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USE OF BLOCKCHAIN TECHNOLOGY TO IMPROVE THE TRACEABILITY OF MANUFACTURING PROCESSES IN THE CRAFT BREWING INDUSTRY

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Abstract

This study evaluated the applicability of Blockchain technology—specifically the Hyperledger Fabric solution integrated with a secure and scalable Internet of Things (IoT) architecture—as an engineering tool to enhance transparency and traceability within the supply chain and manufacturing processes of the Venezuelan craft beer industry. This implementation, supported by a feasibility analysis and an economic impact study, aims to provide immutable certification of manufacturing data for consumers, thereby increasing trust and reducing the risk of fraud. The proposal directly contributes to SDG 9 (Industry, Innovation, and Infrastructure) by promoting technological modernization and industrial capacity through the adoption of an advanced data infrastructure, and to SDG 8 (Decent Work and Economic Growth) by strengthening the growth of craft beer SMEs through fairer, more transparent, and verifiable production processes. In addition, a series of recommendations were developed to implement this solution, enabling greater consumer trust and perceived quality, ensuring compliance with production processes, and reducing the risk of fraud.

Keywords: Blockchain, supply chain, manufacturing, traceability, transparency, IoT, Hyperledger Fabric

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INDEX

Introduction

In the consumer goods sector, specifically in the food and beverage industry, consumer confidence has been affected. Customers expect to know the origin of products to ensure that they are safe, high quality, and produced in accordance with ethical principles, as well as aspects related to sustainability (Verano, 2018).

Currently, the consumption of craft beers in our country has increased in recent years. However, there has also been an increase in cases of adulteration, counterfeiting, and imitation of alcoholic beverages, which has led to various changes in consumption patterns. One of these changes is that buyers now carefully check product labels, hoping to find information about the origin and production process (Garcia, 2020).

Currently, the beer industry is taking a new direction. Craft beer has great and tempting potential, and the great versatility of the formulas allows for different and innovative flavors due to the diverse ingredients (Calvillo, 2017).

In the quest to prevent counterfeiting, new technologies, such as *blockchain*, have become an effective tool to combat it. *Blockchain* is the technology behind *Bitcoin.* Since 2008, it has been implemented in the financial sector in a multitude of projects, but the leap to other sectors such as supply chains has happened more recently (Calvo, 2018).

The degree of decentralization, immutability, visibility, and transparency of data provided by blockchain technology makes it possible to protect digital identities and establish authenticity. The use of *blockchain*, together with other technologies such as the Internet of Things (IoT) and RFID tags, makes it possible to guarantee the traceability of products at any stage of a supply chain.

Based on this, this research seeks to present a comprehensive solution to the problem of consumer mistrust due to product counterfeiting, through the application of blockchain technology in the manufacturing process, using the craft beer industry as a case study, in order to determine the materials and tools necessary for its proper functioning.

Research Phases

Description of the Companies Analyzed Cervecería Social Club

Cervecería Social Club is a microbrewery located in Sebucán, Miranda, Venezuela. Its sales strategy is based on social consumption within its facilities and on contracts for events. The production plant is single-level and approximately 28 square meters.

The company has a single production block, consisting of several tanks, a mill, and a heat exchanger.

The production process is divided into seven phases:

- Selection of raw materials: The company uses only imported raw materials, except for water, which is obtained from natural springs.
- Malt grinding and water preparation: The malt is crushed without pulverizing the husk, and the water is heated to boiling point.
- Mashing: The crushed malt is mixed with hot water to convert the starch into sugars.
- Filtering and draining: The wort is filtered to separate it from the spent grain, which is a solid residue.
- Boiling: The wort is boiled with hops to give the beer its bitterness and flavor.
- Fermentation: The wort is cooled and yeast is added, which ferments the sugars to produce alcohol and CO_2.

Packaging: The beer is packaged in bottles, cans, or siphons.

The company uses PLC technology to automatically control tank temperatures. This keeps error margins low and guarantees the quality of the beer.

Cervecería Norte del Sur

Cervecería Norte del Sur is a microbrewery located in El Hatillo, Miranda, Venezuela. The production plant is single-story and covers an area of approximately 70 square meters. The plant is divided into two lines: one for testing (kitchen) and another for production (plant). Both lines work in the same way, but on different scales.

The production process at Cervecería Norte del Sur is divided into two parts:

- Cold part: reception of raw materials, malt milling, fermentation and maturation, packaging.
- Hot part: mashing, filtering, and boiling of the wort.

The production process can be described as follows:

- Receipt of raw materials: The raw materials used are a mixture of domestic and imported products. The malt is a mixture of domestic and imported, the water is domestic but treated with imported components, and the yeast and hops are entirely imported.
- Malt milling: The malt is crushed without pulverizing the husk.
- Mashing: The crushed malt is mixed with hot water to convert the starch into sugars.
- Filtering the wort: The wort is filtered to separate it from the spent grains, which are a solid residue.
- Boiling: The wort is boiled with hops to give the beer its bitterness and flavor.
- Fermentation: The wort is cooled and yeast is added, which ferments the sugars to produce alcohol and CO_2.
- Maturation: The beer is left to rest at low temperatures to remove unnecessary proteins and compounds.
- Packaging: The beer is packaged in siphons and glass bottles.

The brewery's production capacity is 2,000 liters of beer per production batch, with a frequency of 4 batches per week and an efficiency level of approximately 89%.

La Esquina Brewery

La Esquina Brewery is a microbrewery located in El Hatillo, Miranda, Venezuela. The production plant is approximately 15 square meters and has a single level. The plant has a production capacity of 800 liters per batch, and a frequency of between 2 and 4 batches per week depending on demand.

The production process is divided into the following phases:

- Receipt of raw materials: The raw materials used are a mixture of domestic and imported ingredients. The ingredients received are water, malt, hops, and yeast.
- Malt milling: The malt grains are crushed using the rollers of a mill.

- Mashing: The crushed malt is mixed with hot water to convert the starch into sugars.
- Filtering the wort: The wort is filtered to separate it from the spent grain.
- Boiling: The wort is boiled with hops to give the beer its bitterness and flavor.
- Fermentation: The wort is cooled and yeast is added, which ferments the sugars to produce alcohol and CO_2.
- Maturation: The beer is left to rest at low temperatures to remove solid residues.
- Packaging: The beer is packaged in siphons or glass bottles.

The technology used at Cervecería La Esquina is very poor; it does not use PLC software or hardware, or any type of programmable equipment.

As can be seen, the production processes of the three companies visited are identical, with only the magnitudes of the variables and the terminology of the equipment used changing. Therefore, the craft beer production process can be summarized using the block diagram shown in Figure 1.

Figure 1. Block diagram of the craft beer production process.

Source: own elaboration (2022).

Now that we have a graphical reference for the process, we can determine the variables present in each of the process phases. Table 1 summarizes each stage with the variables present in each one.

Table 1. Stages and variables of the production process of the companies analyzed.

Variables/Stages	Milling	Maceration	Must filtration	Cooking	Fermentation and maturation	Packaging
Volume		■	■	■	■	■
Weight	■					
Moisture	■					
Grain size	■					
PH		■	■	■	■	
Temperature		■	■	■	■	
Time		■	■	■	■	
Density		■	■	■	■	
Salts present					■	
Yeast (cells per ml)					■	

Source: own elaboration (2022).

Control points that guarantee product traceability

To determine the control points that guarantee product traceability, the critical variables found at each stage of production were taken into account. When these variables are outside their normal conditions, it causes a loss of control in the entire process, directly influencing the production and quality of the products obtained.

Table 2 summarizes the production stages and variables appropriate for ensuring product traceability. As determined in the companies analyzed, the production processes of the three companies are identical, except for the values of each variable. Therefore, in this case, the values obtained during the visit to Cervecería Norte del Sur will be taken as a reference.

Table 2. Control points that ensure product traceability.

Stages	Variable	Values
Milling	Moisture	3% - 10
Maceration	Temperature	63ºC - 70ºC
Must filtration	Density	≈ 1,090 g/ml
Cooking	PH	4.3 - 5.2
Fermentation and maturation	Temperature	Lager beer (5ºC - 10ºC) Ale beer (17ºC - 19ºC)
Packaging	Volume / Date of packaging and shipment	-

Source: own elaboration (2022)

Quality control is a systematic process used to ensure that a product or service meets established requirements. In the case of the beer brewing process, quality control is essential to ensure that the final product has the desired characteristics in terms of taste, aroma, color, and stability.

These variables in beer production are:

- During milling: moisture, to guarantee the quality of the flour that will be obtained and predict the degree of grinding.
- During mashing: temperature, to ensure that the enzymatic and biochemical processes necessary to obtain the sugars contained in the malt starch take place.

- In wort filtration: density, to ensure the purity of the wort and the extraction of the properties of the residue.
- During cooking: pH and temperature, to ensure the solubility of compounds and prevent the release of tannins.
- During fermentation and maturation: temperature, to ensure beer stability, flavor development, alcohol content, and precipitation of solid residues.

There are also three stages of the production process with great potential for the placement of quality control points:

- At the end of milling: to verify the quality of the malt husk grinding.
- At the end of wort filtration: to verify the purity of the wort.
- At the end of fermentation and maturation: to verify that the temperatures used were correct and that the properties of the raw material were extracted to the maximum.

The implementation of quality control points in the beer-making process ensures that the final product meets the established requirements and is of the highest quality.

Analysis of the adoption of the main advantages offered by blockchain technology

Blockchain

Table 3 summarizes five of the main advantages of implementing *Blockchain* technology. We will analyze whether these advantages would be adopted and add value when implementing them in the craft beer industry's manufacturing process.

Table 3. Analysis of the adoption of the main advantages offered by Blockchain

Advantage of Blockchain	Description	Justification
Multiple participants	Process involving several participants who must interact with each other and seek to do so in a secure and reliable manner.	Applying Blockchain to manufacturing will allow different participants in the process to securely record data. (Those in charge of each stage of production and the master brewer).
Immutability of data	Blockchain does not allow the manipulation, replacement, or falsification of data stored on the network.	The aim is to increase consumer confidence. With Blockchain, there would be a data record that guarantees that the data has not been manipulated.
Data integrity	Blockchain guarantees the accuracy of the data transported or stored.	Data on the network will not be vulnerable to subsequent modification. Manual or sensor- based data records will be stored accurately and cannot be modified.
Instant traceability	Blockchain creates an audit trail that documents the origin of an asset at each step of its journey (IBM, n.d.).	Using blockchain in manufacturing will allow process traceability to be shared directly with customers.
Integration with IoT	Blockchain will enable the creation of more secure networks, in which IoT devices are reliably interconnected.	With the use of Blockchain, all sensor information could be recorded via IoT.

Source: own elaboration (2022)

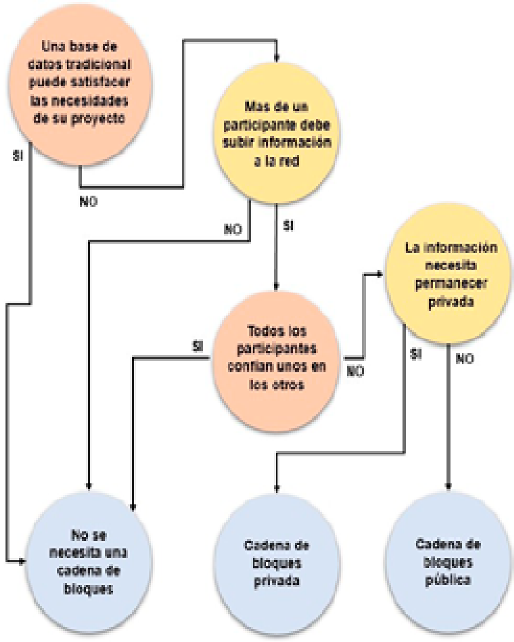
It can be determined that by applying *Blockchain* to the manufacturing process, the main advantages of this type of database will be adopted and add value.

Flowchart for evaluating the type of *Blockchain* to use

Flowcharts were identified as the basic methodology that most studies used to help make decisions about the type of *blockchain* to use in their attempts to adopt the technology in commercial and industrial contexts.

Figure 2 shows the flowchart that will help differentiate between three decision options: private or public blockchains.

Figure 2. Flowchart to determine the type of blockchain (public or private)



Source: own elaboration (2022)

In principle, as mentioned in the previous section, it can be established that the aim is to provide an extra level of trust in the network that a traditional database would not provide. Therefore, we consider that it would not be sufficient to meet the needs of the project.

Following the flowchart, we establish that more than one participant must upload information to the network (process managers, master brewer), and we consider that they do not trust each other in order to provide an extra level of trust in the network. Taking into account that the information must remain private, it is finally determined that the blockchain to be used must be private.

Analysis of *Blockchain* solutions

There are currently different platforms that allow you to create projects and solutions based on *Blockchain*. When creating such a solution, it is important to determine which platform is most suitable to use, so a comparative analysis of the main platforms was decided upon.

To analyze these platforms, different comparison criteria were established (type of Blockchain, consensus mechanism, programming language, smart contracts, license, license cost, transaction cost, and energy consumption) with the aim of determining which *Blockchain* platform is the most suitable for use in the implementation proposal. The analysis carried out is presented below.

Type of *Blockchain*

First, Table 4 analyzes the type of *blockchain* to determine who can run a node within the network.

Table 4. Blockchain type

Platform	Public	Private
Bitcoin		
Ethereum		
Corda		
Hyperledger Fabric		
Multichain		
Quorum		
Polygon		

Source: own elaboration (2022).

Bitcoin, Ethereum, Corda, and Polygon are public blockchains, where anyone can run a node on the network. In some systems, they can do so anonymously, and no one knows for sure who is running it.

In contrast, *Hyperledger Fabric, Multichain*, *and Quorum* are private blockchains, restricting membership to only known entities and creating different levels of access to data in the system.

Consensus mechanism

There are different types of consensus mechanisms that work to achieve similar objectives, ensuring the security and integrity of the network they support. Table 5 below shows the consensus mechanisms used by each *Blockchain* platform analyzed.

Table 5. Consensus mechanism.

Platform	Consensus algorithm
Bitcoin	*Proof of work* (PoW)
Ethereum	*Proof of Work* (PoW)
Corda	*Single Notary, Raft*
Hyperledger Fabric	*Practical Byzantine Fault Tolerance* (PBFT) / *Proof of Authority* (PoA)
Multichain	Similar to *Practical Byzantine Fault Tolerance* (PBFT)
Quorum	*IBFT*
Polygon	Proof of Stake (PoS)

Source: own elaboration (2022).

The consensus mechanism to be chosen depends on the system requirements and the objectives to be achieved with the *Blockchain*.

Smart Contracts

Most Blockchain platforms did not provide the additional capability to execute logical actions. As systems evolved, the ability to allow network participants to automate actions became a common feature (*Mercy Corps*, 2019). Table 6 shows which systems support smart contracts and the compatible programming languages:

Table 6. Use of smart contracts and programming languages.

Platform	Allows the use of smart contracts	Smart contract programming language
Bitcoin	NO	*N/A*
Ethereum	YES	*Solidity, Vyper*
Corda	YES	*Java, Kotlin*
Hyperledger Fabric	YES	*Go, Node.js, Java*
Multichain	NO	*N/A*
Quorum	YES	*Solidity, Vyper*
Polygon	YES	*Solidity, Vyper*

Source: own elaboration (2022).

Ethereum, Corda, Hyperledger Fabric, Quorum, and Polygon are *blockchain* platforms that allow smart contracts to be executed in at least two different programming languages. In contrast, *Bitcoin* and *Multichain* do not allow smart contracts to be executed.

License

Table 7 shows the licenses related to each of the platforms in the analysis.

Table 7. License.

Platform	License
Bitcoin	*MIT License*
Ethereum	*GPLv3*
Corda	*Apache 2.0*
Hyperledger Fabric	*Apache 2.0*
Multichain	*GPLv3*
Quorum	*GPLv3*
Polygon	*Apache 2.0*

Source: own elaboration (2022).

In general terms, *MIT* licenses and *Apache* licenses are more permissive than the GPL family of licenses and show broader compatibility. (*Mercy Corps*, 2019).

Most of the platforms analyzed are open source, meaning they do not incur license fees, with the exception of *Corda and Multichain*, which have an open source version and a paid version.

In general, public *Blockchain* platforms generate a cost per transaction carried out on the network. For example, in the case of *Bitcoin* and *Ethereum*, they generate a transaction cost of $0.39 and $0.18, respectively. In contrast, private platforms such as *Hyperledger Fabric, Multichain*, and *Quorum* do not generate transaction costs.

After studying the technical architecture and feature set of each *Blockchain* platform, it can be established that these systems are very competitive.

All platforms offer administrators considerable flexibility in the selection of programming languages, with Go, Java, and Python standing out as the most common options.

In terms of licensing, MIT and *Apache* licenses were found to be more permissive and compatible than the GPL family of licenses. All platforms provide open source licenses, with the exception of *Multichain* and *Corda,* which offer a dual license.

In terms of transaction cost, private platforms perform best because they do not generate associated costs. On the other hand, all platforms generate low energy consumption except for *Bitcoin* and *Ethereum*, due to their *PoW* and *PoS* consensus mechanisms.

When choosing a *blockchain* platform, a private platform should primarily be considered, based on the flowchart analyzed previously. Therefore, *Bitcoin, Ethereum, Corda*, and *Polygon* are ruled out.

Based on the aspects studied and because it is one of the most recognized and easily accessible pioneering applications, does not incur transaction costs, and is convenient in terms of licensing, energy consumption, programming language, and other related aspects, the use of *Hyperledger Fabric* is proposed as the solution provider for creating a decentralized *Blockchain-based* application.

Table 8 provides a summary of all the features that were analyzed for the proposed solution.

Table 8. Features of the proposed Blockchain solution: Hyperledger Fabric.

Hyperledger Fabric	
Blockchain type	Private
Consensus Mechanism	*Practical Byzantine Fault Tolerance (PBFT) / Proof of Authority (PoA)*
Programming language	*Java, JavaScript, Python, Go*
Smart contract	Yes
Smart contract programming language	*Go, Node.js, Java*
License	*Apache Version 2.0*
License cost	N/A
Transaction cost	N/A
Energy consumption	Low

Source: own elaboration (2022).

Blockchain integration architectures with IoT

Detailed research was conducted on *Blockchain* systems built on a secure, modular, and easily scalable and implementable IoT architecture for recording manufacturing data, compatible with current industrial environments and with the present case study, the manufacturing process of the craft beer industry.

Based on the research, their architectures will be analyzed, detailing the materials, tools, and human resources necessary to propose an implementation model in the manufacturing process of the factories analyzed.

The research on the proposed architectures must have the following characteristics:

- Applicability to the manufacturing process of the craft beer industry based on the requirements sought. Detailed description of materials and tools.
- Detailed explanation of how the architecture works.
- Preferably, the architecture should be based on a manufacturing process.

Table 9 shows the research on proposed *Blockchain* and IoT architectures that meet the above criteria and could therefore be used as a reference for the implementation model in this document, based on the characteristics described. The table shows a decision matrix based on the factors mentioned above to determine which architecture will be taken as a reference.

Table 9. Decision matrix for proposed Blockchain & IoT architectures

Research/ Selection criteria	The proposed architecture proposed could be used for the present research	The research explains in detail how the architecture.	The research details the tools and materials used in the architecture.	The architecture presented is based on a manufacturing process.
Design and Implementation of an Integrated IoT Blockchain Platform for Sensing Data Integrity (Hang et al. 2022).	SI	YES	YES	NO
A Review of Blockchain in the Internet of Things (Atlam et al. 2022)	YES	YES	YES	NO
Blockchain application for security of data from the internet of things (Reyes, 2018).	YES	YES	YES	NO
High-performance Blockchain system for fast certification of manufacturing data (Costa, et. al. 2022).	YES	YES	YES	YES

Source: Own elaboration (2022)

Description of the proposed architecture

Costa, D., Teixeira, M., Pinto, et al. 2022, in their research article, propose a high-performance *Blockchain* system for rapid certification of manufacturing data. They claim that the proposed system increases security, trust, and transparency throughout the value chain during the tracking of products and processes.

The proposed architecture is described and explained in detail below.

Architecture layers.

The architecture is divided into a four-layer platform:

- Field detection layer.
- *Blockchain* and storage layer.
- Network and security layer.
- User layer.

Each layer works independently of the others. Communication between layers is carried out via APIs (*application programming interfaces)*. APIs can be grouped in three ways:

Field detection layer

The field detection layer is the lowest level of the network and the one with the highest abstraction from users, as end users do not have immediate access to details related to this layer. It specifically deals with data collection from the field using sensors and identification devices, where information about the product, process, identification, and location is collected, enabling complete traceability.

Blockchain and storage layer

This layer consists of two functions that are essential for the architecture to function:

1. Data validation by *mining nodes.*
2. Storage of validated data.

It should be noted that the network is not rigid, in the sense that it must be capable of removing or deploying new nodes, adjusting the architecture to the current needs of the company.

Network and security layer

The network and security layer involves all the underlying technologies related to the secure operation of the network, such as the implementation of cryptographic tools, transaction encryption, and blockchain validation mechanisms for the creation and approval of new blocks.

User layer

At this layer, validated users have access to the collected records, which are constantly received from the APIs. Two types of user permissions are considered, each representing a different version of the interface: private permissions and public permissions.

Private permissions are only granted to internal users, who have a higher level of access to the information stored on the network. Public permissions are given to external users, such as suppliers and end consumers.

- *Sensors/Gateways*.
- *Field/Blockchain.*
- *Blockchain/User.*

Node Features

Network nodes can perform two functions: administrative responsibilities or block mining. Mining nodes are responsible for creating blocks (miners) and can be implemented in multiple stages of a production line, departments, factories, or even organizations.

As the number of mining nodes increases, so does the overall trust of the network, because there are more entities to validate and share the common ledger. On the other hand, administrator nodes are reserved for the entity that fundamentally has power over the network. The characteristics of the nodes are described below:

1. Administrative responsibilities: The main functions performed by the Blockchain Administrator include managing the flow of messages between the various layers and nodes and validating user access to the network. The administrator node can perform tasks such as registering a new mining node or gateway on the network.

2. Block mining: They are responsible for creating new data blocks, according to the rules implemented in the network.

The proof-of-work (PoW) blockchain consensus algorithm was considered for application in the proposed architecture; however, considering the authorized nature of the network and the trade-off between performance and security, it is not advantageous. Therefore, blocks are approved according to the proof-of-authority (PoA) consensus algorithm, taking advantage of the high level of trust that can inherently be found in an authorized private network and producing much higher data performance.

Implemented APIs

The set of APIs created is classified according to the layers they interface with.

Sensor/gateway

Used only for data transport between IoT and sensing devices with wireless capabilities and *gateways.*

Field/Blockchain

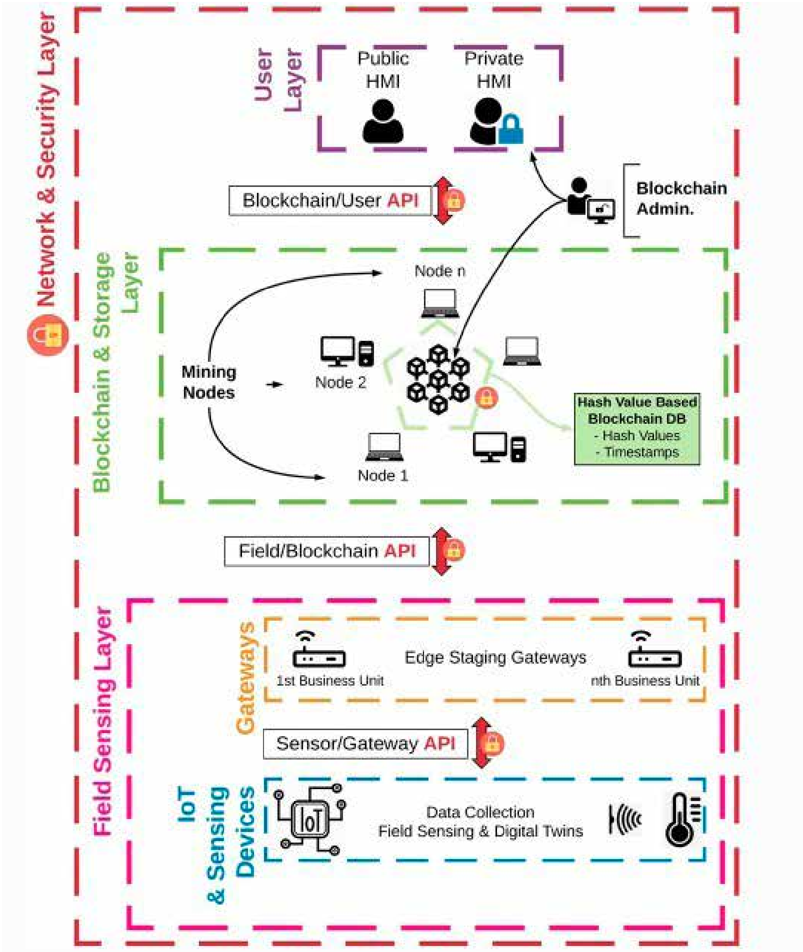
The APIs that act on this group are responsible for maintaining the functionality of the blockchain. Gateways must send payload values to mining nodes, initiating the block mining procedure. The *Blockchain* administrator will send a mining request and wait for confirmation from the remaining nodes in the network. If a block is not accepted by the nodes, an error response is returned.

Blockchain/user

This group of APIs allows users to control and retrieve information from the *Blockchain* network.

Figure 3 illustrates the layers and APIs of the architecture.

Figure 3. Layers of the architecture proposed by Costa, et al. (2022)



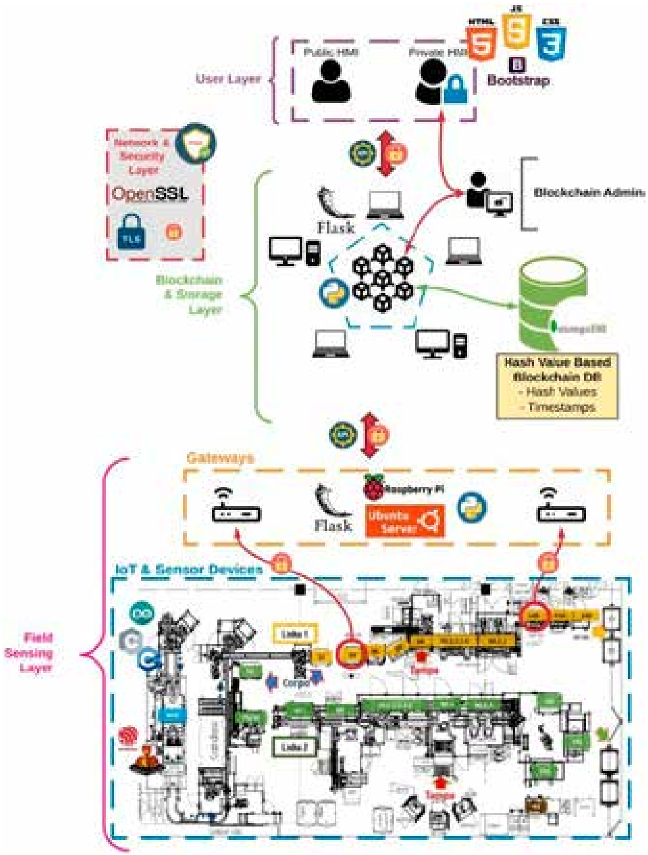
Source: Costa, et al. High-performance Blockchain system for rapid certification of manufacturing data (2022).

Potential list of basic equipment to be used and its characteristics

After studying the functioning of blockchain technology and the existing architectures that can be applied in the implementation proposal of this research, we proceed to detail the materials, tools, and human resources necessary for implementation.

Following the implementation scheme studied, we analyze the equipment to be used in the field detection layers and the *Blockchain* and storage layer. A wide range of technologies were used in terms of both hardware and software solutions. Figure 4 below shows the description of the architecture proposed by Costa, et. al. (2022), detailing the different components used.

Figure 4. Hardware and software used in the architecture proposed by Costa, et al. (2022).



Source: Costa, et. al. High-performance blockchain system for rapid certification of manufacturing data (2022).

Figure 6 highlights that the components used in the field detection layer consist of Arduino ESP32s that connect to the sensors and transmit to a Raspberry PI, which functions as a gateway; and through the APIs, the information is transmitted to the *Blockchain* network and subsequently to the user layer.

The components required for use in the field detection layer are described below.

1. Field detection

In principle, it will be necessary to measure each of the variables involved in the production stages, which were determined in previous sections. These variables are summarized in Table 11.

Table 11. Variables to be measured at each stage of production.

Production stage	Variable to be measured
Grinding	Moisture
Maceration	Temperature
Must filtration	Density
Cooking	PH
Fermentation and maturation	Temperature

Source: own elaboration (2022).

These variables will be recorded using sensors installed in the production plant, which must be connected to a PLC that can handle six analog signals. Therefore, we propose using the Schneider *Electric* SR3B262BD PLC. With regard to the quality certification stages, it is necessary to use a contactless RFID card reader.

These elements must be connected to an ESP32 microcontroller, which will transmit the information to a Raspberry Pi Model B, with 1 GB of memory and an *Ubuntu Server* 18.04 LTS operating system, which will function as a gateway to transmit the information to the Blockchain network via the API.

In summary, the field detection layer will require:

- Schneider *Electric* SR3B262BD PLC.
- Contactless RFID card readers for each stage of quality certification.
- ESP32 microcontroller.
- *Raspberry* Pi Model B.

It should be noted that, for the layers to function, an internet connection is required at all times.

2 Blockchain Network

For the development environment for the Blockchain IoT network, all programming, network configuration, APIs, and any related aspects, we recommend using a CPU or laptop with an Intel Core i5-8500 @ 3.00 GHz processor, 16 GB of RAM, and Ubuntu Linux 18.04.1 LTS operating system. Furthermore, as mentioned above, the use of the *Hyperledger Fabric Blockchain* solution is recommended.

With regard to the node network, as previously studied, creating a *Blockchain* network requires more than one machine for the proposed solution to be a distributed network. Therefore, the node network implemented by Reyes (2018) in the proposed architecture of his research entitled "Application of *Blockchain* for IoT Data Security" will be taken as a reference, where he proposes to configure a decentralized network with three virtual machines, considering Google Cloud to be a good alternative to work with due to the good service they offer. It is recommended that the virtual machines meet the following specifications: *Intel Haswell* vCPU, 3.75 GB of memory, 80 GB hard drive, and Ubuntu 16.04 LTS ADM Xenial operating system. In addition, the use of *the Proof of Authority* consensus algorithm is recommended, given its feasibility in the architecture proposed by *Costa et al. (2022).*

In summary, the Blockchain network will require

- A CPU for programming and the development environment for the *Blockchain* IoT network IoT.
- *Hyperledger Fabric Blockchain* solution
- Node network consisting of 3 virtual machines, using Google Cloud as the service provider.

Implementation model

The implementation of Blockchain in the craft beer industry would improve the traceability of the manufacturing process, which would help reduce product counterfeiting and adulteration.

The proposed solution consists of two interfaces:

- Consumer interface: Consumers can scan a QR code on the beer bottle to view information about the manufacturing process. The information displayed will depend on the company.

- Interface for process participants: Process participants can enter records into the blockchain, such as raw material information or quality test results.

The distributed database where the records are stored is a private blockchain, which allows node permissions to be managed.

To implement this solution, a team of programming and automation experts is required.

A consumer scans the QR code on a beer bottle. The mobile application displays the following information:

- Bottling date
- Brewery
- Type of beer
- Ingredients
- Manufacturing process
- Quality testing

Consumers can verify the information on the blockchain to ensure that it is correct.

Example of how it works

The data will be recorded by production batch, so all beers belonging to that production batch will have the same information and will be recorded in the order and at the moment each stage of production is carried out.

Data recording: Raw materials

Figure 5. Block diagram. Data recording: Raw materials.

Source: own elaboration (2022).

During the raw material selection stage, the area manager will use the process participant interface to enter the data relating to the raw material to be used, in order to upload it to the *Blockchain* network. Example: *Mosaic* Hops | *Cryo Hops brand*| *Alpha* 22.1% | *Beta* 6.5% | Total *Oil* 1.9%.

Data recording: Malt milling

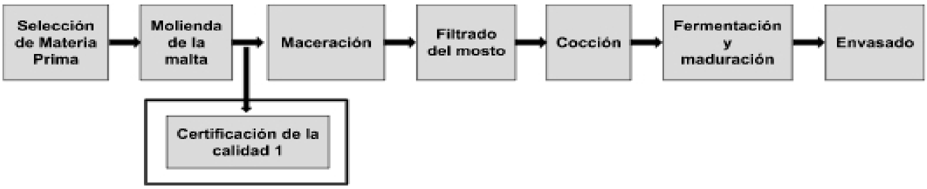
Figure 6. Block diagram. Data recording: Malt milling.

Source: own elaboration (2022).

In this process, moisture data will be recorded using the following criteria as a reference: moisture percentage, using values in the range of 3% to 10% as a reference. Data will be recorded using a moisture sensor and the information will be stored on the network. Example: *Pilsen* malt | 4% moisture.

Quality certification process 1

Figure 7. Block diagram. Data recording: Quality certification 1.



Source: own elaboration (2022).

In the quality certification process 1, the master brewer will validate that the level of pulverization of the husks is correct. If it meets the quality requirements, he will certify it using an RFID sensor, which will upload the time and date of approval to the network.

Data recording: Mashing

Figure 8. Block diagram. Data recording: Maceration.

Source: own elaboration (2022).

During the maceration stage, temperature data will be recorded, taking values in the range of 63°C to 70°C as a reference. Data will be recorded using a temperature sensor and the information will be stored on the network.

Data recording: Must filtering

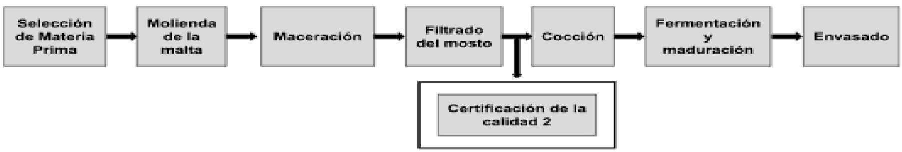
Figure 9. Block diagram. Data recording: Must filtering.

Source: own elaboration (2022).

In this process, density data will be recorded using the following values as a reference: ≈ 1.090 g/ml (without falling below 1.05 g/ml or exceeding 1.1 g/ml). Data will be recorded using a density sensor and the information will be stored on the network.

Quality certification process 2

Figure 10. Block diagram. Data recording: Quality certification 2.



Source: own elaboration (2022).

In the quality certification process 2, the master brewer will validate the percentage of solid residues contained in the wort. If it meets the quality requirements, he will certify it using an RFID sensor, which will upload the time and date of approval to the Network.

Data recording: Brewing

Figure 11. Block diagram. Data recording: Cooking.

Source: own elaboration (2022).

During the cooking process, pH data will be recorded using the following values as a reference: acid pH (4.3 - 5.2). The data will be recorded using a pH sensor and the information will be stored on the network.

Data recording: Fermentation and maturation

Figure 12. Block diagram. Data recording: Fermentation and maturation.

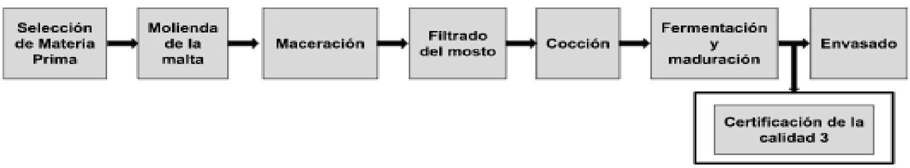
Source: own elaboration (2022).

During the fermentation and maturation stage, temperature data will be recorded using the following values as a reference, depending on the type of beer being produced:

- Lager beer (5ºC - 10ºC)
- Ale (17ºC - 19ºC

Quality certification process 3

Figure 13. Block diagram. Data recording: Quality certification 3.



Source: own elaboration (2022).

In the quality certification stage 3, the master brewer will validate that the density of the beer is within the range specified in the recipe. If it meets the quality requirements, he will certify it using an RFID sensor, which will upload the time and date of approval to the network.

Data recording: Packaging

Figure 14. Block diagram. Data recording: Packaging.

Source: own elaboration (2022).

During the packaging stage, the area manager will use the process participant interface to enter the data relating to the packaging date and upload it to the *Blockchain* network.

Summary of the text on the visualization of the craft beer manufacturing process

Blockchain technology can be used to improve the traceability of the craft beer manufacturing process. This would allow consumers to know the origin of the beer in a reliable and legitimate way.

The text proposes a solution for visualizing the craft beer manufacturing process using Blockchain. The solution is based on the following architecture:

- Raw materials: Information on raw materials is stored on the Blockchain network.
- Production processes: Critical variables in the production processes are measured by sensors and transmitted to the Blockchain network.
- Quality certification: The master brewer performs a quality certification and uploads it to the Blockchain network.
- Packaging: The packaging date is recorded on the Blockchain network.

Consumers can view information about the manufacturing process by scanning a QR code on the beer bottle.

The proposed solution has the following advantages:

- Transparency: Consumers can reliably and legitimately trace the origin of the beer.
- Immutability: Information about the manufacturing process is recorded on the blockchain network and cannot be modified.
- Accessibility: Consumers can easily view information about the manufacturing process.

Figure 15. Example of final result (bottle scan).

Source: own elaboration (2022).

During the product scan, interesting data could be generated for manufacturing companies, which could obtain an ad hoc record of these queries and detect purchasing patterns that could be evaluated with *data mining* or *machine learning* to obtain interesting market information and generate product research with the data generated in each query.

Finally, this study demonstrates that the application of blockchain in craft brewing would be a tool for traceability, security, and the possibility of studying the ad hoc market.

Conclusions

Blockchain is a technology characterized by its transparency, immutability, and data integrity. These properties make it a suitable tool for improving the traceability of the manufacturing process in the craft beer industry.

The use of Blockchain in this industry would allow consumers to know the origin of beer in a reliable and legitimate way, which would help reduce counterfeiting and adulteration of products.

To implement Blockchain in the craft beer industry, it is necessary to integrate it with IoT technology to record the variables involved in the production stages. The most suitable equipment for this integration are PLCs, microcontrollers, Raspberry Pi, and Hyperledger Fabric.

The proposed solution would allow producers to guarantee the quality of their products and comply with production processes. In addition, it would be economically viable.

- Blockchain is a technology that can improve the traceability of the manufacturing process in the craft beer industry.
- The use of Blockchain would allow consumers to know the origin of the beer in a reliable and legitimate way.
- To implement blockchain in the craft beer industry, it is necessary to integrate it with IoT technology.

Recommendations

One of the aspects determined during the research is that most companies that use *Blockchain* do so in their supply chain and not just in a manufacturing process. When *Blockchain* is used as a database in a single organization, the consensus algorithm implemented by this *Framework* is not fully exploited. It is recommended to have at least two different organizations that carry out transactions and record information, for example, between manufacturers, suppliers, and customers, where there is no trust between the parties and consensus mechanisms are ideal for this. However, implementing *Blockchain* only in a manufacturing process is entirely feasible and brings with it a host of benefits. Finally, it is recommended that a detailed study of the integration architecture of *Blockchain Hyperledger Fabric* with IoT be carried out by a team of experts and specialists, as well as the possibility of using it to generate ad hoc craft beer market data.

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