising technology that might be crucial in assuring everyone's access to safe and secure food.

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REFERENCES

[1] M. van Hilten, G. Ongena, and P. Ravesteijn, "Blockchain for Organic Food Traceability: Case Studies on Drivers and Challenges," Frontiers in Blockchain, vol. 3, Sep. 2020, doi: 10.3389/fbloc.2020.567175.

[2] L. X. Lu and J. M. Swaminathan, "Supply Chain Management," in International Encyclopedia of the Social & Behavioral Sciences: Second Edition, Elsevier Inc., 2015, pp. 709–713. doi: 10.1016/B978-0-08-097086-8.73032-7.

[3] R. R. Lummus and R. J. Vokurka, "Defining supply chain management: a historical perspective and practical guidelines Introduction to supply chain concepts," vol. 99, pp. 11–17, 1999.

[4] P. Olsen and M. Borit, "How to define traceability," Trends in Food Science and Technology, vol. 29, no. 2. pp. 142–150, Feb. 2013. doi: 10.1016/j.tifs.2012.10.003.

[5] T. Moe, "Perspectives on traceability in food manufacture," Trends in Food Science & Technology, pp. 211–214, 1998, doi: 10.1016/s0924-2244(98)00037-5.

[6] M. Bourlakis and C. Bourlakis, "Integrating logistics and information technology strategies for sustainable competitive advantage," Journal of Enterprise Information Management, vol. 19, no. 4, pp. 389–402, 2006, doi: 10.1108/17410390610678313.

[7] H. Ringsberg, "Perspectives on food traceability: A systematic literature review," Supply Chain Management, vol. 19, pp. 558–576, Sep. 2014, doi: 10.1108/SCM-01-2014-0026.

[8] S. Jin, Y. Zhang, and Y. Xu, "Amount of information and the willingness of consumers to pay for food traceability in China," Food Control, vol. 77, pp. 163–170, Jul. 2017, doi: 10.1016/j.foodcont.2017.02.012.

[9] J. Qian et al., "Food traceability system from governmental, corporate, and consumer perspectives in the European Union and China: A comparative review," Trends in Food Science and Technology, vol. 99. Elsevier Ltd, pp. 402–412, May 01, 2020. doi: 10.1016/j.tifs.2020.03.025.

[10] J. Qian et al., "Filling the trust gap of food safety in food trade between the EU and China: An interconnected conceptual traceability framework based on blockchain," Food Energy Secur, vol. 9, no. 4, Nov. 2020, doi: 10.1002/fes3.249.

[11] A. Tan and P. T. Ngan, "A proposed framework model for dairy supply chain traceability," Sustainable Futures, vol. 2, Jan. 2020, doi: 10.1016/j.sftr.2020.100034.

[12] R. Bettín-Díaz, A. E. Rojas, and C. Mejía-Moncayo, "Methodological approach to the definition of a blockchain system for the food industry supply chain traceability," in Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), Springer Verlag, 2018, pp. 19–33. doi: 10.1007/978-3-319-95165-2_2.

[13] S. P. Adithela, S. Marru, M. Christie, and M. Pierce, "Django content management system evaluation and integration with apache airavata," in ACM International Conference Proceeding Series, Association for Computing Machinery, Jul. 2018. doi: 10.1145/3219104.3229272.