TRUSTED DOCUMENTATION SYSTEMS FOR SMART FARMING

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Preface

Food is an essential part of human beings' lives and human communities all over the world. On a global scale, the food and agricultural industry involves a large number and diversity of stakeholders involved, including farmers, distributors, retailers, and customers, making agricultural food chain management one of the most intricate and demanding processes. Controlling product quality, conformance across the supply chain, and origination issue are primary concerns. Early tracking and traceability management systems relied on workers recording information on the field and manually transferring it to handbooks or computer systems. This technique has hazards, such as inaccurate data capture and poor resource usage. The rapid development of automated processes and products, as well as communication technology in recent decades, has resulted in the so-called Internet of Things (IoT) paradigm. IoT-based traceability systems offer practical solutions for the agri-food supply chain related to quality monitoring and traceability. However, most IoT solutions rely on centralized platform control, and known security and privacy issues might lead to single-point failure or surveillance. As a result, consumers face difficulties obtaining all transaction information and tracking the origins of products. Blockchain, as an evolving technology with decentralization, tamper-proofing, and traceability qualities, has the potential to address the challenges that are present in the current traditional agricultural product traceability system.

This dissertation proposes two approaches as a documentation system solution by utilizing the blockchain idea regarding food chain security, including food traceability and integration concerns of farm activities. The first approach offers a solution to link legal documentation and blockchain technology within a traceability system with the specific application case of cacao and chocolate production. In this first direction, we assume that the documentation, mainly based on existing media-based documentation practice or supplemented with media such as images or videos, is designed to offer sufficient evidence and visual cues to retrace the whole process. In this study, we improved data security by extending the common blockchain concept to a two-factor blockchain, where both blockchains are connected via digital watermarking of the documentation media. One blockchain traces the documentation steps, the other the watermarking embedding. We propose using digital watermarking technology since one blockchain would be sufficient to ensure the integrity of the sequence of media files generated during the documentation process. At the same time, it would not guarantee the integrity of the media itself. Thus, a second blockchain is required to ensure the integrity of the watermarking process itself. The watermarking algorithm ensures the information at each stage is authenticated, and any alteration or manipulation of data can be detected. The evaluation of proposed frameworks and principles has been implemented and validated by a prototype.

Furthermore, in the second direction approach, we proposed the Encapsulating Block Mesh (EBM) for cocoa production by integrating a unique designed blockchain and applying the principle of a bucket-based transaction implicated by Modular Block Chain (MBC) sensing instruments as a model for farm transactions with the specific application case of cocoa production. In this research, we demonstrate a flow of farm transaction simulation and show how MBC sensing may be used to enhance farm objects' data integrity and security by simulating farm transactions. MBC acts as an information recorder during a farm product's generation, transaction, and consumption, which is subsequently encrypted into a block. Each farm object is connected to a secure block system and validated due to encryption provided by a hash value in each object. The simulation of the proposed method employs a 3D virtual environment or metaverse-based simulation.

The findings of the two approaches reveal that implementing a blockchain concept is feasible and effective and may address the research reported in this thesis by offering documentation system solutions to the traditional agricultural product traceability system. Moreover, we concluded blockchain-based documentation system is appropriate for integrating an agricultural system since the protocol allows farm products at each stage to validate and authenticate product farm transaction data through chained hash values in the blocks. This study is expected to inspire future researchers to enhance and develop the performance of this documentation system model by examining the same principles to be expanded to different stages of the food supply chain in the real-world environment.

Acknowledgment

First of all, shukran wal hamdulillah, thank you to Allah Almighty, who gave me endless blessings, the strength, and knowledge to accomplish this work.

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Ultimately, I must offer my deep gratitude to my dear mom and dad for their unconditional love, which brought 'my life to a halt for moments' at the end of this journey with their sudden departure back into God's lap. I really miss you both and want to meet and get together again. My special and heartfelt thanks to my little family enriched me with love, strength, and motivation.

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List of Abbreviations

BC	Blockchain
DAG	Directed Acyclic Graph
DEMATEL	Decision-Making Trial and Evaluation Laboratory
DLT	Distibuted Ledger Technology
DWMI	Digital Watermarking Image
DWT	DiscreteWavelet Transform
EBM	Encapsulating Block Mesh
EPCIS	Electronic Product Code Information Services
FTSCON	Food Trading System with Consortium blockchain
GPS	Global Positioning System
IoT	Internet of Things
ISM	Interpretative Structural Modeling
ISO	International Organization for Standardization
LPWAN	Low-Power Wide-Area Network
MBC	Modular Block Chain
NFC	Near-field communication
PoW	Proof of Work
PoS	Proof of Stake
PoA	Proof of Authority
PoC	Proof of Concept
PoO	Proof of Object
PDO	Protected Designation of Origin
PGI	Protected Geograpichal Indication

QR Code	Quick Response code
RFID	Radio-frequency identification
TRU	Traceable Resource Unit
UUID	Universall Unique Identifier
WSN	Wireless Sensor Network
XML	Extensible Markup Language

Chapter 1

Introduction

1.1 Background

The ultimate goal of agriculture is to achieve smart farming. Yet, our agricultural system remains fragile, and it is apparent that attaining food security for all by Agenda 2030 requires additional transformation toward sustainable agriculture [1]. Smart farming, which employs data-driven strategies to improve agricultural production management, can assist achieve this goal. Smart farming technologies gather, analyze, and use data to help farmers be more productive, lucrative, and environmentally friendly by combining big data with new artificial intelligence technologies such as remote sensing, automated control, and yield monitoring. Smart farming is also characterized by a complicated data system for agri-food safety due to the fact that agri-food safety data and information are dispersed throughout agriculture sectors and food. Moreover, agri-food supply chains represent related events in the agricultural production of food and describe associated events in agricultural production. Due to its complex structure, the agri-food chain is vulnerable to various vulnerabilities and hazards, including operational difficulties and breakdowns caused by various uncertain factors and circumstances.

Consumers' concerns about food provenance and quality are grave nowadays, leading them to spend even more money on food products whose origination is certified. Despite already developed technology, most traceability systems are centralized, asymmetric, and out of date in terms of data exchange and accessibility. Existing methods lack transparency and customer confidence owing to the lack of a quick and trustworthy mechanism to access product provenance information. Taking all of the above into account, as well as the rapid technological development in value chain areas, we see a significant increase in emerging innovations that pave the way for new digital traceability systems by leveraging information and communication technology (ICT), radio-frequency identification (RFID) sensors, the Internet of Things (IoT), blockchains, and other technologies.

Traditional Internet of Things (IoT) traceability systems use Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), Near Field Communication (NFC), and other technologies to monitor and store certain information at all phases of manufacturing, processing, distribution, and consumption. It has the potential to give useful information for food quality monitoring and traceability. However, because it is built on the centralized server-client paradigm, stakeholders and consumers must rely on a single contact point to store, send, and distribute traceability information[2],[3],[4]. The difficulties posed here are that, because the information is centralized, the sole authority remains the database host. Beyond that, its access right may extend beyond monitoring information to include the possibility of making changes to this information. While the stakeholders' information management systems are typically incompatible, this method of sharing information preserves the difficulty of communication. Furthermore, trust is lacking because the information transmitted is not immutable, data integration and non-repudiation properties are not guaranteed, and third-party access to this information is constantly conceivable. Consequently, most consumers face difficulties accessing complete transaction information and tracing the origination of products. Consumers and food chain participants must be sufficiently informed on the product life cycle to ensure that products are safe, sustainable, and of high quality[5],[6],[7]. The resolution to food safety and quality issues increases traceability, transparency, security, durability, and integrity. Therefore, data privacy and tamper-proof issues are essential in agri-food traceability, which has become urgent for farmers, producers, manufacturers, governments, and consumers[8].

As one of the emerging technologies, Blockchain, as it is known, may solve complexities in each transaction, such as security issues or traceability process of the products in the Agri food-chain. Blockchain is a distributed ledger maintaining a continuously growing list of data records that are confirmed by all of the participating nodes [9]. A block is a record containing data, a value representing the preceding block's hash, and a value representing its hash. The hash represents the cryptographic fingerprint of a block's data amount. Through these hashes, the link between the current block's hash and the preceding block's hash reveals the meaning of the cryptographically connected chain of blocks. If someone tampers with the data, the digital fingerprint will be altered, rendering the chain invalid.

Blockchain system has been widely accepted as a solution to the underlying trust and security issues because of its transparency and prevention of tampering in terms security dimension of food chains with various suggested approaches. Therefore in this study, we propose a new approach, blockchain-based documentation system, to enable traceability in the agri-food domain and to give an alternative solution for traditional IoT issues. In summary, we embraced the blockchain idea and enhanced its features so that it may be utilized to tackle security and traceability issues in the agri-food domain we proposed and will present in this dissertation.

From the background described previously, a question emerges which we wish to prove in this study. The issues that arise are described below.

1. Is it feasible to utilize blockchain-based documentation to enhance food traceability performance?
2. Is it feasible for blockchain-based documentation to validate the authenticity of farm products?
3. Is it feasible for blockchain-based documentation to coordinate and integrate the activities of transaction farms?

1.2 Research Objectives

The primary focus of this dissertation is the implementation of blockchain concept as a trusted documentation system to address security and traceability issues in the agri-food domain. We attempt to achieve this objective by researching two approaches, as shown in Figure 1.1

Two research directions of this study are:

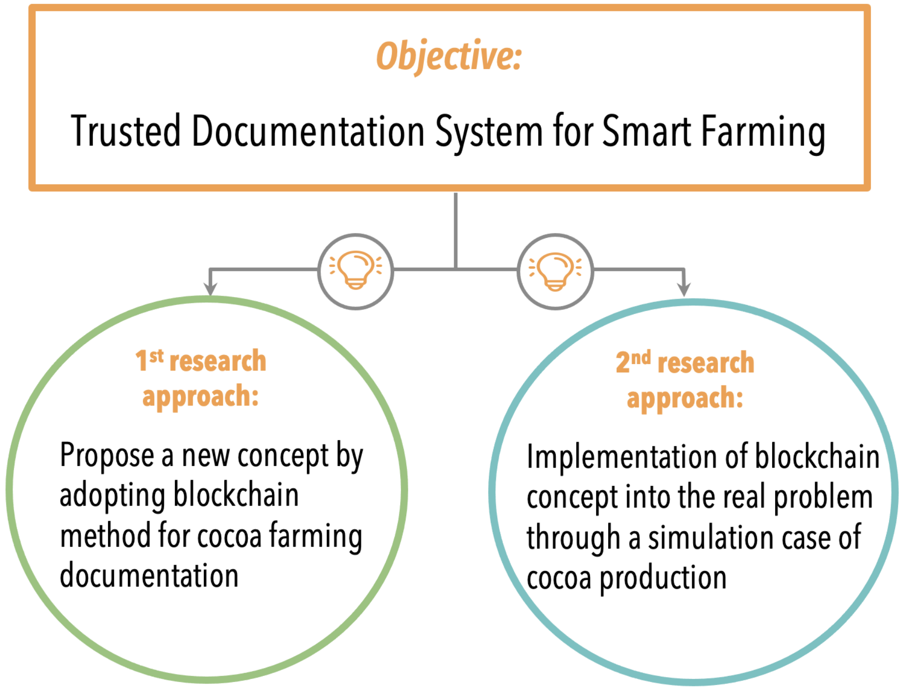

Figure 1.1: Diagram of two approaches for conducting the research

1. Proposing a new concept by adopting blockchain method for cocoa farming documentation
2. Implementation of blockchain concept into the real problem through a simulation case of cocoa production

The first research approach focuses on the two-factor blockchain for authentication that is used in cocoa farming, where both blockchains are connected via digital watermarking of the documentation media. One blockchain traces the documentation steps, the other the watermarking embedding. We propose using digital watermarking technology since one blockchain would be sufficient to ensure the integrity of the sequence of media files generated during the documentation process. At the same time, it would not guarantee the integrity of the media itself. Thus, a second blockchain is required to ensure the integrity of the watermarking process itself. The watermarking algorithm ensures the information at each stage is authenticated, and any alteration or manipulation of data can be detected. The evaluation of proposed frameworks and principles has been implemented and validated by a prototype.

The second research approach focuses on the Encapsulating Block Mesh (EBM) for cocoa production by integrating a unique designed blockchain and applying the principle of a bucket-based transaction implicated by Modular Block Chain (MBC) sensing instruments as a model for farm transactions with the specific application case of cocoa production. In this research, we demonstrate a flow of farm transaction simulation and show how MBC sensing may be used to enhance farm objects' data integrity and security by simulating farm transactions. MBC acts as an information recorder during a farm product's generation, transaction, and consumption, which is subsequently encrypted into a block. Each farm object is connected to a secure block system and validated due to encryption provided by a hash value in each object. The simulation of the proposed method employs a 3D virtual environment or metaverse-based simulation.

1.3 Chapter Section

In this section, we describe the structure of this dissertation, as shown in Figure 1.2. Following the introductory chapter, we outlined traditional documentation for traceability systems, and some published works followed an explanation of traceability related to other terms such as transparency, privacy, and trust. Numerous insights focused on existing traceability approaches and tools implemented in food and agriculture products in Chapter 2. We describe in detail blockchain-based trust management in Chapter 3. In Chapter 4, we model the concept by adopting blockchain method for cocoa farming. In chapter 5, we implement the blockchain concept into a real problem through a simulation case of cocoa production. Finally, Chapter 6 summarizes our work and the results obtained and recommends several possible research areas for future development.

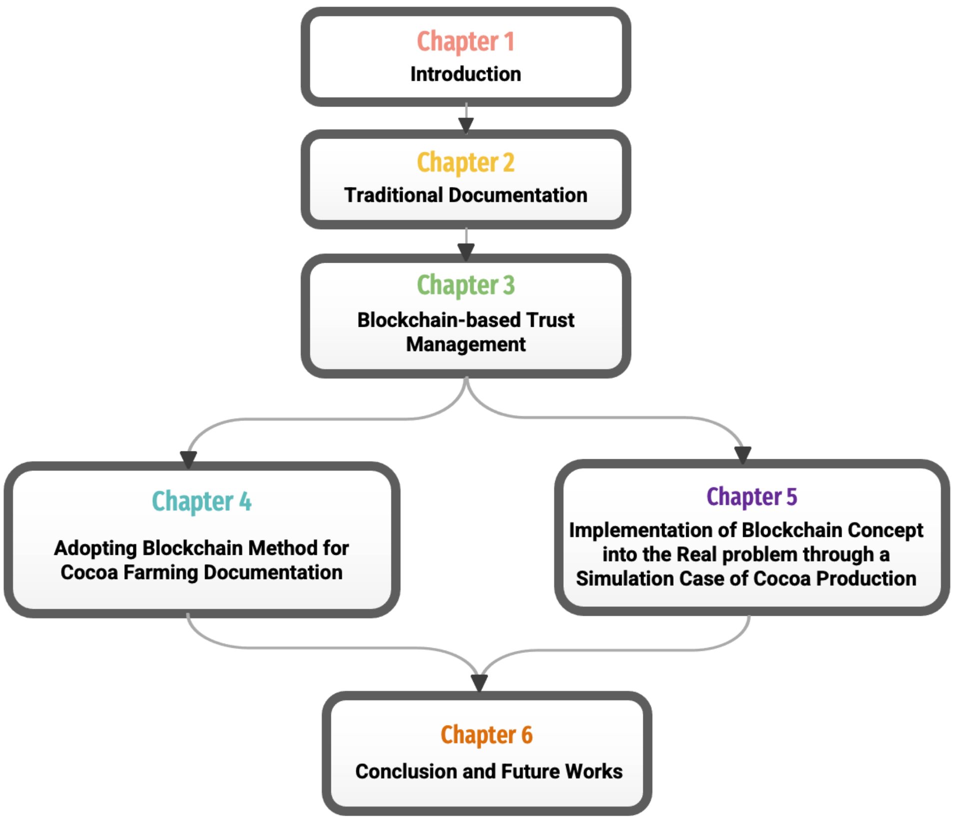

Figure 1.2: The chapter structure of this dissertation

Chapter 2

Traditional Documentation

2.1 Traceability-Definitions and Categorizations

Traceability, often known as the ’one step back, one step ahead’ principle , refers to the ability to recollect all facts regarding the origin of a food product. Another understanding of traceability, given all of the information regarding a food product’s provenance [10]. The International Organization for Standardization (ISO) defines traceability as the ”capacity to follow the movement of a feed or food through a defined stage(s) of production, processing, and distribution” [11]. Traceability is defined by the European Union General Food Law EC 178/2002 as the ability to trace and track food at all stages of production, processing, and sale [12]. ISO 22005:2007 outlines the concepts and standards for designing and implementing a feed and food traceability system. This standard enables organizations functioning at any level of the food chain to trace the flow of products (feed, food, their ingredients, and packaging), identify required documents and tracking for each production stage, provide adequate coordination between the various actors involved, improve communication among the parties involved, and, most notably, improve the appropriate use and reliability of the information, effectiveness, and productivity of the organization.

A traceability system is comprised of data and operations that may keep the necessary information about a product and its components up to and including the end of its production and utilization chain (ISO 2007). Traceability is performance-based and follows the trail as products and materials are received from suppliers, processed, and dispersed as finished goods (ISO 2005). As a result, the capacity to identify products that move through the supply chain is at the core of all traceability systems [13]. Traceability systems have the following basic characteristics as follows:

- Identification of units/batches of all ingredients and products.
- Registration of information on where and when units/batches are relocated or transformed
- Mechanism that links these data and transfers all pertaining traceability information with the product to the next stage or processing step.

These characteristics, notably identity, information, and the relationships between supply chain stakeholders, are regardless of the process or commodity involved. However, the amount of data recorded, the distance (back or forward) the system follows the information, and the level of precision with which the system can identify the movement of a specific product may differ among traceability systems. Practically, traceability systems are record-keeping systems that indicate the flow of a specific product from suppliers to consumers via intermediary processes [14] as illustrated in 2.1.

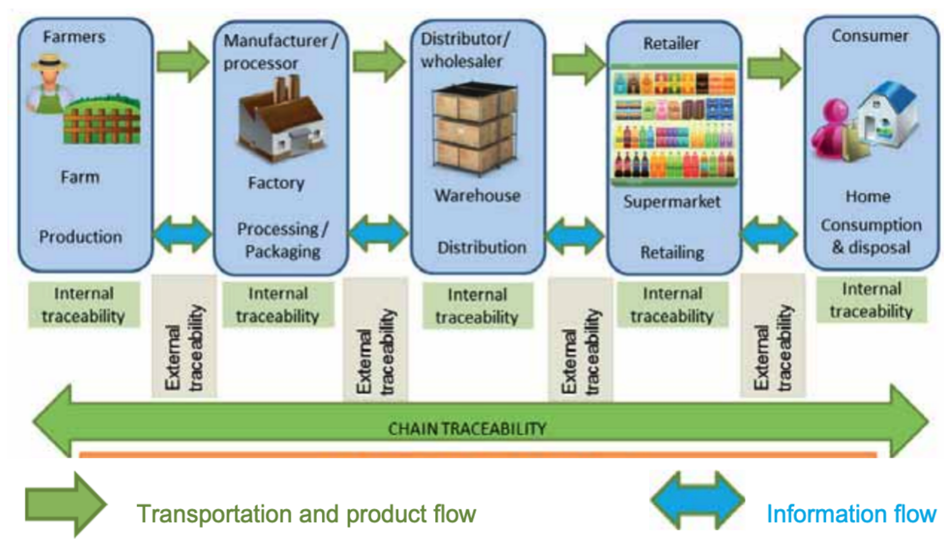

Figure 2.1: Food supply chain traceability

According to Aung, Zhang and Bhatt [14] [15], there are two levels of traceability regarding support transparency and continuity of information across the supply chain e.i. the Internal level (the intra-company) and External level (the supply chain). Internal level traceability is performed by a single actor (business, organization, etc.) and is accomplished through internal procedures. Furthermore, intra-company traceability attempts to identify the origin of the product's materials, packaging, and so on if this supply chain actor is questioned. External traceability, on the other hand, is a mix of intra-company operations and a reconstructing procedure of the entire history of the specific product. Subsequently, all the stakeholders in a supply chain must be engaged and collaborate to achieve a trustworthy outcome in traceability.

Another level of traceability categorization has done The European Community market, distinguishing between obligatory and discretionary traceability [16]. The obligatory traceability is mainly for financial reasons and lacks precise product information in terms of quality aspects. In addition to obligatory traceability, discretionary traceability refers to the ability of each player in the supply chain to select what data to collect [17], and stakeholders are not required to implement voluntary traceability. Only when both required and volunteer tracing systems exist is trustworthy and comprehensive traceability feasible. Supply chain stakeholders willingly submit information allowing a more comprehensive and qualitative traceability system. The intricacy of voluntary control is very complex because each player may have their own rules and techniques for monitoring and tracking a product, resulting in a wide range of obtained data [18].

2.2 Traceability Enhance Trust, Transparency and Sustainability

According to FMI research [19], end-to-end traceability is now a critical enabler of trust, transparency, and sustainability. In 2019, 75 percent of consumers indicated that they would switch to a brand offering more in-depth product information than the label, up from 39 percent of consumers in 2016. To be transparent, brands must understand where the raw materials they use come from, which necessitates the effective use of data. Digitalization is a key driver that is gaining traction. Data powers the vast majority of our daily lives; the food industry must follow suit. Every event that helps improve the quality must be recorded and validated to establish an immutable digital passport that can be accessed from anywhere in the permission ecosystem. Ingredients, origin, manufacturing, production, packing, distribution, and destination must all be available instantly and monitored in real-time. The organization can provide real-time access and enable quick, effective action by incorporating operational diagnostics, traceability, and quality monitoring. In case of a mistake such as product contamination or packaging failure, insights can be immediately uncovered and isolated, ensuring waste is minimized throughout the supply chain. End-to-end visibility allows consumers, businesses, and governments to track down and comprehend a product's entire life cycle. This help promotes responsible production and system effectiveness and serves as the foundation for consistent, end-to-end improvement. Traceability is also important to unlock for the food industry because it works to reduce the negative environmental impact of production by having visibility of all actors responsible for handling materials related to the product. Bodies can collect and validate sustainability credentials, allowing businesses to assess and report on their suppliers' human and environmental sustainability records, effectively increasing standards and assisting in achieving the UN sustainable development goals.

2.3 Agri-Food Traceability Tools and Technology Solutions

Agriculture-food traceability necessitates a massive amount of data collection across the supply chain. Initial tracking and traceability systems relied on employees recording information in the field and physically transferring it to handbooks or a computer system. At the farmer level, we still find farmers who use traditional documentation such as paper or a file system with inaccessible data or a lack of confidentiality in data or information received. This strategy has hazards, such as inaccurate information recording and inefficient resource use.

In recent decades, the massive development of automated processes and products, as well as communication technologies, has resulted in the so-called Internet of Things (IoT) paradigm. The rapid expansion of IoT and sensor technologies benefits data collection by providing quick and dependable solutions. These approaches involve product identification, ingredient analysis, transportation, storage, and data capturing across the full system integration. The most common and well-known methods in supply chains include barcodes, QR codes, RFID, and wireless sensor networks (WSNs). Those tools and applications help the farmer handle the various aspects of farming, such as data processing, water management, field monitoring, soil condition monitoring, crop yield analysis, and disease management. With these technologies, farmers can become strategic and efficient in their daily farm-related tasks and responsibilities. These early digital electronic traceability systems were centralized solutions based on databases with manually or semiautomatic data import.

Due to their advantages, RFID systems provide a secure information and data management solution for agri-food producers, distributors, retailers, and consumers. RFID technology aids in agri-food supply chain management by tracing and monitoring the ”from farm to fork” journey. When a food safety concern emerges, its source and the solution can be identified quickly [20][21]. An augment or complement to RFID tags are wireless sensor networks (WSNs). AWSN comprises wireless sensors and actuators, such as temperature, humidity, sound, pressure, controllers, and other devices that connect with an external system through a wireless modem and store and make data available to stakeholders. WSNs may collect, process, and transmit information such as temperature, humidity, plant diseases, wind speed, insect pests, and animal organ function to a level higher for decision support. WSNs are typically made up of a large number of sensor nodes that are powered by batteries and consume low energy. In agriculture, sensors generally are placed into the soil to collect data on plantation conditions [22]. Furthermore, WSNs may be integrated with more modern technologies like GPS and remote sensing to provide additional functionality.

Gandino created a framework consisting of RFID tags connected to products in a fruit warehouse in 2009 [23]. The prototype is a semiautomatic RFID-based traceability system designed to test and evaluate the performance and possible improvement of traceability through automation enhancements. The experimental system employs RFID tags to read product attributes, RFID readers to gather data from the tags, personal digital assistant

(PDA) devices for personnel to read the RFID readers, and a central computing system with a central database to store the data acquired from the RFID tags on products. This case study reveals that using RFID technology in agriculture traceability may give several benefits and improvements, such as reduced data administration and analysis time.

On the other hand, Salampasis has built and developed a framework based on the Semantic Web concept and provides an open and expandable underlying platform that allows diverse traceability-linked applications to be conceived and developed [24]. The authors proposed an available application framework based on widely used Semantic Web standards that provide a set of core services for storing, processing, and retrieving traceability information in a scalable manner, as well as allowing all stakeholders in the food supply chain to have an information trail that follows the physical route of the product while remaining cost-effective.

Cheng [25] suggest another traceability solution based on a central computer system. The recommended structure comprises printed tags with traceability codes for each product, XML (extensible markup language) files including all the required information about the traceable resource units (TRUs), and a central database in which all of the data is saved and made accessible to stakeholders. The system is streamlined and precise when it comes to restricted data streams. However, as the data amount grows, the database becomes overloaded, necessitating the utilization of additional computer resources.

Costa [20] provided a comprehensive review on RFID and agri-food supply chain traceability in [9], outlining the benefits and potential problems of using RFID technology in the food supply chain. In addition, a fundamental notion for a cloud-based farm traceability system has been developed as a future work proposal.

The research activities described above are the first stages toward developing automated electronic traceability systems. These systems offered or enhanced the methods for collecting traceability information about agricultural products using communication technologies such as RFID and wireless sensor networks. Since then, and as blockchain technology has gained traction in data science, the first concepts and proposals for cloud traceability systems based on distibuted ledger technology (DLT) have begun to emerge.

2.4 Summary

In this chapter, we detailed a fundamental concept of traceability, specifically in the agri-food sector. Then we provided an explanation of traceability related to other terms such as transparency, privacy, and trust, followed numerous insights focused on existing traceability approaches and tools implemented in food and agriculture products.

As stated in the description, the importance of traceability in the food and agriculture sector is an essential concern regarding food safety concerns, particularly the flow of security information throughout the supply chain that is not supported by a trustworthy system—at the same time, existing electronic traceability systems for agricultural products, such as Traditional Internet of Things (IoT) traceability systems, even though providing feasible solutions for the quality monitoring and traceability of agri-food supply chains, still rely on centralized platform control, hence making it more difficult for all stakeholders, particularly consumers, to acquire complete transaction information and track the origins of the products. The recent efforts toward blockchain-based trust management opened a new way, and we finally presented a blockchain-based documentation system to address the challenges of transparency and security in the traceable agri-food chain.

Chapter 3

Blockchain-based Trust Management

3.1 Fundamentals of Blockchain Technology

Blockchain technology first surfaced in 2008 as an integral part of the bitcoin cryptocurrency [26]. Blockchains enable transactional, distributed ledger capability that does not require a centralized, trusted authority to operate. Ledger changes are immutable, and cryptographic timestamping makes serial recording possible. Blockchains' decentralized nature is highly appealing for usage with global financial systems, but it is easily extensible to contracts or activities such as global supply chain tracking. Three 1960s articles proposed certain assumptions that later manifested in the blockchain concept. Accordingly Haber [27] explained how to timestamp documents using crypto-signatures. Banerjee [5] presented a decentralized storage system in which recorded modifications could not be removed, and Schneier [28] demonstrated how to encrypt sensitive information to secure log files on untrusted devices.

A blockchain is distributed database of records in the form of encrypted ”blocks” or a public ledger of all documents or digital events that have been conducted and shared among participating parties, which can be validated at any time in the future. Most system participants validate each transaction in the public ledger, and information cannot be removed after it has been entered. The blockchain has a specific verifiable record of every single transaction ever done, and its blocks may be used to coordinate an activity or verify an occurrence. It is performed without endangering the privacy of the digital data sets or the parties involved. In an effort to prevent third-party sources such as banks, governments, or social networks from being hacked, manipulated, or compromised, this technique employs mathematical issues that take significant computational power to address [29]. This protection makes it more difficult for potential attackers to contaminate a shared database with falsified information unless the attacker controls most of the network's computational power. Consensus is achieved within the network, such as through various voting mechanisms, the most common of which requires specific computers on the network, known colloquially as ”miners,” to solve a computationally intensive mathematical problem and other computers to verify that the solution does not correspond to a previous transaction. The mechanism is known as ”Proof of Work.” Every computer (node) in the network has a copy of the blockchain, and the nodes are synced on a regular basis to guarantee that they all have access to the same database. In this sense, blockchain protocols ensure that transactions are valid and are never recorded to the common repository more than once, allowing participants to coordinate individual transactions a decentralized without relying on a trusted authority to authenticate all transactions [30][31] as depicted in Figure 3.1.

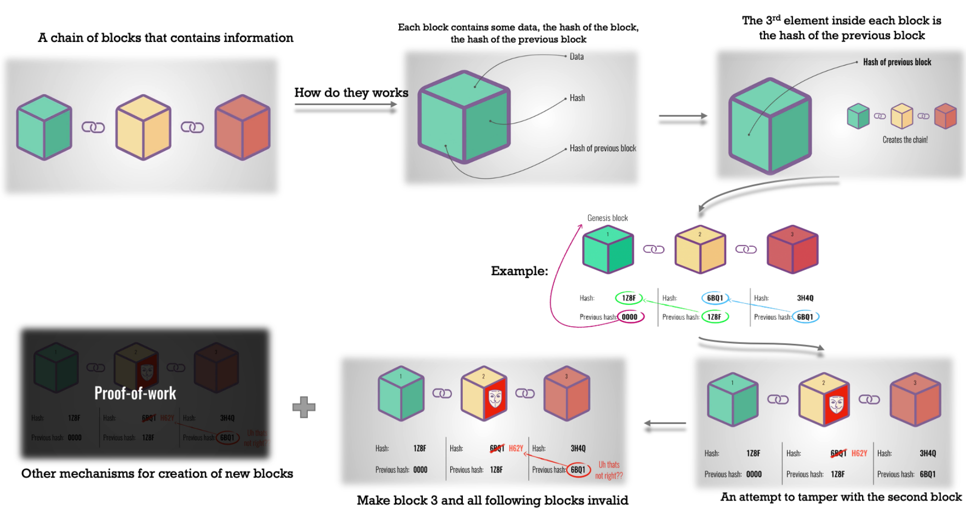

Figure 3.1: Operation of Blockchain

Bitcoin is the most well-known example that is integrally linked to blockchain technology. However, the blockchain principle may be used for any online resource where a trusted authority is required [32].

Blockchains offer end-to-end traceability by introducing a uniform technology language into the food chain and allowing customers to read the origin of foods on their labels via their smartphones. This has increased the need to monitor products through the complex supply chain from retail back to the farm, track an outbreak, ensure that food is organic or allergen-free, or provide customer transparency. When implemented in the food supply chain, [33], digital product information, including such as farm origination details, factory and processing data, expiration dates, storage temperatures, and shipping information, are digitally linked to food items, and their information is entered into the blockchain at each stage of the process. When consensus is established, no permanent record can be changed. Each piece contains essential information that might lead to identifying food safety issues with the product in question. The blockchain record can also help businesses track the shelf life of products in specific stores and increase controls linked to food authenticity.

3.2 Blockchain-based Traceability Operational Framework

Due to food safety and quality concerns, corporations, governments, and consumers have significantly expanded their need for traceability information. Traceability data may be gathered through business transactions and IoT-enabled devices such as Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), QR code, NFC, etc. Although information may be collected in real-time, information sharing relies on a centralized server-client platform, and there is no guarantee that data manipulation will not occur [34][35]. Blockchain technology is believed to be capable of establishing trust mechanisms for information transparency and security and enabling the exchange of valuable information in the traceability management process. The research on blockchain-based traceability reveals significant impacts on the agri-food supply chain, such as transparency and accountability [36][37], traceability and fraud prevention [38], cybersecurity and protection [5],[39]. Several studies explored blockchain applications in traceability systems in conjunction with other developing technologies such as RFID, IoT, NFC, cloud computing, and big data. Zhao [40] described a traceability system that used blockchain with NFC to monitor agri-food, and the approach gave greater transparency and security. Iansiti and Lakhani [41] proposed a wine traceability network based on blockchain. The transaction is accessible to parties in the wine chain, such as the grape plant, wine processing, logistics, and consumption, enabling secure, transparent, and accurate information exchange.

Based on the findings of many studies, Bumblauskas [42] concluded an Operational framework of blockchain-based traceability system as illustrated in Figure 3.2.

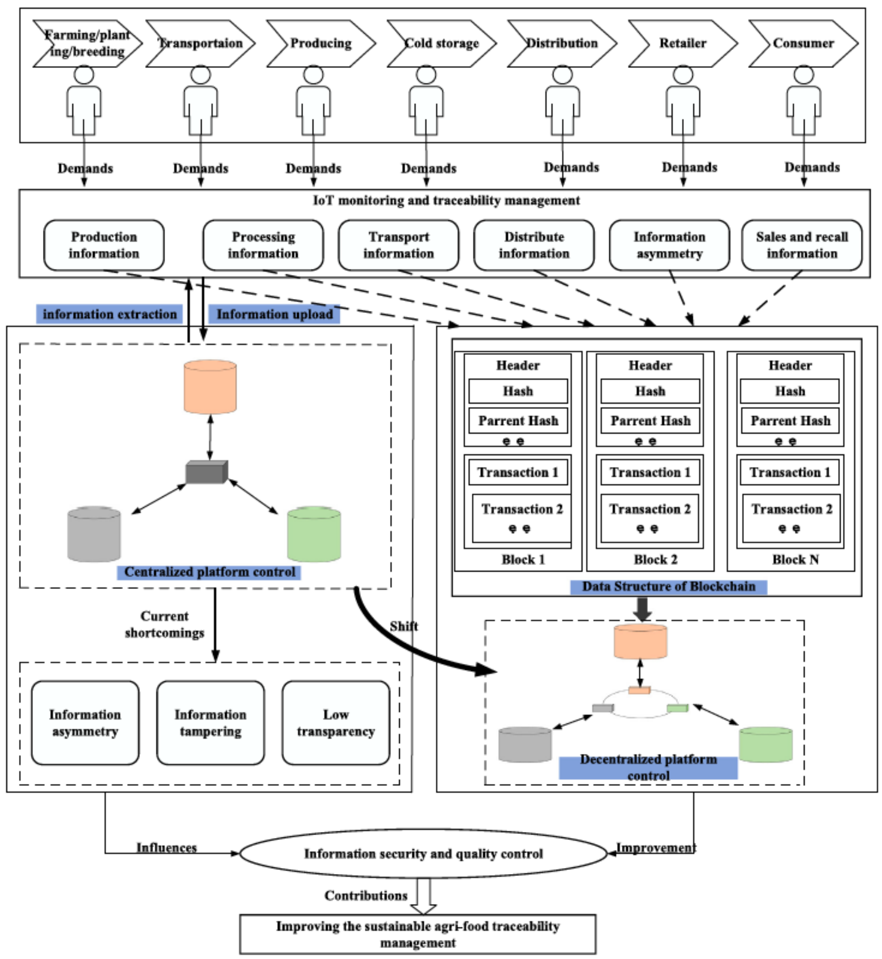

Figure 3.2: Blockchain-based traceability operational framework [42]

In the character of a distributed and decentralized system, blockchain is composed of time-stamped blocks connected by a cryptographic hash. It has arisen as a decentralized public consensus to coordinate transaction operations using digitally distributed databases [43][44][6]. Traceability based on blockchain is secure, more transparent, traceable, and efficient. It has increased the requirement for product information to be traced from farm to sale. It helps to improve the flow of materials and information in the traceability industry. As a result, blockchain improves information security and transparency while also contributing to long-term traceability management via IoT-based devices for the acquisition and persistence of agri-food products [45].

3.3 Blockchain-based Traceability Operational Mechanisms

A blockchain is a shared, distributed, and tamper-proof digital ledger that comprises immutable digital record data packaged in a packet called a block and disseminated to a peer-to-peer network of participants [46] as shown in Figure 3.3. In this figure described blockchain-based traceability operational mechanisms. Blockchain relies on consensus mechanisms to create node trust, and the ledger is replicated at each node in the decentralized system. Changes are confirmed with one another, and transactions are certified by consensus. Smart contracts, for example, enable users to execute data exchange or transactions without needing third-party trust organizations [39]. Successful transactions cannot interfere. All traceability transaction information might be stored on the blockchain in the agri-food traceability business process, and information must be validated permanently and unalterable. As a result, it eliminates intermediaries, lowers prices, improves speed and coverage, and gives customers better transparency and traceability [47].

3.4 Functional Characteristics of Blockchain-based traceability

Blockchain functional characteristics are those which are required for system operation and without which the system would not exist or function correctly. Decentralized network, Distributed Ledger, Consensus, Immutable (Finality), and Security are the functional characteristics of blockchain-based traceability [4], [48]. The following are the primary functional characteristics of blockchain:

1. Decentralized Network: Blockchain Technology's underlying network is a decentralized peer to peer network. All nodes are regarded as peers, and the program has

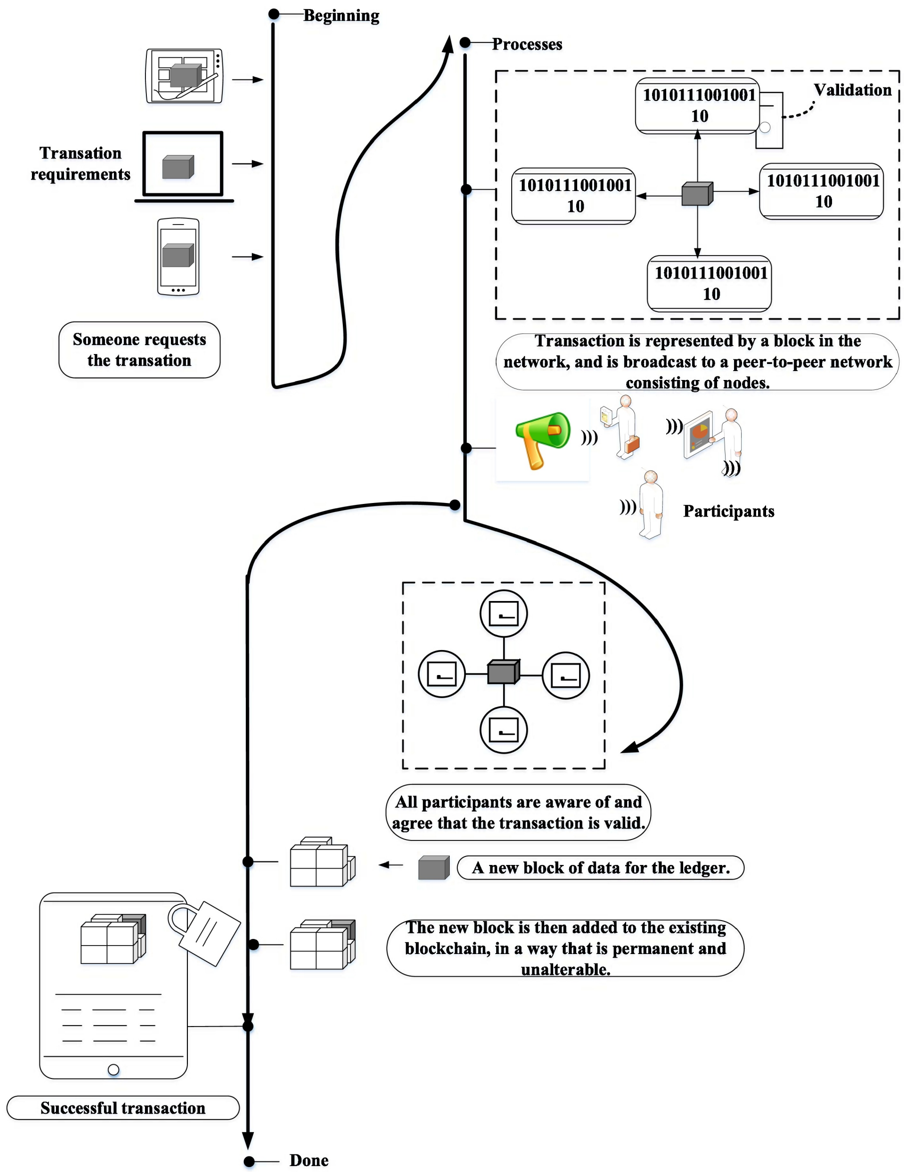

Figure 3.3: Blockchain-based traceability operational mechanisms [47]

granted permission and role to the nodes. Decentralization does away with the need for a central authority (server) for authentication, and a decentralized network avoids the centralized system's single point of failure bottleneck.

2. Distributed Shared Ledger: A Ledger is a record of all relevant transactions. A Distributed Shared Ledger is a duplicated ledger that is kept as a record of transactions by the participating nodes. In this situation, Blockchain is the ledger's data structure. A shared ledger enables authorized users to monitor and assess the status of a transaction throughout its lifecycle.

3. Consensus: For a transaction to alter its state from one to another, members must agree. The "Consensus" is a form of approval, and it is the process via which members agree on the transaction. Consensus attained blocks are added to the main chain alone; if consensus is not established, the transaction is removed from the main chain as an orphaned block. This method eliminates the central authority and shifts the transaction's trust component to its participants. The Consensus Protocol that is used is determined by the Blockchain application design. Consensus algorithms include Proof-of-Stake (PoS), Proof-of-Work (PoW), Delegated PoS, Proof-of-Authority (PoA), and others.

4. Immutable: Once a data block has been encrypted and put on the Blockchain, it cannot be changed or tampered with. It is known as immutable property. The block is written only after the participants' consensus; thus, it is finality. Let's imagine the Blockchain is constructed with ten blocks. If someone tampers with block 6, the hash function is changed. As a result, it alters the hash of the future blocks, making access to those blocks impossible. Keep in mind that the produced hash is a reference to the next block. Furthermore, because writing requires consensus, every effort to change is reported to peers.

5. Security: Hashing is secured using the SHA-256 cryptography algorithm. Furthermore, regardless of the length of the input data, a fixed-length output value is created. This makes hacking more difficult. Moreover, the components that go into block production raise the complexity level of hacking. Another feature that contributes to information security is immutability. As a result, the systemic feature of BCT automatically ensures security.

3.5 Blockchain-based Traceability Benefit and Challenge

The benefits and challenges from a business and technology standpoint cannot be divorced from the mechanism and operational blockchain described above. A business perspective specifically applies across a supply chain, which affects the business of buying and selling agri-food products such as traceability, privacy, efficiency, and sustainability.

- Traceability: Users may utilize the blockchain to track agri-food products as they move through a supply chain. Blockchains could tackle traceability difficulties such as how to coordinate, verify, connect, and record transactions. Aside from transparency, blockchain enables stakeholders to audit transactions. Because the blockchain is immutable, it assures that data will not be tampered with. All eligible users have access to a copy of the transaction history. On the other side, the potential of blockchain in food authenticity ensured that no information was altered that may occur when it was under the authority of a single person. As a result, blockchains might be utilized to address food fraud and improve traceability performance.

- Transparency: A blockchain's key aims are to facilitate information exchange, establish a digital of the information and its process flow, and validate the food's quality as it moves along the chain [49]. These objectives are achieved by allowing each participant to share claims, evidence, and assessments of each other's food assertions. A blockchain object called a ”food bundle” records the journey of food through the supply chain. At the end of its journey, the bundle is the sum of all information contributed by stakeholders over the journey of the food item's lifetime. This information can then be utilized to determine the food's provenance, quality, sustainability, flavor and taste profiles, and various other characteristics.

- Privacy: Blockchain's anonymity and security properties may help keep personal and business concerns and connections private and potentially improve company data privacy. Blockchain transaction visibility and anonymity might provide agri-food product traceability, dependability, security, and information timeliness.

- Efficiency: Blockchain technology can potentially improve company performance with less effort, improve overall efficiency, throughput, and trustworthiness of linked platforms, and facilitate corporate development. With digital product movement and certificates, blockchain gives real-time information on food products and may cut trace time from nearly a week to a few seconds. When an animal or plant outbreak occurs, this feature enables the early identification of infected items. Human involvement might be reduced via trust and self-organization. Integration with IoT devices improves supply chain efficiency, and blockchain is used to enhance agricultural operations' security and flexibility.

- Sustainability: Blockchain technology can potentially improve the ability to maintain a business in economic, environmental, and social aspects, as well as to aid supervision and management, thereby reducing food adulteration, improving food safety and quality, and reducing uncoordinated issues, thereby increasing sustainability. Blockchain technology has the potential to improve resource allocation as well as the demand and quality prediction. Better management might decrease economic loss and product waste while also helping to cut emissions. The use of blockchain to record water quality data might lead to more sustainable water management. Socially, blockchain has the opportunity to empower the poor in developing countries while also ensuring food security.

From a technology perspective, blockchain has some technical challenges frequently encountered while operating an enabled traceability supply chain, such as scalability, privacy, latency, and interoperability.

- Scalability: Some challenges in blockchain implementation include chain constraints with a rising amount of transactions, large block sizes, slow response times, and expensive fees. As the number of users grows daily, so do blockchain scalability issues.

- Privacy: Though data security, storage and management are essential aspects of data management in blockchains, data privacy and confidentiality are still issues. This is especially true for public blockchain, which stores data and much privacy-related information as a public ledger.

- Latency: The time lag between a user's actions and the system's responses requires more computer resources and processing time. Transaction speed is a fundamental problem of blockchain applications. For example, Ethereum could only process 15 transactions per second, compared to 45,000 transactions per second on existing systems [50]. Huge transaction volumes necessitate more time and procedures for validating large blocks. The transaction rate or each block processing time and security check take several minutes, indicating that blockchain architectures would suffer significant latency issues.

- Interoperability: Information exchanges for different block transactions or data from other blockchain systems are crucial interoperable architecture in blockchains. As the number of blockchain apps increases, so does the interoperability issue.

3.6 Blockchain-based Agri-Food Traceability Case Studies

Following the blockchain-based traceability system described above, and as the blockchain technology matured and became more widespread in other application domains, a growing number of research initiatives for agri-food traceability systems emerged. Tian introduced a novel proposal for a system based on RFID and blockchain technology for Chinese agri-food markets in 2016, intending to improve food safety and quality while lowering losses during logistic operations [21]. According to Tian, RFID and blockchain technologies are utilized to ensure food safety and quality along the whole supply chain. The article covers two categories of agricultural products: (i) fresh fruits and vegetables and (ii) meat, such as hogs, poultry, and cattle. The proposed network uses blockchain technologies to ensure that all stakeholders have access to all transactions and information about a specific product. Tian's primary objective is to cover the whole data collecting and information management process for every transaction between stakeholders in the agricultural supply chain. The complete system includes monitoring, tracking, and tracing of agri-food quality and may be described as a ”farm to fork” solution.

In 2016, Kim proposed an ontology-driven blockchain tracing solution. Kim's fundamental aim is to translate and describe several critical traceability components into various ontologies. Like Feng Tian [21], Kim uses blockchain technology to create a traceability system with diverse ontologies, where each might achieve and be a part of certain transactions. Kim recommends the usage of smart contracts in addition to blockchain technology and ontologies. The Ethereum platform is utilized in this study and written in the Solidity programming language [51].

Furthermore, in 2017, Tse focused on China's increasing food safety problem. They proposed a blockchain solution for the agriculture supply chain based on the information and transaction security amongst all parties involved. A PEST (political, economic, social, and technical) environment analysis is offered in this paper in order to describe the obstacles and potential of the DLT solution [52]. Marinello suggest a blockchain system concentrating on the supply chain of Italian animal products. They examine the animal products supply chain to discover the specific phases of tracking and tracing a product. Further, they investigate how the number of participating parties at each supply chain stage affects the complexity level of information flow in various situations [53].

The expanding academic interest in blockchains and traceability in agriculture gained traction in 2018 with the publication of several research efforts on the subject. Leng [54] explain a dual chain approach for the agricultural supply chain, and the complexities and issues of China's agriculture industry, concluding that inadequate organization is a major constraint. The proposed dual blockchain system is made up of a user information chain and a transaction chain. The user information chain is used to record and store the agricultural business enterprises' user information on the public service platform. In contrast, the transaction chain records and saves all transaction data. The results of the proposed framework's trials show that the double-chain solution not only ensures the transparency and security of transaction information, as well as the privacy of industry information, but it can also enhance the credibility of the public service platform and system's overall efficiency.

Latino suggest another intriguing idea involving the agriculture supply chain and the use of Industry 4.0 principles [55]. Latino discuss the concept of food democracy, in which customers are viewed as citizens and food as a democratic right rather than a commodity.

The researchers promote the idea of voluntary traceability while using Industry 4.0 technology. Their approach focuses on a system that includes a big data platform for managing acquired data. This allows for data paternity concerning the supply chain operator and product traceability. The need for voluntary traceability is emphasized, with an emphasis on the number and quality of data generated for each product and the requirement for a big data platform to handle them.

Caro offer an integrated solution for the agriculture supply chain based on a blockchain platform called AgriBlockIoT [8]. AgriBlockIoT is a completely distributed system that collects and distributes traceability data by combining blockchain technology with IoT devices. The suggested approach has been tested on two different blockchain systems, Ethereum and Hyperledger Sawtooth. In terms of latency, CPU, and network use, trial findings revealed that Ethereum outperformed Hyperledger Sawtooth significantly. AgriBlockIoT integrates IoT and blockchain technology to provide transparent, fault-tolerant, immutable, and auditable data that may be utilized in an agri-food traceability system. Lin suggest another agricultural supply chain method based on blockchain and IoT technology [56]. Specifically, the authors attempt to merge blockchain, IoT, low-power wide-area network (LPWAN), and current business resource planning tools (ERP). The suggested platform, which intends to overcome the conventional agri-food supply chain regarding food safety and trust challenges, incorporates all participants in a typical agriculture supply chain ecosystem.

Many more articles on the use of blockchain technology in the agriculture supply chain were published in 2018. Many studies offer comparable strategies for integrating blockchain into the agricultural supply chain, with minor differences. Mao [57] [58] developed the FTSCON (Food Trading System with Consortium blockchain), an agri-food supply chain automated merchant transaction system. FTSCON increases transaction security and privacy protection by utilizing smart contracts and a consortium (private) blockchain that is more efficient in terms of financial cost and processing resources than a public blockchain. Kim [59] present the Harvest Network, a design for developing a ”farm to fork” food traceability system that combines the Ethereum blockchain, IoT devices, and GS1 messaging standards. The Harvest Network proposes the concept of tokenized smart contracts, in which the contract is not subject to global consensus and does not need to be certified by the whole network but is instead processed by dynamically scaled node clusters, enhancing efficiency. Hayati et al. introduce the Food Trail platform, which employs a four-layer architecture in combination with smart contracts to facilitate transactions across the whole food chain [60].

In 2019, the agricultural sector's research interest in blockchains will continue to rise as more academics, firms, and scientists add to the current knowledge base. Koirala offer a consortium blockchain system in which a central authority (CA) determines the network's stakeholders and the certifications that allow them to participate. The authors provide a complete discussion of their proposed architecture and methods, as well as the proof of concept (PoC) technique for validating smart contract transactions [61]. Following the same idea, Baralla [62] offer a framework for the food supply chain in Sardinia utilizing a consortium, Ethereum-based blockchain, and smart contracts. Baralla emphasize the benefits of employing this strategy to promote smart tourism and preserve the originality of Sardinian domestic products. Lin [63] propose another intriguing article concerning consortium blockchains and smart contracts. In particular, it offers a system incorporating blockchain, smart contracts, and electronic product code information services (EPCIS). To make the blockchain more efficient, they propose limiting the data kept on the blockchain by utilizing an on-chain/off-chain strategy, where on-chain data are those necessary to monitor and trace a product, and off-chain data are corporate data, the majority of which is secret.

Salah offer a cutting-edge analytical approach to blockchain and smart contracts application in the agri-food supply chain in their paper [64]. This article illustrates how blockchain and Ethereum smart contracts can efficiently monitor and track stakeholder transactions in the agriculture supply chain and enable fully functional integration. The authors present a set of algorithms for smart contract validation and execution as part of the implementation architecture. The suggested system is intended for tracing and tracking the soybean supply chain. It could be modified to give trusted and decentralized traceability to other commodities and products in the agricultural supply chain. Scuderi investigate the use of blockchains in products with protected designation of origin (PDO) and protected geographical indication (PGI) in the European Union. Their research allows customers to check the provenance of raw materials and receive information on the process of production, process controls, packaging processes, and product distribution and certification to identify potential adulteration [65].

Creydt provide an evaluation of the importance of blockchains in agriculture and the three generations of blockchains (Blockchain 1.0, Blockchain 2.0, and Blockchain 3.0) and their characteristics [66]. Greydt also discuss the growth of blockchain technology, which will see data stored as a directed acyclic graph rather than blocks (DAG). This technique is anticipated to process data faster, potentially addressing throughput, latency, and capacity scalability issues in transaction execution. Kamble undertake a detailed investigation in the same context to model a blockchain-enabled traceability system in the agriculture supply chain. Kamble build hierarchical levels and interactions between supply chain players using interpretative structural modeling (ISM) and the decision-making trial and evaluation laboratory (DEMATEL) approach [67]. The study highlighted thirteen enablers for deploying blockchain technology in agriculture supply chains, including anonymity and privacy, immutability, smart contracts, protected and shared databases, traceability, transparency, and others, which agriculture supply chain specialists confirmed. Mondal propose another intriguing idea in this regard, describing a blockchain-IoT-based system that uses the proof of object (PoO) concept as an alternative to the blockchain's proof of work (PoW) and proof of stake (PoS). PoO is a validation mechanism in which the object's owner is required to prove possession. Consensus is obtained, and a new block is uploaded to the blockchain as long as the other stakeholders authenticate this claim. The authors use an analytical approach and give experimental results for the suggested model regarding consensus algorithm implementation, security problems, and sensor technologies [68].

3.7 Summary

In this chapter, we described the efforts made by blockchain technology to open the way for blockchain-based trust management. We first introduce the fundamentals of blockchain regarding the emergence of blockchain. Then we showcase how blockchain technology can provide better solutions to food traceability concerns in terms of full information transparency and security in food supply chains by reviewing its characteristics and functionalities and identifying blockchain-based solutions, including architecture design framework and mechanism for addressing food traceability issues following blockchain-based traceability benefit and challenge, and several existing case studies of blockchain traceability system in agri-food sectors. Finally, to address the research reported in this thesis and offers an alternative solution to traditional IoT system, we leverage the blockchain idea and enhance its features that may be utilized to tackle security and traceability issues in the agri-food domain.

Chapter 4

Adopting Blockchain Method for Cocoa Farming Documentation

4.1 The Complexity of Cocoa Production

One of the challenges to realize sustainable cocoa sector is the low level of productivity and quality of cocoa, especially those produced by farmers. Low inputs which then result in low output (quantity and quality), chronically inhibit the growth of cocoa commodities. This condition is worsened by climate and weather factors, pests and plant diseases, and other maintenance factors that affect the quality of production from cocoa beans to processed products such as chocolate bars and so on. Nowadays supply chains are long and complex and include many different actors, beginning with the farmers, followed by collectors, traders, manufacturers. At the end, the processed products are difficult to trace back to their origins in a trusted way. Traceability (tracking and tracing) has become a major issue in the food chain [69],[70],[71],[72],[73],[74] and quality and supply concerns are merging with traceability issues [75]. Recently, the researchers are paying more attention to the need for investigating different factors that can contaminate the products which belong to global food supply chains. These type of researchers can result in faster, cheaper, real-time, more accurate and ratify testing method for food safety and quality warranty [76].

In recent decades, a series of serious cocoa accidents have occurred. In 2018, there was Mars chocolate manufacturers recalls chocolate bars in 55 countries after plastic was found in their products. The recall, affecting 55 countries, could end up costing the company tens of millions of dollars [77]. In the same year, an investigation that reported in some news organizations about Ivory Coast shows some cases of “dirty cocoa”. Much of the world’s cocoa grows in Ivory Coast, the examination result showed that a significant amount of cocoa that used in famous companies such as Mars, Nestle, Hershey’s, Godiva, and other major chocolate companies was grown illegally in national parks and other protected areas in Ivory Coast and Ghana [78]. These illegal products can be mixed in with ”clean” beans in the supply chain, which make it extremely difficult to know what products are safe and which one is affected. The importance of these cases can pose the following question: how does the industry make sure that illegal or ”dirty” cocoa beans do not end up in the world’s most famous and well-loved chocolate brand?.

From a different perspective, the cocoa supply chain begins with the farmer, who grows, harvests, extracts, ferments, dries, and packs the cocoa beans. The cocoa beans are then gathered and often combined by local buyers, merchants, local buying stations, and exporters until they arrive at the chocolate production factory. Various characteristics of chocolate are heavily influenced by the activities carried out from the beginning of the supply chain. Various research and surveys reveal variances in farming procedures for cultivating, fermenting, and drying cocoa beans, not only among nations but also amongst farmers within the same country. The majority of cocoa beans produced globally are grown by small-scale farmers and mixed in more principal amounts until they reach the chocolate producer. As farmers’ activities define many of the qualitative characteristics of cocoa beans, it is simple to assume that chocolate producers frequently receive mixed batches of cocoa beans due to various farming practices. Moreover, because cocoa farmers lack the financial means to conduct reliable analysis for identifying cocoa cultivars, mislabeled cocoa beans are frequently trafficked [79].

As a result, chocolate manufacturers can only make some assumptions about the qualitative parameters by original location. To prevent dependency on a single nation or source, cocoa traders or chocolate makers frequently mix multiple batches of cocoa beans to produce chocolate with homogeneous and consistent raw ingredients. The processing conditions for making chocolate are then adjusted based on the predicted qualities of the bean mix, which is frequently based on basic indications such as cocoa origin.

Many research studies focus on how specific cocoa farming practices or environmental conditions impact certain cocoa bean properties. Consider how different fermentation procedures affect the amino acid content in cocoa beans. For example, Loureiro [80] provide a fair summary of the influence of various post-harvesting procedures on the flavor profile of the chocolate. However, due to numerous participants' involvement in the supply chain's early stages, information on farming practices seldom reaches chocolate producers.

4.2 Methodology

4.2.1 Proposed Concept

Along with the advancement of information technology, the food traceability system, which can degrade individuals' disquiet about food safety by providing precise information on the safety and quality of the entire process, from producers to consumers-has been amply disseminated in the food industries [81].

The primary aim of this concept is to link legal documentation and blockchain technology within a traceability system with the specific application case of cocoa and chocolate production. For improved data security, the common blockchain concept is extended to a two-factor blockchain, where both blockchains are connected via digital watermarking of the documentation media. One blockchain traces the documentation steps, the other the watermarking embedding.

The cocoa supply chain traceability system which we propose mainly relies on existing media-based documentation practice, i.e., we assume that the documentation is enriched by media like photos or videos. The requirement that the image is captured from multiple cameras and sensor devices with the specific encrypted image to secure the authenticity of the pictures is made such that it provides sufficient evidence and cues to retrace the complete process. When the watermark information is not visible to naked eye, it is referred to as invisible watermarking. The data from the raw material from the farmer will be embedded into the image of the cocoa generated by the farmer or manufacturer. This difficult and challenging process of traceability can be automated, simplified and accelerated by efficient use of Blockchain technology. While one blockchain would be sufficient to ensure the integrity of the sequence of media files generated during the documentation process, it would not allow to ensure the integrity of the media itself. For this reason, we propose the use of digital watermarking technology. However, the need automatically arises to ensure the integrity of the watermarking process itself, and a second blockchain is needed. Assume blockchain to be used in default way, i.e. including automatic hashing and hash control, community validation and proof of work. Linking documentation and blockchain by digital watermarking done by using two blockchains where both blockchains are connected via digital watermarking of the documentation media, one blockchain traces the documentation steps, the other the watermarking embedding. Digital watermarking is the process of embedding information in digital multimedia content such that the data (which is called the watermark) can later be extracted for a variety of purposes including tamper prevention and authentication. As mentioned, the whole watermarking algorithm can have different purposes such as copyright violation prevention, tamper localization, hiding data or authentication. The watermarking processes can be either fragile, robust or semi-fragile. The fragile watermarking techniques are perfect for tamper detection and localization, on the other hand, robust watermarking are useful for authentication and bypassing different operation such as digital noises and compressions [82] [83]. Linking is done by embedding textual information in the media data and logging the embedding in the second blockchain.

The Two-factor blockchain for traceability cocoa supply chain procedure is depicted in Figure 4.1 followed by a detailed explanation:

1. The farmer and manufacturer provide textual information and an image (photograph).

2. The image is watermarked with the text information. (giving DWMI).

3. The hash value of DWMI and text and (not-watermarked) image are stored in a Block of node 1 or blockchain 1 (BC 1).

4. DWMI will be stored in a block of node 2 or blockchain 2 (BC 2) as documentation.

5. Consumers will see the documentation results in BC 2.

6. For the tracing process, the validation process is done between the existing hash in blockchain 1 and the watermark documentation in blockchain 2. In this stage,

the validation process will result in the authentication of farmer and manufacturer information.

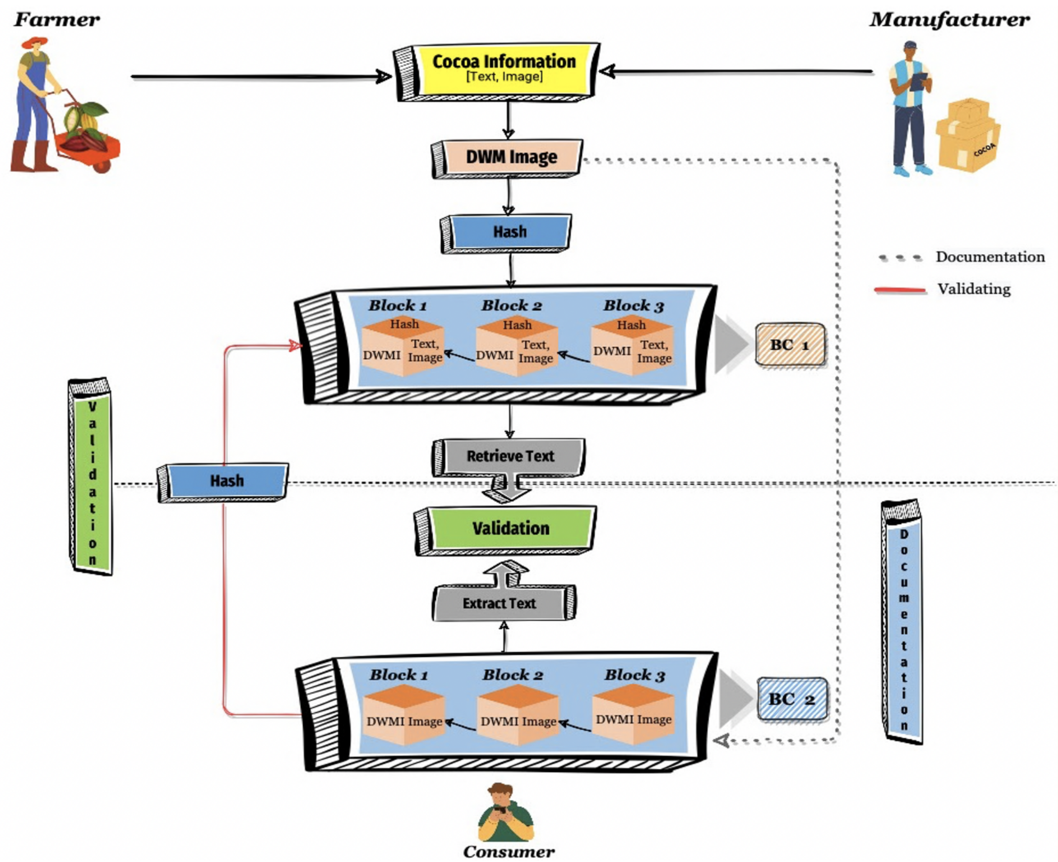

Figure 4.1: Concept of Two-factor blockchain for traceability cocoa supply chain

4.2.2 The proposed Watermarking Procedure

In this section the proposed watermarking algorithm for securing the blockchain process is described. The watermarking procedures usually has different purposes. The main goals are to be blind, fragile and robust.

As the first step, texts containing cocoa information are transformed to binary form, as well as images to be transformed into binary form. For the embedding process frequency domain Discrete Wavelet Transform (DWT) is used. The basic idea of DWT transformation in image processing is to decompose an image into 4 parts of frequency: The low frequency part that called LL, and another high-frequency parts are HL, LH, and HH. The output of the sub-level frequency district will be found when DWT is transformed by low-frequency district. The differences from sub-images are as shown below:

1. LL: A bearish estimation to the original image conceived the entire information about the whole image and it applied of the low-pass filter on both x and y coordinates.

2. HL and LH: The high-pass filter on one coordinate and the low-pass filter on the other coordinate is gained of HL and LH.

3. HH: The high-pass filter on both x and y coordinates found from the high-frequency component of image in the diagonal direction [84].

The wavelet transform can provide time and frequency information simultaneously, thus providing a time-frequency representation of the signal [85]. Discrete Wavelet Transform has advantages in identifying parts in the cover image, where watermarks can be inserted effectively [86]. The advantage of the DWT method is that the image quality that is the place for text insertion is not much different from the quality of the original media.

The watermarked then goes through the hashing process stage, which aims to get watermarking hashed to check the integrity of image files. This way, it can be validated whether a byte series of data is altered (tampered). A cryptographic hash is a sort of 'fingerprint' for text or data files. SHA-256 generates 256-bit (32-byte) hash that are nearly unique to text and are one of the most robust hash functions available. Hashing is used as a method to store data in BC 1. In addition, BC 2 contains the results of a digital watermarking image. When a consumer trails a validation process, extract text and images from a digital watermarking image BC 2 and then cross-check (validate) by retrieving from BC 1. The validation process will result in the authentication of information from farmers and manufacturers as a result of the process traceability. So, to summarize, a watermark aims to store text information in images, which is accomplished by the hash value at the end.

4.3 Evaluation of the Concept

Based on the description of the concepts and principles described above, there are several aspects or actual impacts of the idea that we may conclude can represent the traceability prototype system, as follows.

4.3.1 Objectives

Blockchain system can overcome complexities occurred in the supply chain such as traceability process of the products and lack of security which measures the whole procedure. In case that a farmer wants to send images to the manufacturer or vice versa, authorization is required from each party. Furthermore, blockchain is known as a peer to peer structured system which can solve different securities problems such as lack of confidentiality in data or information received by consumers and other parties of the process. However, the security aspect of the blockchain process can be covered by applying different hashing function and utilizing different watermarking methods. Using a good fragile watermarking algorithm for blockchain data makes it almost impossible for attackers to intrude.

4.3.2 Potential for Manipulation

As mentioned already, the proposed watermarking and blockchain algorithm in this concept can provide particular transparency for both the consumer and manufacturer from beginning to end. It assumes that farmers and manufacturers record the correct information, such as photos and documents. However, one of the fundamental problems with the whole system is that there is no way to guarantee the correctness of the photographs before the digital image is in our supply chain. Another problem is tracking the growth of cocoa and ensuring that the pictures of cocoa at different times of growth are consistent with the same physical objects. However, this class of problems has to be delegated to the documentation process itself, i.e., it is expected that it has to follow common standards and discipline. For example, the documentation process already involves accounting means, back confirmations, witnesses, or provides a sufficient number of cues. The essential add-on in trust provided by using blockchain is to prevent manipulation from third parties, as well as simplify the identification of an injection point of a rogue intermediate producer in the whole processing chain. Under this assumption, our proposal is more secure than existing systems.

4.3.3 Access Control

In terms of access control, even if the blockchain is considered to be public, information can still be controlled by the user because the proposed blockchain algorithm in this concept is secured by cryptographic verification using two-factor authentication mechanisms as proof of work.

4.3.4 Advantages of Proposed Algorithm

The following can be considered as advantages of the proposed algorithm :

1. Level of security : As mentioned before with the addition of different hashing and watermarking algorithm, the originality of the pictures is verified every step of the way.

2. Effort in general : Blockchain systems as general keeps data in textual format while in this system digital images or even other media are utilized to keep different types of information such the size of fruit, chemical content, the time when the picture is taken etc. So in this way less effort and storage is used to gather all the information for a particular bean or a fruit.

3. Convenience : Usually, like bitcoin, blockchain entries are rather hard to read, only long numbers. In this paper, we used digital images which make it more to understand for the user.

4.3.5 Energy Usage

Energy usage is known to be too costly on the long run. Some of the alternative developments, for example the stakeholder-based proof of work, make such problems obsolete. In other cases, a peer-to-peer energy trading model to solve the energy usage problem is already envisaged.

4.3.6 Concept of Implementation

The security of the proposed concept relies on the fact that it is not possible to manipulate a watermarked image such that the hash value of the manipulated image is equal to the hash of the original image that is stored in the second blockchain. Neither the stored hash value can be manipulated, per definitionem of a blockchain, nor the image manipulated such to have a different image with same hash value.

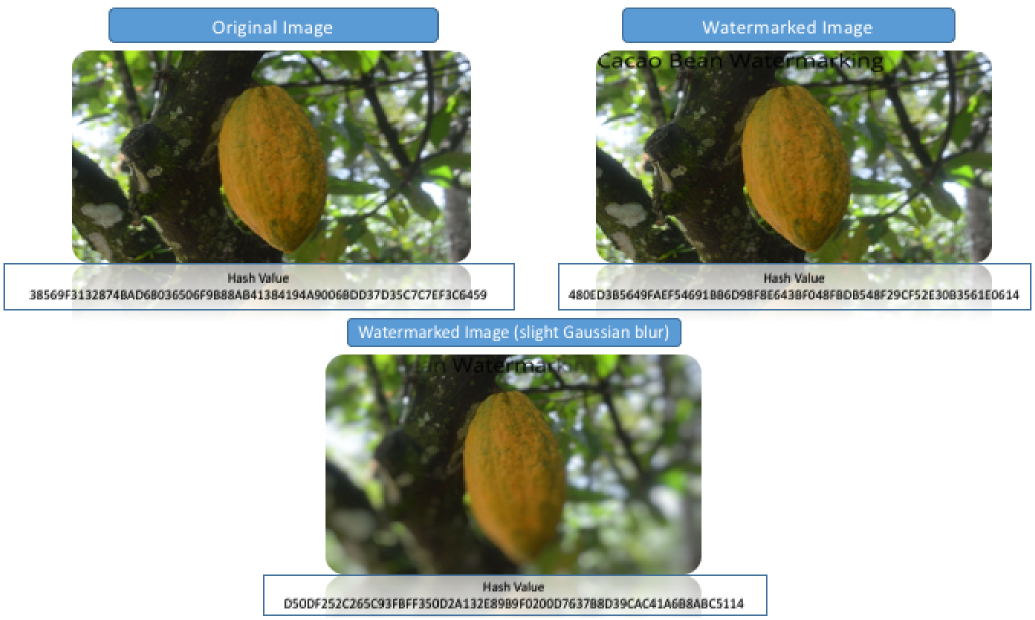

Figure 4.2: Hash values and watermarking of a cocoa fruit

Hash values and watermarking of a cocoa fruit: upper left the original image and the SHA256 hash values; upper right, same image after watermarking, perceptually not changed, but a different hash value; lower image, an attempt to remove the digital watermark by Gaussian blurring, but even then, the original hash value cannot be restored.

Figure 4.2 shows how the concept of security occurs within the blockchain system. The image before and after digital watermarking appear to be the same but the hashing process shows the difference, once the modifieded watermarking image can be known by the difference through the hashing process.

4.3.7 Traceability

The two-factor blockchain systems can be used to improve the security and traceability on farmers', manufacturers' and consumers' level. BC 1 is used to store hashing of the watermarked data and information derived from both farmers and manufacturers. BC 2 is used to store the watermarked document. When traceability occurs, the system will generate hashing from BC 2 and compare with hashing stored in BC 1. The hashing validation process will ensure the integrity and authenticity of the data. BC 2 is open to the public, which means that it can be accessed in the process traceability. Moreover, the proof of work is run by farmers and manufacturers when making new blocks. A new block is added by each manufacturer who's issue a new production which is different from the previous production while the farmer level can create new blocks if they have different cocoa content and quality. Here, we assume 4-5 peers per each farmer and manufacturer.

4.3.8 Application Profile

The key feature of using the traceability function in the two-factor blockchain is to present the information to all the supply chain members through a unique reading-verification approach using a digital image. The primary aim of digital watermarking here is mechanism verification that functions for storing metadata or text information in images, which is accomplished by the hash value at the end. The feature of two-factor BC allows for greater flexibility in practice, decentralizes the information storage, allowing it to handle at different places and under different authorizations and schedules, and a second blockchain can well achieve it.

4.4 Summary

In this chapter, a blockchain-based traceability system for the cocoa production and supply chain is proposed. Information about cocoa is stored safely through watermarking techniques at all user levels, so it is hard to manipulate.

In first direction, we assume that the documentation, mainly based on existing media-based documentation practice or supplemented with media such as images or videos, is designed to offer sufficient evidence and visual cues to retrace the whole process. We then improved data security by extending the common blockchain concept to a two-factor blockchain, where both blockchains are connected via digital watermarking of the documentation media. One blockchain traces the documentation steps, the other the watermarking embedding. The watermarking utilized in the proposed algorithm ensures the information at each stage is authenticated, and it can be detected in case there is a change or manipulation of data of any kind. A unique reading-verification process ensures the correct linking of both blockchains, thus improving the reliability of the whole product tracing.

Chapter 5

Implementation of Blockchain Concept into the Real Problem through a Simulation Case of Cocoa Production

Later in this section, we present the second research approach that includes a proof-of-concept experimental system called Encapsulating Block Mesh (EBM) for cocoa production by integrating a unique designed blockchain and applying the principle of a bucket-based transaction implicated by MBC's sensing instruments as a model for farm transactions. In this chapter, we demonstrate that Modular Block Chain (MBC) sensing may be used to enhance farm objects' data integrity and security and to support farming documentation by simulating farm transactions.

5.1 Introduction

Many tools and applications have been developed to assist farmers in managing the numerous aspects of farming that are affected by sensing technology, such as data processing, water management, field monitoring, soil condition monitoring, crop yield analysis, and disease management [87]. Farmers may become more strategic and effective in their daily farm-related tasks and responsibilities by utilizing these smart technology. Centralizes, manages, and optimizes farm production and operations, automates data capture and storage, monitors and analyzes farm activities and consumption, and maintains business expenses and farm budgets [88]. However, complex food supply chains characterized by production, distribution, transportation, processing, retail, and food consumption are increasingly exposed to a wide range of risks [89], including contamination, domino effects, resource depletion, difficulty in the following origination, and quality disputes, create this technology ineffective in terms to the security data stored which is automatically vulnerable to distortion, manipulation, and so on. Simultaneously, farming as the vital component of the overall goal agri-food chain causes such complexities to be triggered, somehow guiding back to the production level.

A few reported food safety issues headlines, such as horse DNA [90] in 2013, were detected in various food products worldwide, which took some time to trace back to where the horse meat came into contact with the other meat products. Other reports in 2019 address the effect of China's covid-19 crisis and coronavirus shutdowns affecting American farmers [91]. Farmers across the country have a surplus of produce, milk, eggs, and so on that they are dumping, letting rot, or plowing under due to drastically reduced demand, which has also caused global problems in other parts of Michigan, forcing the shutdown of their restaurants, resulting in a domino effect on their profit [92]. The supply chain is already jeopardized as a result of these challenges. This indicates that even if they are not a link in the pandemic chain, interaction has already occurred in this supply chain. In other words, it isn't easy to trace back any source of the origins by natural influences or different environments to any of the challenges described. Another viewpoint is that, while contemporary technology provides significant agricultural benefits, its acceptance and application in rural areas are restricted. This is due to farmers' lack of education and the cost of maintaining this technology.

To face the challenge of tracking the origin of farm products, it is important to establish a farm transaction model that incorporates a sensing instrument by integrating unique design security systems with a proper encryption mechanism to ensure the tracking back of product provenance while maintaining data confidentiality within these tools. So that captured event data is traceable and distributed in a secure, comprehensive manner, making it nearly impossible for attackers to infiltrate all supply chain nodes.

A farm transaction model is presented in this study by demonstrating a flow of farm transaction simulation representing a 'versatile innovative instrument' with an array of sensors, controllers, networking hardware, computing equipment, and internal memory functions to enhance data integrity and security of farm object. Each farm object is linked in a secure block system, ensuring that farming data is monitored, stored safely, and integrated and is difficult to manipulate due to the encryption provided by a hash value in each object. For this purpose, We specially design a unique blockchain concept in the form of blockchain modularity in which farm objects take turns recording information on the process of generating, transacting, and consuming a farm product into a block. The block contains a record of every transaction ever made and provides a hash value of its contents, including the previous block's hash. Each block is then encapsulated and linked to the previous farm transaction block and keeps the hash of that block. Any modification to any block in that chain will break the chain later on by having an invalid hash value. Based on the proposed model, a proof-of-concept experimental system called Encapsulating Block Mesh (EBM) integrates blockchain technology with the specific application case of cocoa production has been implemented and validated on the simulation environment. Subsequently, the block contents data are later transmitted to the central terminal as the corresponding entry of the events log, which monitors the overall activity of transaction events.

The innovative findings of this study is developing and implementing sensing instruments in special farming transaction models with the integrity of the special security design using the blockchain concept. Offer farm management for farmers to monitor their farms with a detailed level of security, high accuracy, and can be traced with legality valid information from each farm object in real-time. The block security system is interconnected so that it can be ensured that the farming data collected can be monitored, stored securely, integrated, and difficult to manipulate because it is encapsulated in encrypted blocks in each farm object.

5.2 Related Work and Motivation

Sensor and sensing technology has been incorporated into the supply chain for smart farming practices for over a decade. Citrus fruit production [93], UAVs for vineyards [94], and using multi-purpose satellite systems to enhance cotton cultivation [95] are just a few examples of sensor deployments for specialty crops. In the instance of cow health [96] discovered a number of prevalent disorders in dairy cattle that may be detected using non-invasive, low-cost sensor technology. There are more advanced sensor platforms available, such as camera systems that detect back position [97] and ingestible tablets for heart rate assessment [98]. Caja [99] and Rutten [100] examined the literature in terms of the documented usage of sensors for managing the health of dairy herds in agri-food sectors such as dairy farms. Sensors that monitor arbitrary features of a cow or aggregate sensor data to offer information such as estrus predominant.

On sensor networks, specifically Wireless Sensor Networks (WSNs), have seen widespread use in agriculture [101][102] and the food business [103][104]. Application domains include crop management [105], phenotypic assessment [106], rustle prevention [107], and greenhouse management [108] are only a few examples of application domains. In applications such as irrigation control, wireless sensor and actuator networks (WSANs) are gaining traction [109][110]. Moosense [111] is a WSN that uses both ground-based and animal-mounted sensors to control a variety of animal characteristics such as ambient environment factors and nutrition intake (customised food auger and fluid kiosk). Gonzalez [112] illustrated the potential of a heterogeneous WSN in providing data in real-time to help in the analysis of animal behavior and allow effective herd management.

Each of these analyses provides farmers with various farming models that include integrated technology for focused, effective decision making and the possibility to monitor their farms in real-time with unprecedented detail. However, none expressly addresses whether the obtained information is securely stored, distributed, and traceable, including models developed to simulate such circumstances. All indicate the effectiveness of sensor and sensing technology usability to detect and monitor the physical, chemical, or biological property quantities and characteristics of various farming products while disregarding the requirement for data privacy, confidentiality, and integrity.

Motivated by the above, our primary objective is to develop a farm-specific model, i.e., a farm transaction model based on ”the bucket principle.” Since the applied concept gives a visual representation of a bucket-based transaction that occurs from interactions with other farm objects and following processes in the farm food life-cycle from field to consumer implicated by sensing instrument, we believe in an integrative approach that can mediate the actual constraints of farm operation information recorded such as security, durability, integrity, and traceability by improvising the utilization of a one-of-a-kind blockchain plan.

5.3 System Architecture

This section initially discussed the proposed farm transaction model, which encompasses the key aspect implicated in the cycle farm transaction, such as physical assets and objects that we named 'the bucket principle,' complemented by a brief overview of blockchain transaction. A bucket-based transaction was first presented with the "Satyr Farm" farm simulation game operating in the OpenSimulator-driven simulation environment. The system model is then presented with the specific application case of cocoa production, followed by described Encapsulation Block Mesh (EBM) concept and subsequently the farm simulation operation of the proposed EBM described in detail.

5.3.1 The Bucket Principle

In other blockchain applications, the validity of a transaction is usually a rather straightforward task. Consider bitcoin transactions as shown in Figure 5.1. Alice wants to transfer an amount of n bitcoins to Bob, where she has a wallet of m bitcoins. So, the only condition here is that $m \leq n$ while other circumstances of the transaction do not matter: like the true identity of either Alice or Bob, their location, day and time the transaction took place, or the weather. The story is different for such transactions in the farming and general food supply chain environment. We may point out a number of aspects that make such transactions appear different. Assume a simplified model where a farmer brings the apple harvest from some trees to a storage site.

- The transaction involves a physical object, subject to physical and subsequent features, weight, volume, freshness etc.
- Identity of the agent's matter. For example, the agents need to be spatially close to the "wallets" (that appear to be physical assets as well, trees, plants, soil, container etc.).

- The transactions are inevitably linked to other transactions, foregoing that transaction, accompanying it, or, with some delay "unlocking" it.
- The transaction can be sensed and recorded, e.g., by a video camera or subject witness.
- The transaction has quality means on their own. In our example, the apples have been carried by hand, or within a large container lowering apple quality by inflicting damages. In a similar way, the transaction includes aging.
- Generally, such transactions need energy to be maintained, due to the physical nature of its constituents. At the same time, it needs human cognition and intervention to become subject of documentation and recording.
- A classical transaction e.g., of a bitcoin transfer can only be valid or invalid. Farming transactions appear valid to some degree as the outcome of the transaction at the goal site can vary even having same starting point, while there can be unknown, lost, or manipulated circumstances at the origin.
- The transactions expire in some sense. At one point in time, all products made from an apple have been eaten by a living being. There is no primary need to log transactions forever if there is nothing to do or to conclude from the information in a ledger anymore.
- Farming doesn't happen on a terminal, so the interfacing among physical "not connected" objects need to be organized.

Those aspects above may put into question if blockchain is a suitable concept here at all, compared to the surveying of a number of virtual wallets. Of course, it can be argued that this just increases the number of data that has to be stored within a block and nothing else. This can indeed account for a number of aspects, but not all. Most of all, the mutual influence of transactions and the locality aspect. In that regard, and to overcome those problems, we propose a transaction model called "bucket principle" that reflects the transactions in a farming (and subsequent food supply chain) in a way that

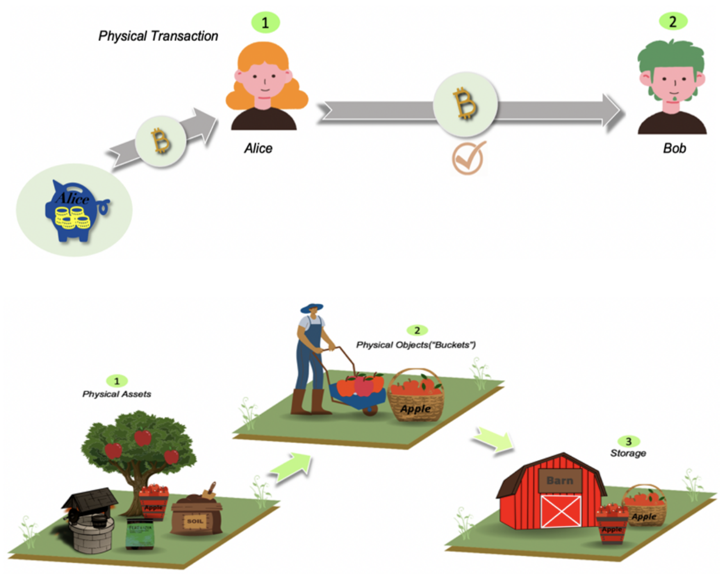

Figure 5.1: Classical Alice-Bob bitcoin transaction vs farm transaction.

makes it accessible to the integration in a specially designed blockchain. The principle can be stated as:

Bucket Principle: *All transactions in farming and the subsequent food supply chain can be modeled by the means of transport of an item S from site A to site B within abstract bucket B. The bucket alone can maintain all documentation tasks while logging related events: creation or filling of a bucket, picking up or dropping of a bucket, replenishing, emptying, or consumption of a bucket's content.*

To reconsider above example the apple harvest will be filled into a basket, for example. Now, this can be the proverbial wicker basket, and it is brought by hand to a nearby storage site, keeping it cool until the storage site is filled up to load a truck. Many other such farm activities would refer to real-world buckets. But it is also an abstraction: pruning a tree, the farmer will have to bring tools for pruning to the tree. For watering, one might to have to bring a hose nearby, or dig a ditch to guide water flow it where the bucket then is the channel leading to the tree.

The Bucket Principle has several implications. First of all, it can be seen as a "smart tool" operating in a communication environment like edge computing or an IoT infrastructure, which can have sensors, controllers, networking hardware, computing facilities, and internal memory. We agree that the focus in "smart farming" so far was on the sensor equipment, and not much engineering efforts have been put into "Tools IoT" so far. But the argumentation so far gives a good hint that such developments are overdue, and obviously feasible. On the bottom line, even carrying items by hand can become an abstract bucket transaction by using a specially designed data glove.

A bucket has content, that is at the same time a symbolic name and a physical entity. While the latter is obvious, the former can cause documentation problems. Receiving site *B* might call the content of the bucket differently than the originating site *A* according to documentation and registration needs. It implies the need for a bucket (in conjunction with it's filling) to have a unique id, thus it needs a digital identity.

It also has to be added that the action commonly referred to as transport, e.g., by a cargo ship, isn't such a bucket here. That transport has to be modeled as a *remote storage*: there is a bucket that brought the content of a storage that became subject of being moved to another location. Arriving there, buckets will be filled with content of the same storage, just at a different location.

However, while not applying to transport in classical meaning, it extends to many other subsequent transactions of farm items: cooking, placing items in a supermarket shelf or market booth, consuming like eating, after all, yes. While here is not the place to consider the universality of the bucket principle, as we are primarily interested in its implications for the design of a monitoring blockchain.

The Bucket Principle, up to our best knowledge, was initially introduced along the "Satyr Farm" farm simulation game[1] running in the OpenSimulator driven simulation environments[2] and that was introduced in the OpenSimulator driven hypergrid around 2018. The simulation provides a visual cue of a bucket-based transaction that is the result of interactions with farm objects. For example, as shown in Figure 5.2, to water a tree the avatar mediating user control in the simulation interacts with a well that renders a 3D model of a water bucket and that starts following the avatar as it moves to the tree to water. There,

[1] https://satyrfarm.github.io
[2] https://opensimulator.org

the water is replenished to the tree, and the bucket itself dismissed. The whole Satyr Farm follows this method in all transactions. In subsequent developments, we could demonstrate that the same principle allows extension of the farm to the various stages of the food supply chain, including factory, supermarket, and food consumption and recycling.

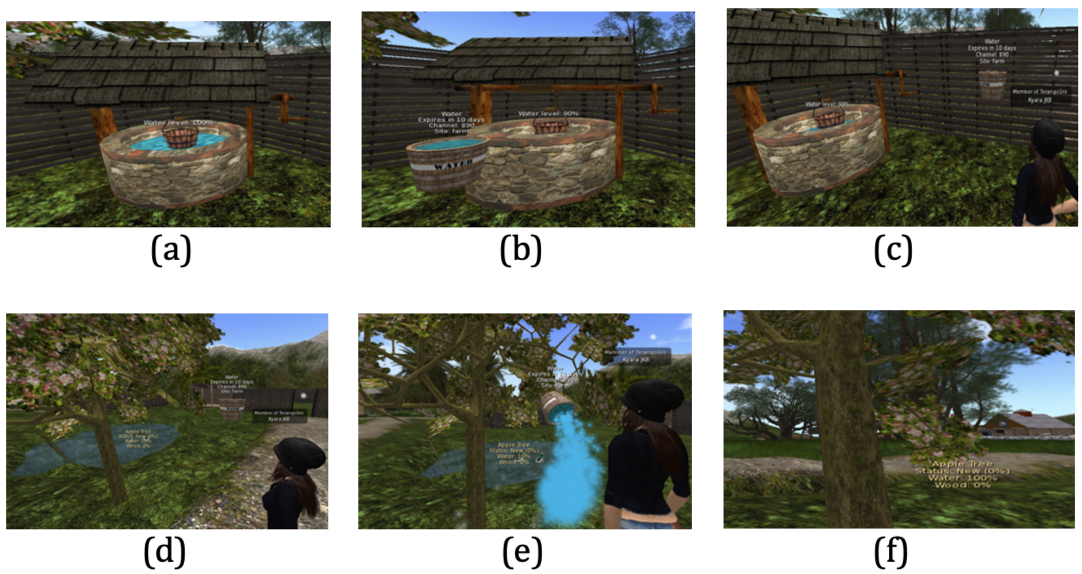

Figure 5.2: A bucket-based transaction in the used simulation environment.

5.3.2 Encapsulating Block Mesh (EBM)

The Bucket Principle explanation aforementioned gives the base for a smart farming documentation system that integrates blockchain technology. We will point out three major practical requirements:

1. Concurrency: A farming transaction does not happen in isolation but under the concurrent ongoing of other transactions that are either a condition for the proper fulfilment of current transaction, or an influencing factor, up to issues of resource sharing and replenishment.

2. Locality: There is no reasonable method to link farm items over long distances, especially among different, maybe even competing farms. The documentation should

be done close to the related sites and only based on Near Field Communication in a technical way.

3. Sparsity: We can't assume to have blockchain recording all over a farm. This is accompanied by the circumstance that several factors affecting trust and quality of farm products are not single-point events but spread over some area and time. Hardware for recording and documenting can be damaged, stolen, or being tampered with. So, the means of validating a blockchain has to account for gaps. The degree of trust into the validation has to be related by the depth to which the events proceeding the current transaction can be safely traced back.

Taking those three requirements into account, we propose the following concept of "Encapsulated Block Mesh" extending the cocoa production blockchain concept.

Modular Blockchain (MBC)

As previously stated, a bucket-based transaction has various implications, such as a "smart tool" operating in a communication environment such as IoT infrastructure and including sensors, controllers, networking hardware, and internal memory. It is referred to as MBC. In this scenario, MBC node serves as a smart sensor integrated on a farm object to record, collect, and store essential farm product information which encapsulating it in a strong cryptographic proof for data authenticity and integrity with a block-generated contract within.

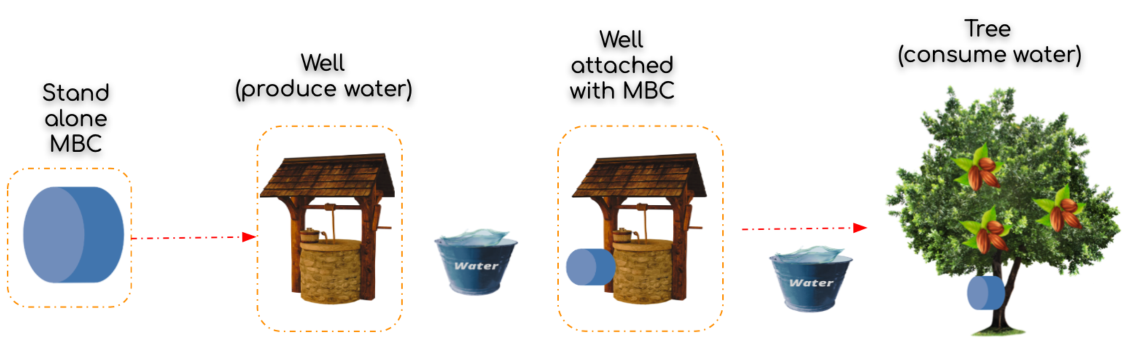

Figure 5.3: A block-generated contract within MBC

Cocoa Production Transaction Model

We selected the cocoa production model, specifically locally cocoa processing, as cocoa processing has a number and unique stages and aspects, quite a straightforward chain, and a well-defined structure. The steps involved in primary cocoa processing are also the corresponding variables in the chain, including planting, harvesting, fermentation, drying, and bagging/storage [113][114]. In the system model 5.4, we consider that each cocoa farm object, including well, tree, fermenter, drier, and bagging in the storage, has a built-in sensing device called MBC. The buckets, as the result of finishing a processing stage, process events such as event logging and documentation hence enabling any farm item to receive messages and links to other farm items. All data from the buckets are later transmitted to the central terminal as the corresponding entry of the events log, which monitors the overall activity of the buckets.

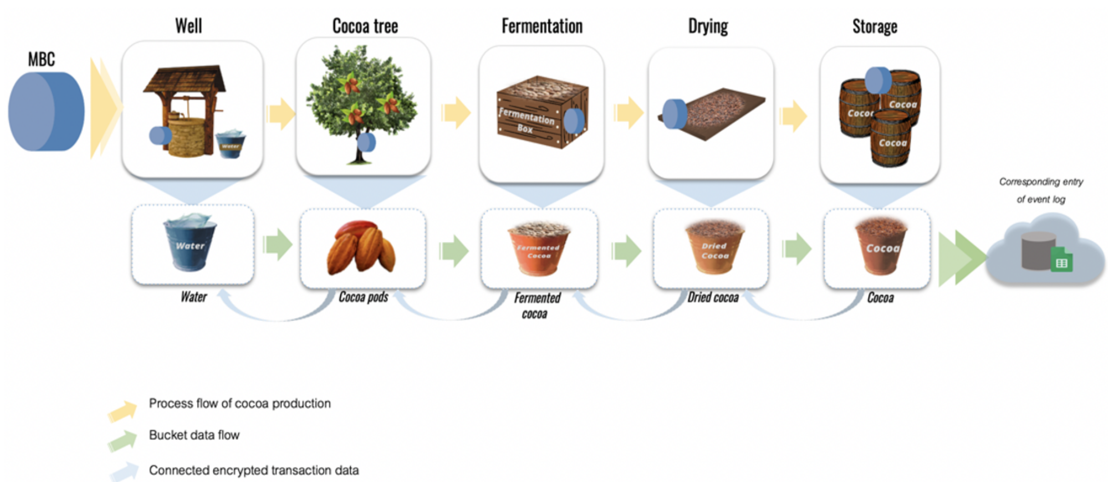

Figure 5.4: Cocoa production transaction

Figure 5.3 depicts a contract produced by a block within MBC node. Initially, a stand-alone MBC was used, which was later integrated into the farm object (well). Furthermore, the MBC-connected well will generate a bucket of water, which will carry a record log of events, which will subsequently be transferred and consumed to the next farm object, i.e., a tree. There are two sorts of blocks created based on the events that occur.

1. A bucket of water generated by a well has information stored in blocks. As described

in Algorithm 5.1, the previous block, hash 1, is the information generated in each transaction. An entry "NOPE" indicates that no specific information is stored here for the case of produce events. The block event was unrelated to consuming a bucket, referred by hash 2, and hash 3 is the information generated each time the farm object produces a bucket. Next, create a new block, and it is classified as a produced event.

2. In the delivery of the bucket of water, the bucket will carry the amount of water and confirmation of the content transfer. As described in Algorithm 5.2, the hash of the very first block is generated in each transaction as hash 1. Hash 2 is content transfer originating from the bucket of produce event, and hash 3 is information generated each time the farm object consumes a bucket. The farm object, particularly the tree, will absorb the water, triggering MBC to form a new block. It is categorized as a consumed event.

Since our model is primarily concerned with documenting all farm operations in nearby areas, we consider MBC compatible with the NFC tag and solely interact with the NFC. NFC serves as a gateway, allowing access to data stored in the cloud. The MBC mesh's purpose is to secure the event log recordings and does not require internet connectivity. Hence, there is a requirement to employ NFC as a peer to transfer information and store data on tags to prevent MBC from being hacked. So, if the end-user wants to access sensor data from outside, it has to ask NFC to get the required data.

Next, the pseudo-codes of blocks that are generated based on the events that transpired.

Algorithm 5.1: MBC Produce Event

function mbcProduce(Block):
    Get last previous block, $B_{last} = Block(last)$
    $Hash_1 = Hash(B_{last})$
    $Hash_2 = NOPE$
    $Hash_3 = Hash(eventinformation)$
    $B_{new} = [Hash_1, Hash_2, Hash_3]$
    return B_{new}

Algorithm 5.2: MBC Consume Event

function mbcConsume(Block):
  Get last previous block, $B_{last} = Block(last)$
  $Hash_1 = Hash(B_{last})$
  $Hash_2 = mbcProduce()$
  $Hash_3 = Hash(eventinformation)$
  $B_{new} = [Hash_1, Hash_2, Hash_3]$
  return B_{new}

5.3.3 Implementation Principles

To implement the EBM, we simulate local cocoa processing activities, including the primary cocoa bean processing chain, especially harvesting, fermentation, drying, and storage. This activity process represents MBC which collects, stores, manages key product information of each farm product. The following illustrates the MBC are linked in the EBM in Figure 5.5

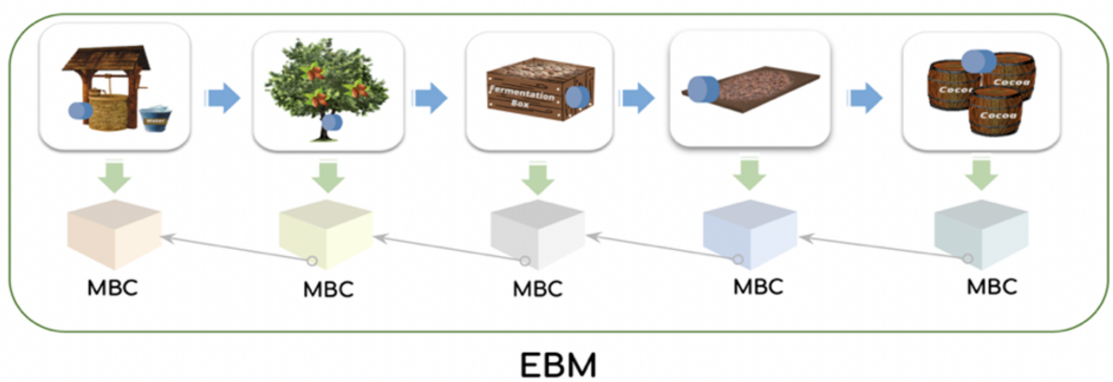

Figure 5.5: Block Mesh

- Harvesting. This process starts with flowers and ends with cocoa beans growing in pods. The cocoa tree consumes water during its growing period and eventually generates cocoa pods as the produce event.
- Fermentation. The fermentation process should begin after pod shattering. The box fermentation collects cocoa beans per pod and finishes with the beans being equally fermented. This process is categorized as consuming and producing events.

- Drying. After fermentation, the fermented cocoa seeds must be dried, and the fermented seeds must be spread on trays exposed to sunlight. The drying plate receives a bucket of fermented cocoa, and the process ends with a bucket of dried cocoa. This process is classified as consuming and producing events.

- Storage. The dried beans are packed into sacks for storage in a warehouse. The storage is obtained in a bucket of dried cocoa and then transferred to various locations. The final stage of cocoa processing is categorized as a consume event.

5.3.4 Farm Simulation

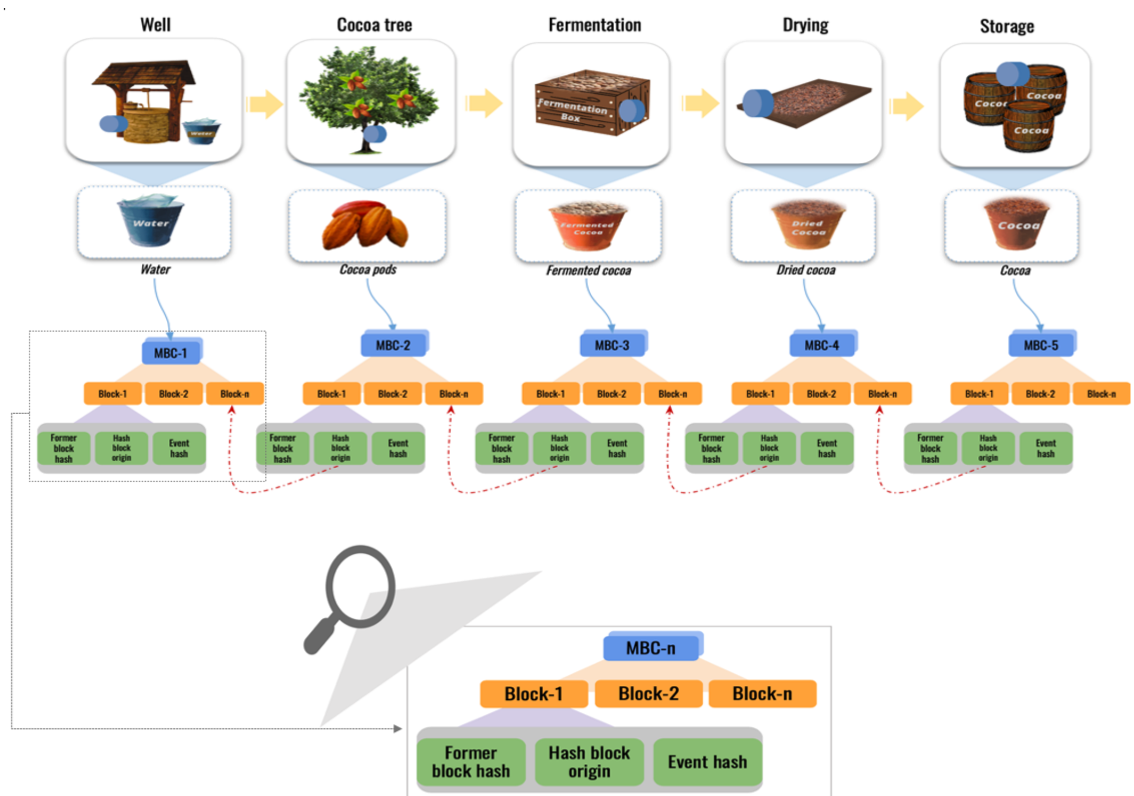

Figure 5.6: EBM for Cocoa Production.

In this section, we have implemented the EBM for cocoa production on a simulation platform as depicted in Figure 5.6 followed by a detailed explanation. An open simulator environment was employed to illustrate and demonstrate the farm transaction by Encapsulating Block Mesh (EBM), i.e., a cloud-hosted instance of the OpenSimulator server (version 0.9.1). This OpenSimulator provides an appropriate research environment by supporting several frameworks, such as server-client architecture, grid architecture, avatar-based control, concurrency, and scripting support. It became feasible to develop an experimental framework for conducting simulations that can be evaluated, analyzed, and enhanced through multi-institutional collaboration inside the so-called hypergrid connecting the various server simulations globally [115].

Experimental Environment

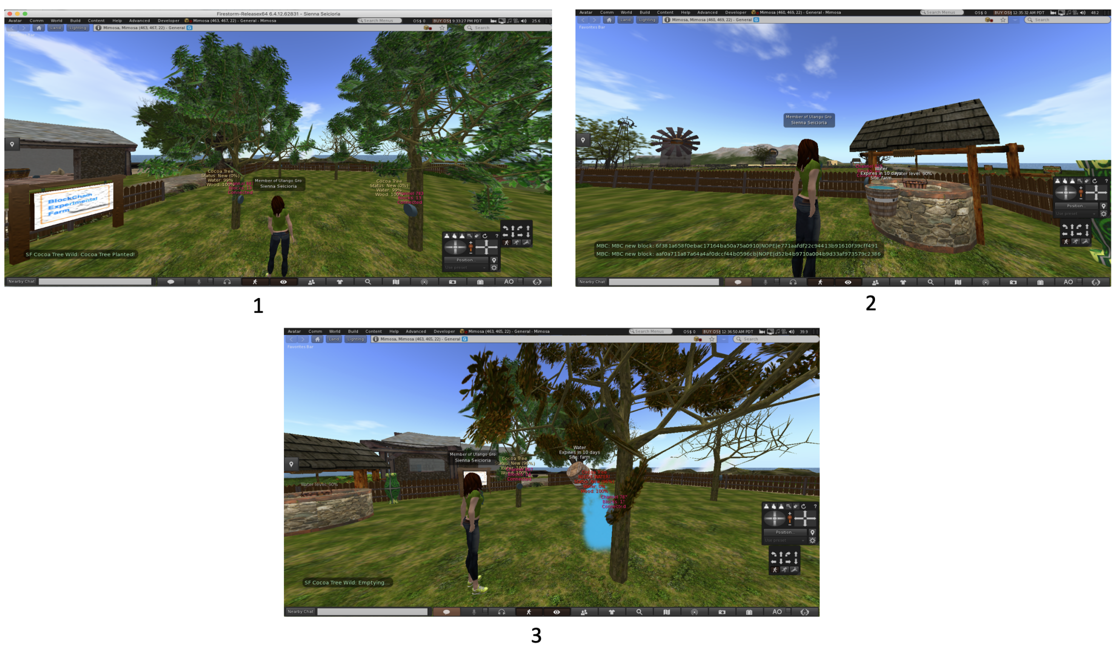

Figure 5.7: Watering cocoa tree

Cocoa processing involves several vital aspects before it is transformed into a cocoa product. In this experiment, we confine the modeling of the cocoa production process to watering, harvesting, fermenting, drying, and bagging. The following scenarios are considered.

- Watering the cocoa tree. At this point, the well serves as a water supplier as one of the

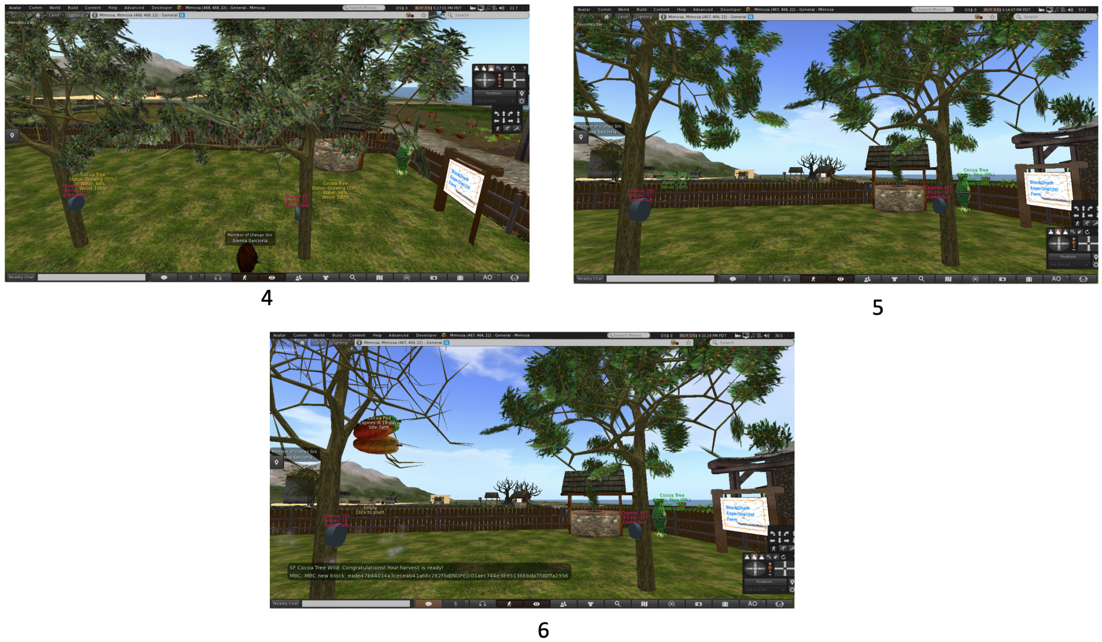

Figure 5.8: Harvesting

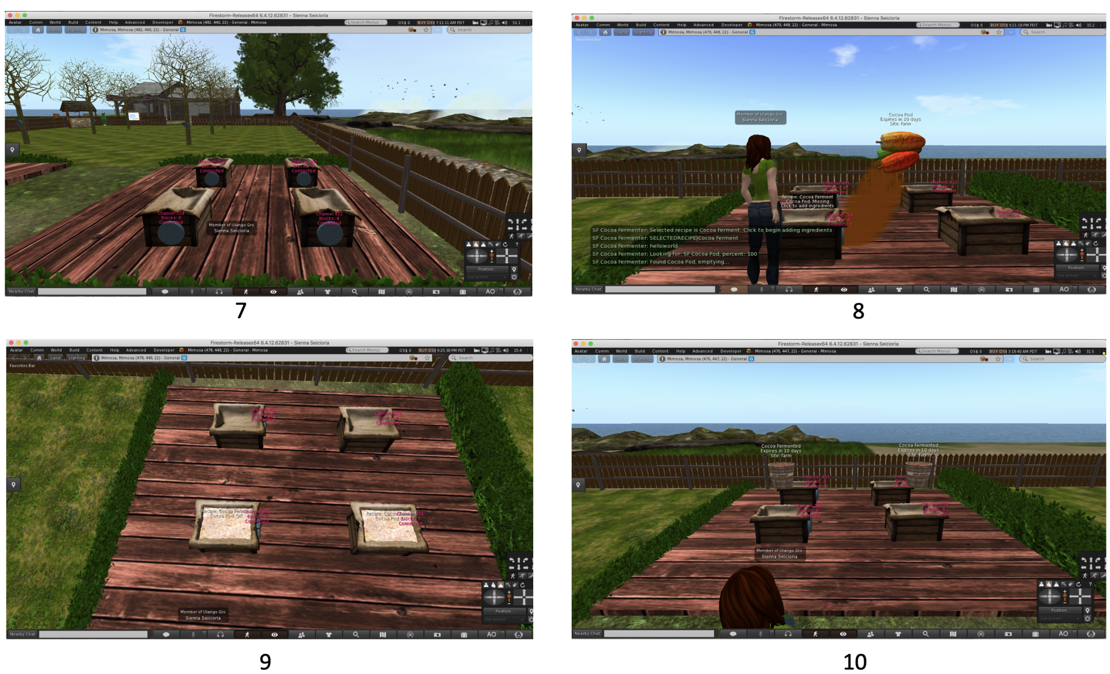

Figure 5.9: Fermentation

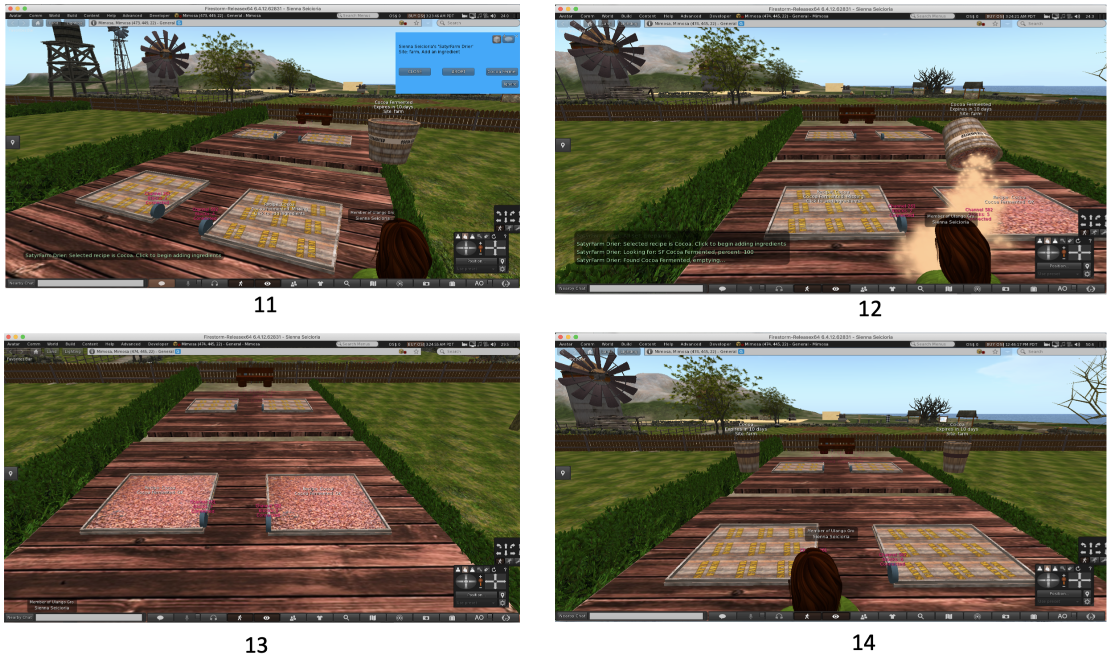

Figure 5.10: Drying

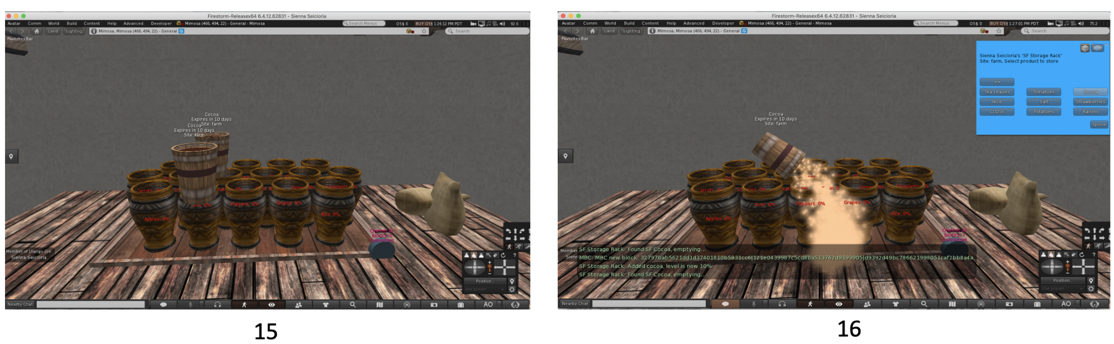

Figure 5.11: Storage

vital components to ensure healthy growth and cocoa yield. This stage, which represents the first activity of the cocoa plant growth process, is classified as a produce event in which the well generates water consumed by the cocoa tree as illustrated in Figure 5.7.

- Harvesting. Which begins with flowering and finishes with cocoa beans growing in pods. This stage is divided into two parts: consume events and produce events, in which the cocoa tree consumes water during its growth phase and ends up by generating cocoa pods as illustrated in Figure 5.8.

- Fermentation. After pod breakage, fermentation should take place. This step is also divided into consume and produce events, in which the box fermentation receives cocoa beans per pod and finishes with the beans being evenly fermented as illustrated in Figure 5.9.

- Drying. The fermented cocoa seeds must be dried after fermentation, and the fermented seeds must be spread on trays under sun exposure before they are shipped to the storage in the warehouse. This step is divided between consume and produce events. The drying plate receives a bucket of fermented cocoa, and the process culminates in producing a bucket of dried cocoa as illustrated in Figure 5.10.

- Bagging/Storage. The dried beans are now packed into barrels/sacks for storage in a warehouse. This step is classified as a consume event in which the storage is obtained in a bucket of dried cocoa and then transferred to various locations as illustrated in Figure 5.11.

EBM specific parameters and settings will be described in Table 5.1 as follow.

Table 5.1: Application-specific parameters and settings of simulation

Process of Event	**Description**
1. Produce Event	Farm object generates a bucket.
• Code 96	The code used by the farm object to send to MBC as a create event.
• UUID's bucket	Initial information in the form of the identity of the farm bucket received by MBC.
• Hash of former block	The hash of the very first block is generated in each transaction.
• Hash of "NOPE"	NOPE signifies the block event was not related to consuming a bucket.
• Hash of create event	The hash that is generated each time the farm object produces a bucket.
2. Consume Event	Farm object consumes a bucket.
• Bucket of content transfer	Content transfer originating from the bucket of produce event.
• Code 97	The code used by the farm object to send to MBC as a consume event.
• Hash of former block	The hash of the very first block is generated in each transaction.
• Hash of origin block	The origin identifier of previous blocks.
• Hash of consume event	The hash that is generated each time the farm object consumes a bucket.

The following EBM for cocoa processing will be described in detail.

- After connecting to MBC, each farm item, includes well, cocoa tree, fermentation, drying, and storage, is assigned a unique channel number and block count. The MBC of each farm object contains a block component structure that includes a former block hash, hash block origin, and event hash.

- The well will generate blocks, which will subsequently be carried and absorbed by the cocoa tree. The previous hash block, which was produced from a bucket of water, is then used as the identifier or original hash block for the following event object.

- The cocoa tree which is the next consumption event will receive several buckets of water and be consumed. Each tree has transaction records for tree watering, one of which is a result of the cocoa harvesting stage, specifically cocoa pods. The block contains hash data from watering activities, while the other block contains hash data from cocoa pods. All blocks have an identical block component format, consisting of a hash of the previous block of transactions, the origin of the block hash as an identifier of the origin of the previous block from Well's MBC, and a new hash event for consuming events already consumed by the cocoa tree. In event fermentation, the hash of the previous block of the resulting cocoa pod becomes the identifier or block hash of origin for the next event object.

- At fermentation stage, as the following bucket, the cocoa pod provides information on the transfer of event data content from the tree, which will be transmitted to the fermentation stage. Each fermentation box are comprised of transaction records block in which the cacao pod is poured into the fermentation box while other block of fermented cocoa is generated. The former block hash of each generated fermented cocoa becomes a further identity for the object in the drying event.

- Similar to the process in the fermentation stage, in the drying stage, each drier plate comprise record of transactions where a fermented cocoa bucket as a result of a fermentation process is poured into the drier while other blocks is generated dried cocoa. The former block hash of each generated dried cocoa in becomes the identifier for the object in the final storage of the cocoa processing journey.

- Storage as the cocoa processing series' final generates has the same block component structure as the previous stages of cocoa processing. The transaction records in each block contain event log data from a bucket of dried cocoa that will be utilized as a secondary identification for the event's next step.

5.3.5 MBC Event Log

In this section, we constructed gateway communication between MBC to the cloud storage, specifically transferring the farming transaction data recorded on MBC until it is stored in cloud storage. In this case, we are using Google Doc.

Each MBC will record and keep every transaction that occurs. Therefore, we construct a storage method that takes advantage of cloud storage, in this case, Google sheets as storage media. Every transaction performed by MBC will be broadcast to a certain communication channel specified in the script. To listen to every transaction that occurs on each MBC, we improve the communication gateway in the form of a script placed in a farming simulation. This script's function is to record and report every transaction from each MBC's farming simulation to the Google cloud. Some parameters such as *key_id* and *HTTP_Requests* function are needed to construct the communication between farming simulation and Google Spreadsheet. However, like other cloud storage media, this is a plain external log that is mostly unprotected. Hence the event log protection derives from its connection to the reliably EBM.

5.4 Experimental Results

We now have a few records log of transactions from MBC's. Since our transaction model runs in parallel from one transaction to the next, thus necessitating authentication and validation of the farm product data as the block updates each time and proceeds to the next block. We then investigate the certain MBC of the block on the farm object.

5.4.1 Validation

Figure 5.12 illustrates the detailed block of MBC, with each block identified and tracked through the operational procedure of the proposed EBM. The following is an overview of the transaction validation procedure for cocoa processing.

- A bucket of water is produced by the well that initiates the cocoa production process. A bucket of water with the bucket's information content distributes it to MBC. The contents are the bucket's UUID, the token, and the event. From here, the transaction data is hashed into blocks, and MBC generates a block and then proceeds to send back the new block to the water bucket, and it becomes the first block of the bucket. The validation process occurs if the transaction data is traced by tracing the identity of the hash. Here, between the existing hash block origin and the previous block hash of MBC. If the hash values fully comply, the transaction is considered valid.

- Assume that the cocoa tree requires transaction data from a bucket of water at an early stage. The bucket of water then transports a certain amount of water and other content transfer information to the cocoa tree for consumption. The cocoa tree then provides information comprising hash origin and consumption events to MBC, following which transaction data is hashed into blocks until MBC creates new blocks. If both hash values match, the transaction is considered valid. In such situation, the validation procedure is carried out by tracing the identity of the hash, which matches the previous hash block of the bucket of water and the origin of the hash block in the cocoa tree.

- Regarding transaction validation during the fermentation stage, drying to storage, as aforementioned, it appears to follow the same workflow in terms of producing blocks in each transaction. Produce and consume events are the two sorts of blocks that are created. Validation is accomplished during transaction block tracing by finding and matching the identity of the hash between the previous hash block of the cocoa tree and the hash block origin at the fermentation level. If the hash values of the two transactions are matched, the transaction is considered valid. Something similar will occur at the drying and storage levels.

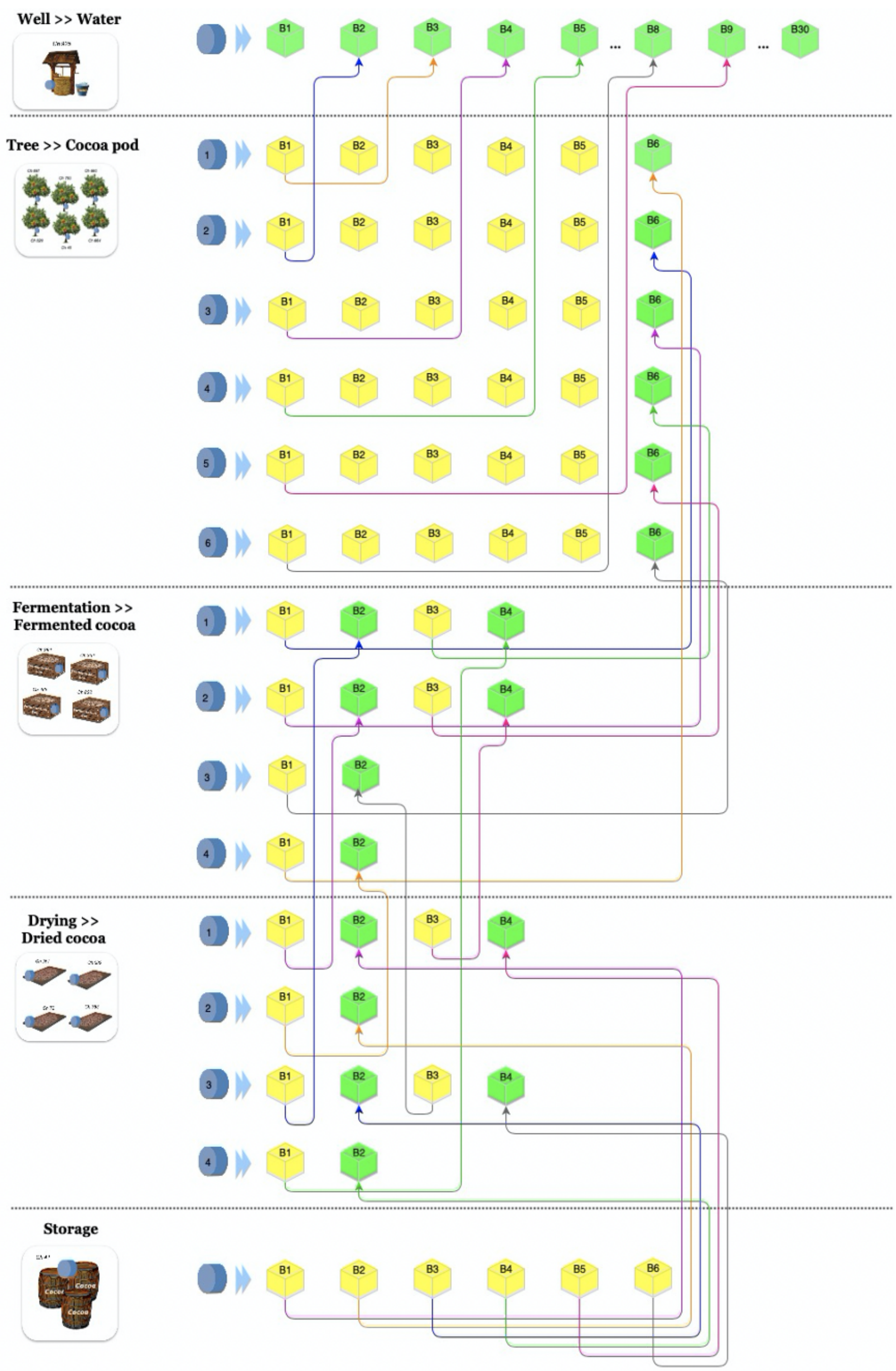

Figure 5.12: Detailed traced block of the MBC.

5.4.2 Investigate The MBC's

The investigative step is taken to monitoring the block on the harvested cocoa, transporting it to the fermentation box to obtain fermented cocoa, which is subsequently transported to the drier plate to get dried cocoa. The distribution process finishes with warehouse storage.

- Investigation 1:

  Inquire about the origin of the dried cocoa in the warehouse storage, in this case, randomly selected storage rack at block 2. (Table A.16)

  MBC Block 2:

former block hash	: `be12382f98fd9240ed80fe1a322175a9`
hash block at origin	: `d9e1e110f5cf22ed97f4a05ccd15a932`
event hash	: `fe7ccaa75cebbf540c5c9517731d4f7e`

  As can be seen, the hash of the origin block is `d9e1e110f5cf22ed97f4a05ccd15a932`.

  Now double-check with the drier:

  After calculating the hash, the result of the retrieve hash block origin is

  `d9e1e110f5cf22ed97f4a05ccd15a932` which corresponds to the second entry in block 2 of drier plate 2. It signifies that the dried cocoa in the warehouse storage originated the dried plate two and allowed the UUID of the MBC of the drier plate to be verified.

- Investigation 2: After double-checking the origins of the dried cocoa, the next step is to inquire about the origins of the fermented cocoa in drier plate two block 1. (Table A.13)

  MBC Block 1:

former block hash	: `fff7a973d18eac54302e41ce70530816`
hash block at origin	: `3616c124ebd63803f088017de4b85c55`
event hash	: `f5551d1423cc272844822b938b020d74`

  As can be seen, the hash of the origin block is `3616c124ebd63803f088017de4b85c55`. Double-check with the fermentation box:

  After calculating the hash, the result of the retrieve hash block origin is

3616c124ebd63803f088017de4b85c55 which corresponds to the first entry in the block 1 of drier plate two. It indicates that the fermented cocoa in the drier plate originated in fermentation box four block 2 and allowed the UUID of the MBC of the fermentation box to be verified.

- Investigation 3: Inquire where the cocoa pod originated from in fermentation box four block 1.(Table A.11)

  MBC Block 1:

former block hash	: fff7a973d18eac54302e41ce70530816
hash block at origin	: 017a6b68a8299277067841085d79b803
event hash	: 31a73da207677efd5f1603b9ef1e7d39

  As can be seen, the hash of the origin block is 017a6b68a8299277067841085d79b803. Double-check with the cocoa tree:

  After calculating the hash, the result of the retrieve hash block origin is

  017a6b68a8299277067841085d79b803 same as the first entry in the block 1 of fermentation box four. It indicates that the cocoa pod in the fermentation box four originated in harvest cocoa of tree 1 and allowed the UUID of the MBC of the the cocoa tree to be verified.

- Investigation 4: Since the well has 30 blocks while we got the last block traced from the tree 1, the tree has been watered in between. Thus we can read the ”former block hash” directly. Now we investigate the former block hash of the bucket of water that was watered the cocoa tree 1. (Table A.2)

  MBC Block 1:

former block hash	: fff7a973d18eac54302e41ce70530816
hash block at origin	: f77bc30541130cb9d10e6afc4ebd9ccf
event hash	: 327e5bcd1e522ff90d3da725c9d6454c

  As can be seen, the hash of the origin block is f77bc30541130cb9d10e6afc4ebd9ccf. Double-check with the well:

  As a result of the calculating hash, hash block origin is `f77bc30541130cb9d10e6afc4ebd9ccf` which is the same as the former block hash of the well. The UUID of the MBC of the the well can be verified.

To put it another way, we have securely identified one source of the water that watered the tree, finally leading to the examined cocoa beans in warehouse storage.

5.4.3 Corresponding Entry of Event Log

The cocoa processing encapsulating block mesh is used as the foundation for capturing transaction data of cocoa processing in order to ensure data integration, safety, and traceability of the overall activity of transaction events. The cocoa processing encapsulating block mesh method's final output can subsequently be saved on the cloud-based spreadsheet. Figure 5.13 shows a screenshot of the output page of the corresponding event of the data log.

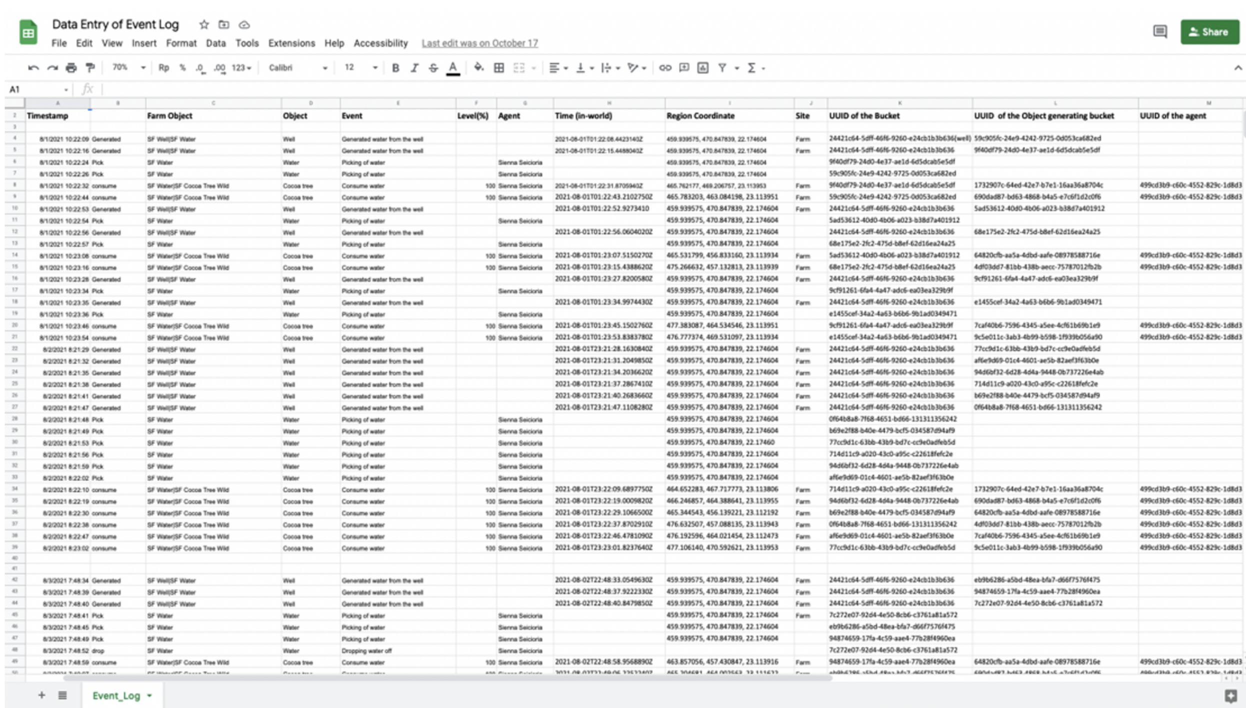

Figure 5.13: Corresponding entry of event log.

5.5 Discussion

Our proposed EBM has been evaluated in terms of its secure data documentation. In particular, the protection of records data in the event log and the degree of trust of transaction validation have been analyzed by encapsulating the blocks for all farm entities involved in the process.

Our farm model works in parallel from one transaction to the next as a condition for effectively fulfilling ongoing circumstances and transactions. It demonstrates that it is valid to utilize the value of one entity to integrate another entity at a different goal site even if it has the same starting point. Hence the sustainability, relatedness, and reliability can be proven of the whole product tracing while avoiding manipulation of data-related decision-making.

Considering the possibility that MBC may be damaged, stolen, or tampered with, it may be assumed that there is no guarantee that the blockchain can record throughout a farm. However, authenticating blockchain related to the depth to which the events preceding the current transaction can be reliably tracked back is of great concern here for the trustworthiness of this method.

In other words, the hash value match and relatedness blocks in each event where an event that continues the current transaction occurs and wherever its area is a benchmark for the legitimacy of a transaction in the block.

After simulating EBM, the interfacing among physical objects unconnected has been constructed and organized. It is evident that the documentation of farming transaction records is more structured, complete, secured, and protected, and each farm product is identified, integrated, and verified. It implies that the proposed blockchain approach EBM corresponds to the conditions of a farming transaction.

5.6 Summary

In this chapter, the Encapsulating Block Mesh (EBM) for cocoa production by integrating a unique designed blockchain and applying the principle of a bucket-based transaction implicated by MBC's sensing instruments is proposed.

We chose the cocoa production model, specifically locally cocoa processing, since cocoa processing has a number and unique stages and aspects, a relatively simple chain, and a well-defined structure. Planting, harvesting, fermentation, drying, and bagging/storage are all variables in the chain that are involved in primary cocoa processing. We consider that each cocoa farm object, including well, tree, fermenter, drier, and bagging in the storage, has a built-in sensing device called MBC, where the buckets, as the result of finishing a processing stage, processes events such as event logging and documentation hence enabling any farm item to receive messages and links to other farm items.

The transaction documentation model is recorded at each level of cocoa processing and will be connected to events that occur on other farm objects chained together in blocks using a strong cryptographic method. First and foremost, the overall practical system requirements have been defined. Then, we introduced a protocol that allows each cocoa farm stage to validate and authenticate product farm transaction data through chained hash values in the blocks. A remarkable feature of the proposed EBM is protecting the recorded data in the event log to eliminate data tampering and distortion, allowing data to be monitored safely and transparently. The claim procedure validation and MBC analysis demonstrated the validity of our EBM.

From the objective finding of this study, we may refer to a realistic portrayal of a flow of farm transaction model in which simulation validated the proposed method. Farm objects take turns to record information on the process of producing, transacting, and consuming a farm product into a block. Each block is then encapsulated, linked, and verified with the previous farm transaction block. This outstanding simulation model is ideal for real-world agriculture system documentation implementation. The simulation technique is also meant to aid farm management in managing or developing a documentation system that uses a specially designed security sensing instrument.

Chapter 6

Conclusion and Future Work

Blockchain is growing in fame, as are applications of technology use cases. One of the most prominent and familiar examples of modern uses for blockchain technology is in cryptocurrencies, such as bitcoin and finance. While the use of distributed ledgers in the supply chain is relatively recent, the number of applications for distributed ledgers appears endless. Blockchain system has been widely accepted as a solution to the underlying trust and security issues because of its transparency and prevention of tampering in terms security dimension of food chains with various suggested approaches. Therefore the primary objective of this research is to offer a documentation system solution by utilizing the blockchain idea regarding food-chain security, including food traceability and integration concerns of farm activities. We propose a new approach, a blockchain-based documentation system, to enable traceability in the agri-food domain and to give an alternative solution for traditional IoT issues. In conclusion, we embraced the blockchain idea and enhanced its features so that it may be utilized to tackle security and traceability issues in the agri-food domain that we propose in this dissertation.

The first approach presents a solution to link legal documentation and blockchain technology within a traceability system with the specific application case of cacao and chocolate production. In this first direction, we assume that the documentation, mainly based on existing media-based documentation practice or supplemented with media such as images or videos, is designed to offer sufficient evidence and visual cues to retrace the whole process.

We then improved data security by extending the common blockchain concept to a two-factor blockchain, where both blockchains are connected via digital watermarking of the documentation media. One blockchain traces the documentation steps, the other the watermarking embedding. The watermarking algorithm ensures the information at each stage is authenticated, and any alteration or manipulation of data can be detected. The evaluation of proposed frameworks and principles has been implemented and validated by a prototype.

Furthermore, in the second direction approach, we presented the Encapsulating Block Mesh (EBM) for cocoa production by integrating a unique designed blockchain and applying the principle of a bucket-based transaction implicated by MBC's sensing instruments as a model for farm transactions. By simulating farm transactions, we demonstrate how Modular Block Chain (MBC) sensing may be used to enhance the data integrity and security of farm objects by simulating farm transactions. MBC acts as an information recorder during the generation, transaction, and consumption of a farm product, which is subsequently encrypted into a block. Each farm object is connected to a secure block system and validated due to encryption provided by a hash value in each object. The simulation of the proposed method employs a 3D virtual environment or metaverse-based simulation.

Based on the findings and analyses in each chapter, it is obvious that each method used in this study provides different features of traceability documentation solutions. We cannot expect them is the ideal solution. Still, we can expect them could be a value add to the agri-food supply chain and support the claim that blockchain can improve food and agricultural products' traceability and integrity of farm activities.

Furthermore, we were able to answer the research question stated in Chapter 1 after assessing and stimulating the experiments in this study.

1. According to the study findings, blockchain can enhance food traceability performance; as we proposed in our model of the cocoa traceability system, which blockchain and watermarking algorithm provide particular transparency for all users level by extending the common blockchain to a two-factor authentication which consumers and manufacturers provide information data with the addition of different hashing and watermarking algorithm thus originality of the data (images) is verified every step of the way. Furthermore, in the second approach, a designed blockchain is integrated by applying the principle of a-bucket-based transaction which is implicated by MBC

(sensing instruments) and offers the solutions to a trustworthy traceability system collaborated with a sensing device.

2. In the first approach, validate the authenticity of cocoa information using the hash to store data in Blockchain (BC) 1. Then Blockchain (BC) 2 contains the results of a digital watermarking image. When a consumer trails a validation process, extract text and images from a digital watermarking image BC 2 and then cross-check by retrieving from BC1 by comparing the hash result. It indicated the authenticity of cocoa data from farmers and manufacturers could be validated in the traceability process. While in the second approach, we employ an MBC sensing instrument integrated into a farm object to record, collect, and store essential cocoa farm product information encapsulating it in a strong cryptographic proof for data authenticity and integrity with a block-generated contract within. The validation process is considered valid if the existing hash block origin and the previous block hash of MBC fully comply.

3. Blockchain technology utilizes digital distributed databases in which blocks are connected in an appropriate linear manner that cannot be altered. The feasibility and added value in both specific approaches are propagating data effectively between the farmer and the manufacturer via a two-factor authentication blockchain and the other between each level of cocoa farm activities, such as planting, harvesting, fermentation, drying, and bagging/storage via encapsulating block mesh to ensure data integration, safety, and traceability of overall transaction events.

The two approaches provide knowledge about the potential for practical use of blockchain-based documentation systems that are still being studied. The outcomes of this study are appropriate and show promise. Despite many barriers and challenges to overcome, the results indicate that consumer demand for transparency or allowing consumers to know where their food has been, and the need for improved traceability may drive the performance of the food-agricultural industry, for example, cocoa and chocolate production. This study is also expected to address farming documentation issues at several levels of the food supply chain, including factory, supermarket, and food consumption. Farm management may use these approaches to manage or develop a documentation system employing a specifically built security sensing instrument in the natural environment.

Following the design and implementation of both approaches, for future works, we may create a token system or a uniquely identified asset or Non-Fungible Token (NFT) that can be used to control the textual information. We may include a tag/label as proof of ownership in the entire farm asset data, which can then be linked to decentralized storage IPFS (InterPlanetary File System). IPFS enables NFTs to represent data of any size and format, such as photos, in a secure, verifiable, and distributed manner that is time-tested.

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Appendix A

The Block Event Hash Values

Table A.1: Well

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	NOPE	e57dd29e50f7b4d4676fcbd360a2a3f8
2	2b686a7c8601b901ab8dfd8a9d255ac8	NOPE	657d125c2693b2718350bd556b493ffb
3	f77bc30541130cb9d10e6afc4ebd9ccf	NOPE	6823b54bfff5969f432f9787de991fab
4	e5e130b88e093499fb8f6aaa300400b6	NOPE	46be480f59381b4b16c571f4e0e8a64b
5	4c760f7a1b0ca3542fe5d2aba8ad017e	NOPE	872604e1f8d8ffa837468202c27fbd53
6	127621e1abf18c792c6c1f566fba243f	NOPE	529813506deec4e77493f8651d04ed13
7	b45be60147a7cc2daa34cef71942bd6d	NOPE	9c9a63fb5699170175e9f19015e81a04
8	ab6b314704fca1ec8ec2eeba7946d225	NOPE	28886af72c1ffafb52e36dcf83da9aa3
9	f9f14141fd090b38ce86cee8cd10208e	NOPE	23134c7962420edd64b9000c6237b20b
10	6336806085e3b1b398b9d795a78ac28a	NOPE	e025b3ea1c595c599e3e9542755fbf30
11	c304a81c184818778e12e2a465743572	NOPE	3c6316bb026e20f4b497ebcd186c6f1c
12	2a418e361721c0c35722dc3f44d97fd5	NOPE	18dac09d1ce818f3e80bb939c312c94e
13	21ca390e3a5260596028af93927dbf6f	NOPE	ceb55a4f9cf6f36a4d6533ab3af2f344
14	758e14ecd188acaa352ee73fb565dd33	NOPE	3caa7e7eedebbe619f7516c88232e08d
15	be1c438246d6471521a9fdf4b799c3ea	NOPE	5463688b1f6f766cd0335b49c950b27f
16	7538340e74dcc686bcbe33c5b0a1e6ec	NOPE	2b19ec927e2076d03b51806987453316
17	f49444fe520d3aa73a2a3849caf36232	NOPE	33a0c93dcd5ec8585384bec6c1b7ed01
18	c60b5ea0d579c1aeba7312393d61b8f9	NOPE	6f6c9b7fec611acf13ae1bed3f0e10a7
19	64b09997c23c5651a761a90d5e6a3273	NOPE	ca848ccd11bc9ddb90a3a6b82979e595
20	88e875c13fc12794f273e657729238c4	NOPE	3f4ce43619d24e580c251b7389f9d8dc
21	0c632c4845b349fa993f5878a3575737	NOPE	2f0f870ff0f2826c6e8fe572db69f490
22	22cf3686af45b3e5a6093f040e178b01	NOPE	847968257d0adb1184188e5d286ebda3
23	998a8b241021d888f03f09383878688c	NOPE	62a8e5a40acd2862a4340ba5596d0701
24	54840d45afffa4332dd35a080b5746d5	NOPE	5efbbcd965a092fc43d05644849c427e
25	8559095dbb33dd22fb15675d000023a1	NOPE	24b2d8beaced5aecebadbad1f393077a
26	98b010bd5c2641257a8f06c443e7d1cd	NOPE	e9937b640838f082970b67b05dc094e3
27	63d8ab9a53527ff864f7951d4c2ffc5e	NOPE	66d91d3bba59deb5a021c18b80ca7923
28	330a7177f55f2cbe10e58bdc4720a855	NOPE	2005017c54b4092c4335cff78abcfe27
29	408519e6139b07849f2585b2c29b3421	NOPE	279afb0ecb2bf9223d94e23b60172d5b
30	2db1e2cc196f3b78d6d0bc6a8ba02678	NOPE	38000344f4d52878b1d4396cc92f7807

Table A.2: Tree 1

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	f77bc30541130cb9d10e6afc4ebd9ccf	327e5bcd1e522ff90d3da725c9d6454c
2	dd2a481807268e16e510fd1dc587ce20	c304a81c184818778e12e2a465743572	812bc2cde0695a1a99b0c3d6cda881a2
3	3e55384c6d35f3d864ba3713c8100a15	7538340e74dcc686bcbe33c5b0a1e6ec	35db30956459d6604ad93b0620b0aa6c
4	f2aca1105308dfa11a898473997699ee	998a8b241021d888f03f09383878688c	46ab46939d4769d936862b451184c531
5	15c54c6970ede71b5959429a4b11c648	330a7177f55f2cbe10e58bdc4720a855	e4908ab822db8858010bf637d7f0c0b4
6	ff682f6161312e1117ff16422dc46dca	NOPE	23a2b3b6aec72451a08af0d2da86b42c

Table A.3: Tree 2

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	2b686a7c8601b901ab8dfd8a9d255ac8	deb41d87667b21468f04b5acb79fa085
2	31636d37495e8277c13c95148de7dc93	6336806085e3b1b398b9d795a78ac28a	3e78a147bb315dc706af478f6025fe1e
3	6af327fca1139f5f2073b8ad599e33fa	758e14ecd188acaa352ee73fb565dd33	90a171f92058f05a92d0c93ae41c5477
4	254828ec0945efa3fa6959554ad39d8c	54840d45afffa4332dd35a080b5746d5	9c62cfa31101717ddb20edf09e7e38e3
5	899e5b9f4034bac0502e53e13226c32f	63d8ab9a53527ff864f7951d4c2ffc5e	fe25d67eb432f707874cf689bd7d4151
6	38a8e1d31f7df1715b54176d8af01189	NOPE	ad6b11736be1b88503a7c1d5f230ba24

Table A.4: Tree 3

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	e5e130b88e093499fb8f6aaa300400b6	91507f9d2feec89e4347f8ef4e10c439
2	ab638335c76fde17260bf6775b03f3fd	2a418e361721c0c35722dc3f44d97fd5	2054e6caeb0f20aada1fb8e8e2611e56
3	6da1e0f9b74cd56c7e21b00e803f2ce3	be1c438246d6471521a9fdf4b799c3ea	1b61ed771e63a3c04f9d9477403e74a4
4	b17a82d1231ff9a3be8330e82358e94a	8559095dbb33dd22fb15675d000023a1	c0e31da9fee418c18a739c57753d3f00
5	def5decbbdc59498e886390c6e1520be	98b010bd5c2641257a8f06c443e7d1cd	f444853e0ac54ef077e5034b18b7069d
6	5a6b0916feb3b5edcd89da71516c047d	NOPE	4f2367931d670fe0cfeaf11403882e25

Table A.5: Tree 4

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	4c760f7a1b0ca3542fe5d2aba8ad017e	a1f915bd02b4055a1ed6e9cccbad809f
2	7c33a136fee6f09a4bf4978bd9b5e2f2	21ca390e3a5260596028af93927dbf6f	166c09a6f0bfa0d8f897090a54d42dac
3	2f5522a8e7313839f87d12fc0d24df94	c60b5ea0d579c1aeba7312393d61b8f9	cc790b20420e7634da462be40bd3dc10
4	192fc2038e5db537bdba7aa44a3263cd	88e875c13fc12794f273e657729238c4	2430e43fb02616071bb7a4114a2c5f1b
5	9f5e77abc5d3a3a04385ee03cd429da5	8f25e89ca0b897e1e099af7c25270214	582cf172fa340fa4af335caf4ace54bc
6	33ecc21f27310dbc28013d8699013a38	NOPE	456b456115b5e7ef06f61e8d8f78f7f6

Table A.6: Tree 5

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	127621e1abf18c792c6c1f566fba243f	285dda67e2a5a44c5a25a029f174ffc5
2	b1845125e31771b19cd3ffa99681d2c3	f9f14141fd090b38ce86cee8cd10208e	cc8a3008f4b185c9ce004f723a12f360
3	efab4637d548cdfd70b8bd13bf2f9afc	f49444fe520d3aa73a2a3849caf36232	e475c880dcc561805d764c9ed9ce5416
4	f2455f916dd1ff690259ce913b559e6c	0c632c4845b349fa993f5878a3575737	51e0e1133246d68e266668032c5cd724
5	f55a38001f7a682903c91eededcfa5c1	408519e6139b07849f2585b2c29b3421	f6967fb451bc928d2f3d7f99003410d5
6	4ccdb0cf56cd364cf7d36f078df75e64	NOPE	9b55bbaffbd3bdc1d69c17ccf3b8bfb4

Table A.7: Tree 6

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	b45be60147a7cc2daa34cef71942bd6d	764a40463057bd5278365150e12d348f
2	1cc89f7df6b8ec667320359a78ab5d28	ab6b314704fca1ec8ec2eeba7946d225	9d2016c662ff5d31b8e428080835fd16
3	ede95a11abb3fe5d0971772f326b458a	64b09997c23c5651a761a90d5e6a3273	b9967b72fdd5ac39f84049831cdb57fb
4	74bbe8e39abd392d2e16c3b19cf3bf89	22cf3686af45b3e5a6093f040e178b01	3001b9c6ecf6e0def4a871591ba055d9
5	1c5b07bbd20c3fd8501cdbbee048a2ea	2db1e2cc196f3b78d6d0bc6a8ba02678	f0eb3fb96d8786882a7fa5319a351672
6	de4445c42470314ff6aaf4ff6eca5905	NOPE	9b28d36a31d6e0204912267338f6a986

Table A.8: Fermentation Box 1

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	8cd261c40ebb9cefaae17fa3795a1435	3c047473a8ec1b43e25589da561c4fa4
2	341f7c950afc7fb316f3372da690d597	NOPE	b7907fbf5bbc22f0e4f0a82a8731bc95
3	85807726a37a81e239354c085dc58911	210f9fdcf44974c6b8118b856265b72c	3b9999e23c9a189c52c4b40f36b247d6
4	10691e511c294ab745d4d2d898b0bb9a	NOPE	26d60839f9d28bb3889109bf60b4ac3b

Table A.9: Fermentation Box 2

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	bae871823b83c1f96f8946db58f79e26	58a572742e9594aa74a87b595a3bda7f
2	a859101fbe8c23fcdc9e4e5e65b282f4	NOPE	857e15fd48c1a236737b24bd5ecfddca
3	2629b590e584815f46c1515c25aaea4a	3c6652bdb2402277f2624f0b6146e377	b1f500fc24300657d057a0038548cb08
4	f9c04d83be42e64782df33f196a37159	NOPE	2822d2b574bfbcc6a4eeddf7e994abff

Table A.10: Fermentation Box 3

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	028ba03293f3a90bc88e25e356e766c8	604f99b6cb01c2149bfdc0331dd3c9ed
2	1d5a18141d76c51bc63a2d3433ed16f3	NOPE	7bf950c7903e0b5bbc3f4b455a609a07

Table A.11: Fermentation Box 4

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	017a6b68a8299277067841085d79b803	31a73da207677efd5f1603b9ef1e7d39
2	b466b91076cfc90f39f9e88905141f84	NOPE	3ab5ce6471ea7bcd39154d434054a138

Table A.12: Drier 1

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	2629b590e584815f46c1515c25aaea4a	cd829eeb4a05265ed7c4e5bae10bb79f
2	432fed641dab4733ba24bf81e9665023	NOPE	e7d0dd071eca2c95df9235167ae9b3f2
3	8e37264acd37c4ad2f19a28c7ce32ef7	9ff389b611e36a118a135c876a1ec5b6	8fe6762da16a69f2bc4241e18ddec6ce
4	a8a4be40a5339d596c32172f0d9091c8	NOPE	ea9a2ff0bb42cd6d3f6aad3e414902ba

Table A.13: Drier 2

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	3616c124ebd63803f088017de4b85c55	f5551d1423cc272844822b938b020d74
2	f20d259f742a16387f98a587344c94f6	NOPE	9efdbf2ce2df9d88ab457d9267d46371

Table A.14: Drier 3

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	85807726a37a81e239354c085dc58911	5b824e46784dbaf44e5f16b9e130dbcd
2	08d7037538bf163c48e6a5b1b0234e1a	NOPE	2cd56eeae9afeba963a9690b0f78d601
3	54e7154d726af7b521ce456085f93477	bd3c7c82e1d2324ffc4d120a1594d9d5	0a1ca99f12a25f270c747d22fe40f1c2
4	d65b6b98ee4b8297ed48fd018c1f50bc	NOPE	3bbd9af9881033ac963452790c56472e

Table A.15: Drier 4

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	1c95778108c10289c60a5867ca48e37d	997c0c644449bfc37fa32e9afa9f2d5d
2	50e1ffae45052a9206023e6b0dacd2c3	NOPE	57e9a39524d427a2c56f4931ef789063

Table A.16: Storage

Block	Former Block Hash	Hash Block Origin	Event Hash
1	fff7a973d18eac54302e41ce70530816	8e37264acd37c4ad2f19a28c7ce32ef7	1b29eb80901752ba79e10a98501491c8
2	be12382f98fd9240ed80fe1a322175a9	d9e1e110f5cf22ed97f4a05ccd15a932	fe7ccaa75cebbf540c5c9517731d4f7e
3	ec2fb067490be6e3bb004d0528c4b1bf	54e7154d726af7b521ce456085f93477	9aeeb41a3d8d9e26f65271c3bfba6894
4	95301626934335f5e76aa2d10f715744	f935e4a5a03e75007688326cc2241264	5c380d674e523499c94d31610cd7831e
5	d73fabb43416561382cbe55a5db95d8f	603a189b5a8dd9c8400de137c19e3968	26ca7014e41a97bc894376c9ef63e75a
6	951957d29fbf48930f3a481e0bef1365	7035e45e5e31c51d1183049f6dadfd38	23609fd5eb455a4a2b67480b76787bc8

Appendix B

Publication List

Journal

1. Andi Arniaty Arsyad, Irawan Widi Widayat, Mario Köppen, “Supporting farming smart documentation system by modular blockchain solutions”. Journal of Decision Making: Applications in Management and Engineering (DMAME), pp. 1-26, Volume 5, number 1. Publisher: Decision Making: Applications in Management and Engineering (DMAME)) March 2022. (doi.org/10.31181/dmame0326022022a)

International Conferences

1. Andi Arniaty Arsyad, Sajjad Dadkhah, Mario Köppen, “Two-Factor blockchain for traceability cacao supply chain”. Xhafa, F., Barolli, L., Greguš, M. (eds) Advances in Intelligent Networking and Collaborative Systems. INCoS 2018. Bratislava, Slovakia , September 2018. Lecture Notes on Data Engineering and Communications Technologies, vol 23. Springer, Cham. https://doi.org/10.1007/978-3-319-98557-2-30

2. Andi Arniaty Arsyad, Sajjad Dadkhah, Mario Köppen, “Two-Factor blockchain using watermarking as a proof of work”. 2019 International Conference on Platform Technology and Sevice, Jeju-Korea, 28-30 January, 2019.

3. Nurdiansyah Sirimorok, Rio Mukhtarom Paweroi, Andi Arniaty Arsyad, Mario Köppen, "Fungi network simulation for the study of communication system". Intelligent Networking and Collaborative Systems. INCoS 2022. Kwansei Gakuin University, Japan, September 2022. Proc. Lecture Notes on Data Engineering and Communications Technologies

Seminar

- Andi Arniaty Arsyad, Mario Köppen, Two-Factor Blockchain for Cocoa Farming Documentation, International Student Seminar 2021/2022, November 19, 2021, organized by Kyutech and Hefei University of Technology (China) / Anhui University (China).