Tracing Sustainability Indicators in the Textile and Clothing Value Chain using Blockchain Technology

Luis Alves*‡, Estrela F. Cruz*†, and A. M. Rosado da Cruz*†
* ADiT-LAB, Instituto Politécnico de Viana do Castelo, 4900-348 Viana do Castelo, Portugal
† ALGORITMI Research Lab, Universidade do Minho, Guimarães, Portugal
‡ Corresponding Author: luas@ipvc.pt

Abstract — **In the current days, the Textile & Clothing industry sector is one of the largest and one with the greatest environmental impact, not only due to the consumption of water and the use of toxic chemicals, but also due to the increasing levels of textile waste. In addition, this industry often resorts to countries with cheap labor where workers' rights are typically not met. The solution may involve the final consumer who, while purchasing these products, supports the entire value chain. If the final consumer chooses to buy products that are more socially and environmentally sustainable, it inspires the industry to follow this trend. For this, the final consumer must know the social and environmental indicators of the entire value chain and must trust on the information received. In this paper, Design Science Research is being used to build a system architecture capable of tracing these environmental and social indicators using decentralized and distributed technologies, like blockchain and smart contracts, to build Decentralized Applications (DApp).**

Keywords – Blockchain, Traceability, Sustainability, Textile and clothing value chain, Decentralized application, Smart contract.

I. Introduction

Climate change is largely related to the increase in greenhouse gases (GHG) in the atmosphere [1]. This increase is due deforestation and the burning of fossil fuels to sustain intense industrial, agricultural and transport activities. One of the sectors that most contributed to this increase is the in the Textile & Clothing (T&C) industry, which is currently among the largest industries in the world, and it is still growing. The globalization of the markets has made the T&C value chain extremely long and complex. The demand for cheap labor means that products (both intermediate and final products) are transported from one country to another, from the production of the raw material until reaching the final consumer [2].

The T&C sector is a major contributor to climate change, given its energy use and waste production, but also its great dependency on high-turnover/low-life-time products, which is the basis of *fast-fashion*. A sustainable approach is necessary for a textile system that would minimize the environmental and social impacts brought upon the planet.

It is important to know the environmental impact of the value chains and find a way to measure it [3]. Environmental indicators must be measured and stored, to know information about each one of the steps in the value chain.

As the complexity of the value chain increases, it becomes more difficult to track a product from raw material to the end consumer. However, it is increasingly necessary to do this tracking so that the final consumer can know the history of the product and thus make the decision about which product to buy [2].

A traceability platform allows companies and consumers to gain insights into product items or lots by linking previously recorded data. This connection generates the idea of a digital twin which consists in creating a virtual replica, fully faithful to a physical object, so that this digital model can provide all the important data and in all perspectives of use of the product [2].

Blockchain is one of the technologies that better address the various challenges posed in the value chain [4] in a Business to Business (B2B) domain through the creation of smart contracts and web decentralized applications that interact with the distributed ledger.

This work is structured according to Design Science Research (DSR) methodology. This research methodology requires the creation of innovative artifacts in order to solve a specific problem on a specific domain [5], [6]. Herein we are proposing an architecture for creating a Decentralized Applications (DApp) based on Blockchain.

This article is structured as follows: the next section covers a background review of T&C traceability platforms, as well as blockchain technology. In section III, the DSR methodology process is covered, namely how it has been used to build the artifact - at this point, the smart contract for traceability. Then, section IV presents our proposed solution for traceability on the Hyperledger blockchain, linking to off-chain non- traceability data, and section V presents a use case for using the solution. Finally, section VI concludes the paper and draws some lines of thought for future work, to be implemented on top of the proposed artifact.

II. Background Review

Traceability in a value chain is especially useful to trace the quality of the products, to ensure the authenticity of a product's origin and to provide an easy and fast way to track and locate a product to collect it in case of public health threat [7]-[9].

Traceability mechanisms allow insights upon product items or product lots through connecting data that was previously siloed. When we allocate a digital identity to materials at a product lot or item level, and follow it through a value chain, we can capture information from primary production all the way through to its ultimate use and to its disposal or re-use in the future [2].

Blockchain is a distributed database, shared by all business partners of a value chain. Each one of the business partners may

This contribution has been developed in the context of Project "STVgoDigital: Digitalização da Cadeia de Valor do Setor Têxtil e Vestuário"-PPS1 (reference POCI-01-0247-FEDER-046086), funded by FEDER (European Regional Development Fund) through Operational Programme for Competitiveness and Internationalization (POCI).

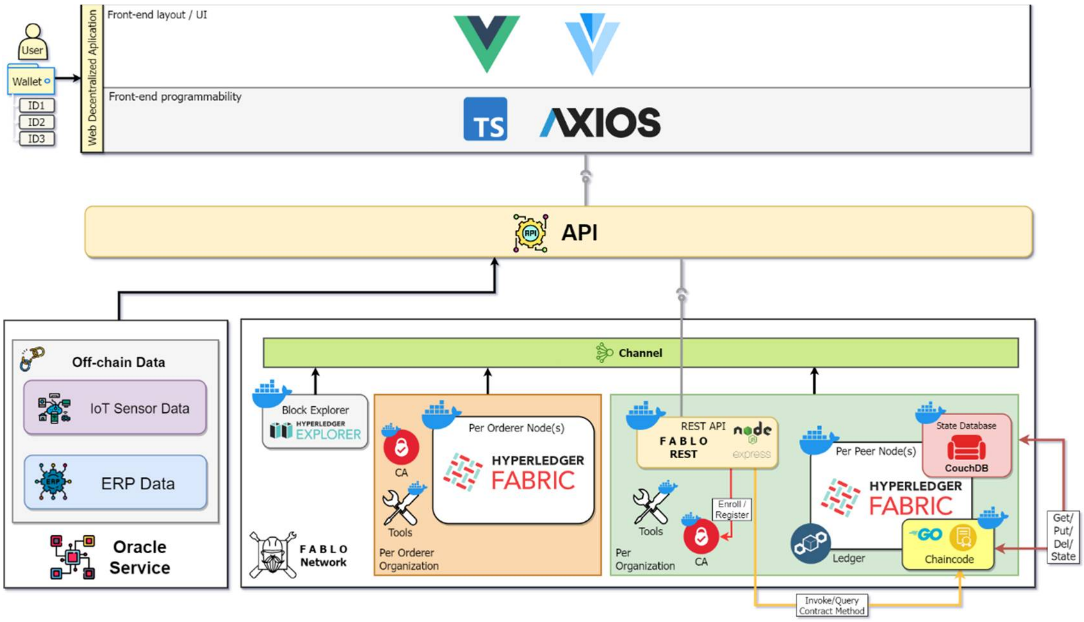

Figure 1 - Platform architecture

add information (add a block to the chain) and can consult the existing information in real time and with security [2].

Lately Blockchain is being used to trace all types of products, especially food related products as is the case of fish and fishery [10], coffee [11], wine [12], shrimp [13], etc... Some other approaches are more generic to trace any type of food, like [14], [15] and many others. In [2] the authors proposed a Blockchain-based platform to trace and assure an origin of any type of Protected Designation of Origin (PDO), Protected Geographical Indication (PGI) and Traditional Specialty Guaranteed (TSG) products.

Blockchain is also being used to trace products in other areas, like the automotive supply chain [16], wood supply chain [17], healthcare sector [18], steel [19], among others. In a more generic way, in [1] the authors proposed a Blockchain- based solution to trace the carbon footprint of any product or organization. The T&C value chain is no exception, and there are also some approaches to trace T&C products using Blockchain technology, as are the cases of:

- In [2], a state-of-the-art survey has been developed, in order to identify approaches for tracing products and product lots.
- In [20], the authors started by studying the potential of blockchain to trace the T&C value chain, and then presented a blockchain-based solution to it in [21].
- In [22], the authors proposed a blockchain-based system architecture to promote the circular economy in fast fashion by tracing clothes' reuse.
- In [23], the authors proposed a Internet of Things (IoT) and blockchain-based architecture for traceability in apparel supply chains. The authors intend to capture real-time information from different parts of textile and cloth manufacturing.
- Rinaldi el al. presents a report about "improving trace-ability of the garment and footwear industry" [24]. The authors conclude that it is necessary to create regulations, forms of measurement, and the definition of standards. In order to achieve transparency in the value chain, the participation of everyone, from governments, consumers, and all companies involved in the value chains, and the adoption of new technologies that allow traceability is necessary [24].

III. Methodology

The methodology that was followed for the elaboration of this research study is DSR. This research method approaches the development of a solution to a previously identified problem through a building/evaluation loop [5]. It is a methodology in which design is used progressively as it is tested, through the creation of an artifact. Thus, it is possible to assess which components of the artifact are suitable for solving the problem and which are not, being able to improve the artifact until reaching an adequate solution to the problem [25].

The DSR research process involves six activities [5], [6]. The first two activities, *Problem identification and motivation* and *Objectives Definition*, have been previously developed, and are the focus of the PPS1 subproject of the STVgoDigital research project (http://www.stvgodigital.pt). The main objective, in the PPS1 subproject is the development of a solution for traceability of environmental and social indicators of textile and clothing products throughout all their value chain. This should include a blockchain-based traceability platform, integrated with the business applications. And applications for the final consumers, enabling them to consult sustainability information about product lots throughout the entire textile and clothing value chain. The 3rd DSR activity, Design and development activity, involves the design and construction of the artifacts. In the current iteration, this means designing the platform architecture and developing the smart contract for the traceability core of the system. This is described in section IV. The Demonstration phase (4th activity), discusses and analyses the use of the artifacts to solve one or more instances of the problem, and the Evaluation phase (5th activity) assesses how well the artifacts support the solution to the problem. The discussion and demonstration are summarized in section V. This paper also intends to obtain feedback from the scientific community, that allows to improve the discussion in order to enhance the artifacts in future iterations. In the 6th and last DSR activity, the Communication activity, communication to management-oriented public is made, in order to trigger strategic organizational responses from the disruptions of using the created artifacts [5]. This activity is made by communicating results to the industry members of the research project consortium and obtaining their opinions and further artifacts' improving ideas.

IV. Proposed Solution

In this section, after presenting the architecture for the proposed solution in subsection IV-A, the data model for on-chain data and the smart contract for product's traceability are outlined, in subsections IV-B and IV-C, respectively.

A. Platform Architecture

Fig. 1 illustrates the full stack architecture proposed for the traceability platform, focusing on the traceability backend and the consumer front-end, and ignoring, here, the integration with business applications. This integration will be made through the same Application Programming Interface (API) as the consumer's Decentralized Application (DApp).

Starting from the backend, Fablo is a tool to generate a Hyperledger Fabric blockchain network and run its several components on Docker containers. Hyperledger Fabric is being used as the protocol provider as it is a consortium-oriented platform. This is instead of public or private platforms. Being consortium oriented, enables the definition of different participant profiles, that may respond to the needs of a value chain context. Fablo can also deploy useful containerized tools, like Hyperledger Explorer, to take an in-depth look to on-chain data, and Fablo REST, a simple Representational State Transfer (REST) API server, to call Hyperledger Fabric's smart contracts' methods and provide them to the upper layers.

Other components, provided by Fablo's Hyperleger Fabric network, are the Certificate Authority (CA) containers for registering and enrolling users on the system, and Tools' containers for various auxiliary purposes. Regarding the off-chain data integration, an oracle service can be used to input data from external sources, such as the specific IoT sensor data on which the environmental score is based on, as well as linking on-chain data to more detailed information that does not need to be on-chain for scalability purposes, such as the value chain participants detailed information. An oracle service acts as a link between on-chain and off-chain data ("real world" data), being able to input information that the blockchain doesn't have access to [26].

The language of choice for developing the smart contract (a.k.a. chaincode, in the Hyperledger Fabric), is *Go*, because it is the main supported language in Fabric, and its lightweight low-level capabilities make it ideal for smart contract development.

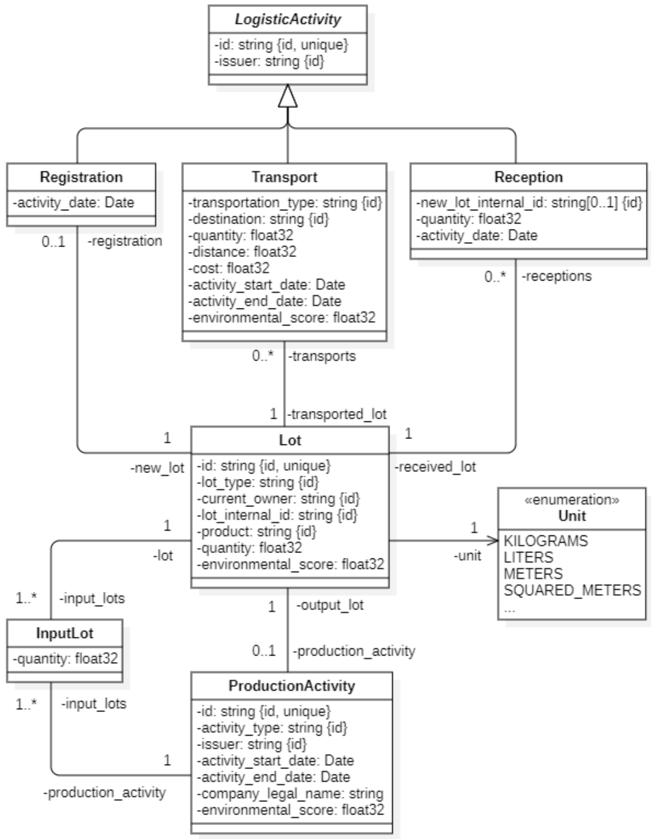

Figure 2 - Class diagram of the on-chain data model

For the Web DApp front-end, Vue.js is going to be used, because of its developer friendly ease of use, that allows for an incremental adoption, in the sense that it may be used as a library or a full-featured framework.

The activity flow of the chaincode development lifecycle is as follows:

1) The developer uses the Hyperledger Fabric's *Go* packages to build the chaincode (In Fabric, a chaincode is a collection of one or more smart contracts).

2) When a chaincode version is finalized, it is then packaged and installed on the organization peer, which will endorse a transaction or query. The chaincode definition must be approved by enough organizations, to pass the lifecycle policy.

3) If the definition consensus, usually a majority, passes within the selected organizations, the chaincode is committed to the specified channel through a transaction.

The activity flow for a user to submit or evaluate a transaction on the client Web DApp is as follows:

1) The user interacts with the Web client, which makes a request to the Fablo REST API to execute a transaction in the smart contract/chaincode. This request includes the chaincode method to invoke or query the chaincode,

TABLE I
SMART CONTRACT/CHAINCODE TRANSACTION METHODS.

TRANSACTION METHOD	DESCRIPTION	AUTOMATIC ARGUMENTS	MANUAL ARGUMENTS	OUTPUT
CreateRegActivity	Creates a Registration activity	id, issuer, activity_date	new_lot	reg_activity
ReadRegActivity	Reads a Registration activity by id	-	id	reg_activity
UpdateRegActivity[1]	Updates a Registration activity	-	id	reg_activity
DeleteRegActivity[1,2]	Deletes a Registration activity	-	id	reg_activity
CreateTranspActivity	Creates a Transport activity	id, issuer, environmental_score	transportation_type, destination, quantity, distance, cost, activity_start_date, activity_end_date, transported_lot	transp_activity
ReadTranspActivity	Reads a Transport activity by id	-	id	transp_activity
UpdateTranspActivity[1]	Updates a Transport activity	-	id	transp_activity
DeleteTranspActivity[1,2]	Deletes a Transport activity	-	id	transp_activity
CreateRecActivity	Creates a Reception activity	id, issuer, activity_date	new_lot_internal_id, quantity, received_lot	rec_activity
ReadRecActivity	Reads a Reception activity by id	-	id	rec_activity
UpdateRecActivity[1]	Updates a Reception activity	-	id	rec_activity
DeleteRecActivity[1,2]	Deletes a Reception activity	-	id	rec_activity
CreateProdActivity	Creates a Production activity	id, issuer, company_legal_name, environmental_score	input_lots, output_lot, activity_type, activity_start_date, activity_end_date, environmental_score	prod_activity
ReadProdActivity	Reads a Production activity by id	-	id	prod_activity
UpdateProdActivity[1]	Updates a Production activity	-	id	prod_activity
DeleteProdActivityy[1,2]	Deletes a Production activity	-	id	prod_activity
ReadLot	Reads a Lot by id	-	id	lot
GetLotTraceability	Lists the lot's activities, as well as its previous traceable lots' activities	-	id	lot_traceability_activities

when writing or reading data respectively, as well as the method's arguments.

2) The chaincode, which is installed on every non-orderer peer and channel, directly reads, writes or deletes the assets represented as documents on the CouchDB key-value-based database. This database contains the world state, meaning the latest and up to date representation of the items of the blockchain network's ledger.
3) If the transaction consensus passes, the ledger and the world state database update themselves (if this was an invoke/put transaction). Query/get transactions do not need consensus approval.

As for the oracle service, the off-chain data is sent to an external API that communicates with the embedded organization REST API, here represented as the containerized Fablo REST. The next subsection overviews the traceability smart contract.

B. On-Chain Data Model

The core of the traceability platform is the already mentioned traceability smart contract/chaincode. Figure 2 depicts the entity classes' diagram, or data model, of the chaincode. This represents the data to be stored in the blockchain (on-chain). This data refers to data elements stored off-chain, such as the production units and other data elements.

There are two main entity classes to consider, **Lot** and **Activity**, since these are the assets that we want to trace in the blockchain. **Activity**, not represented in the diagram in Fig. 2, represents all activities that may use and/or create Lots, and this is refined into two subclasses, namely **ProductionActivity** and **LogisticActivity**, explained below. Some class attributes have an {id} tag next to them, to classify them as identifiers of objects from other classes that are off chain, such as **issuer**, which identifies the production unit that is endorsing the activity transactions that the issuer is invoking:

- **Lot** - is the main asset to be tracked on which the value chain operations work on. The lot definition contains information about its type, current owner, an internal identifier to be used inside the production and/or company that currently owns it, the product of the lot, the quantity of the lot, the unit in which the quantity is measured, and an environmental score, which is calculated off-chain every time an activity using that lot occurs. A single lot can be related to various instances of transports and receptions, but when it comes to its creation in the system, it can only be related to either a single registration activity or a single production activity (these activities are defined below). This is due to the constraint of a lot being either produced inside the platform or outside the platform.

- **Production Activity** - is an activity that consumes lots and creates a lot, making it the only activity that can converge the history of one or more lots with a new Lot, by using them as **Input Lots**, along with a quantity to indicate how much of each input lots' total quantity is be used to produce a new single lot. The production activity has information regarding the activity type, the activity issuer (in this case, the production unit that's producing the lots), an activity start and end dates, the production unit's company legal name, the output lot that it produces and an environmental score for the activity;
- **Logistic Activity** - is an abstract class representing a logistic activity on a lot in the value chain. This class is refined into three different sub-classes, each referring to the lot it has operated on:
    - **Registration** - is a logistic activity used when a production unit wants to register a lot that is created outside of the developed system, instead of being created through a production activity, but needs to enter the value chain to be used as an input lot for production activities.
    - **Transport** - is a logistic activity used to register a shipment of a lot to another participant in the value chain. To support this functionality, this class has data related to its transportation type, distance and cost, a destination operator that must be registered in the system platform, the lot and its quantity to be shipped, the activity start and end dates, and the environmental score of the activity (because transportation has an impact on the environment just like the production activities).
    - **Reception** - is a logistic activity issued upon the arrival of lots to a production unit. This activity is required after a transport activity because the transported lot should be properly received and its quality assessed, to continue through the value chain. Data related to this activity includes the activity date, the quantity of the lot that is received and a new lot internal identifier, which may be used to reference the lot within that production unit. However, because some production units belong to the same group, this last field is not mandatory, since companies from the same group can use the same system to manage the lots within it.

C. *Smart Contract's Defined Methods*

To operate on the previously presented data model, a set of chaincode transaction methods has been defined to support the desired functionality for the platform. Table I presents these methods, which mainly support the management of the lot activities that happen on the value chain. There are also methods for reading a lot's information and its full traceability data. Some arguments are automatically filled, especially those

Algorithm 1: CreateProdActivity pseudocode

```
Input: (automatic and manual arguments of
   CreateProdActivity from Table I)
Output: prod_activity
if output_lot exists then
 | throw "lot already exists" error
end
if production_activity exists then
 | throw "production activity already exists" error
end
if production_activity.ID
  ≠ output_lot.production_activity.ID
  || issuer ≠ output_lot.current_owner then
 | throw "missing info integrity with the output lot" error
end
// Audit input_lots data
if 0 input_lots inserted then
 | throw "must have at least 1 input lot" error
end
foreach lotID, quantity in input_lots do
   if lotID does not exist then
    | throw "lot does not exist" error
   end
   lot = readLot(lotID);
   // Validate inserted quantities
   // (0 ≤ quantity ≤ lot.quantity)
   switch quantity do
      case ≤ 0 do
         throw "input lots' quantities must be greater
          than 0"
      end
      case > lot.quantity do
         throw "input lots' qty must not exceed each lot
          qty"
      end
   end
   updateLotAmount(lotID, lot.quantity-quantity);
end
createLot(output_lot);
PutState(production_activity);
return production_activity
```

with information regarding the production unit calling the transaction method, as well as the indicators/score data. Other methods need data to be manually inserted such as lots' information, quantities and other information regarding the activity. However, there are a couple of business process constraints regarding some of the methods, more specifically the ones that update or delete any type of activity. These are annotated with superscript numbers, as follows:

1) Can perform transaction if activity passed as argument has not yet ended (current date is before activity predicted end date or activity end date is null).
2) Can only perform transaction if lot passed as argument does not have further activities associated, after the activity passed as argument.

There are also internal methods for managing the lots' information, to transfer lots' ownership, update quantity and others that have not been listed in Table I. These are methods that are not callable from the defined Fablo REST API, depicted in Fig. 1, as these lots should be entirely managed through the activity methods.

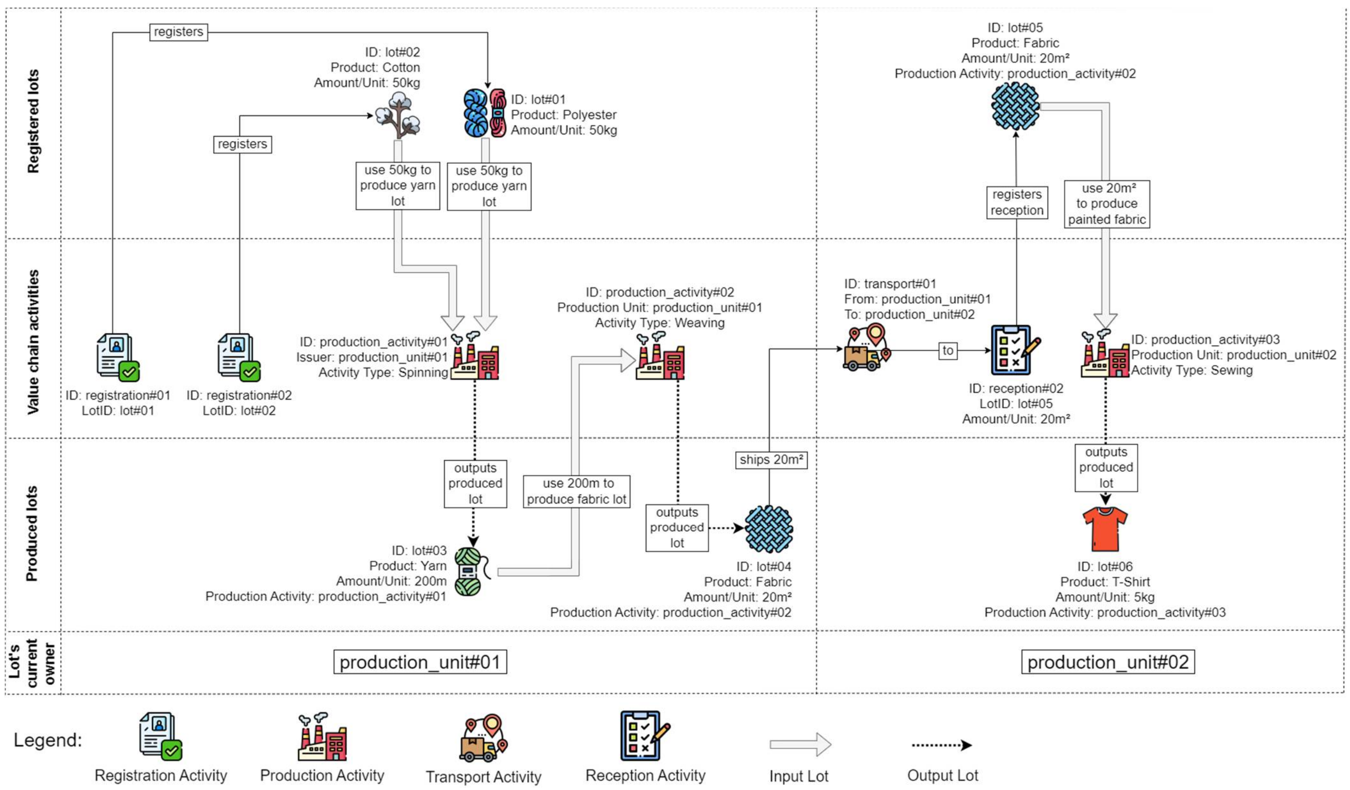

Figure 3 - Traceability case study

Algorithm 1 shows the pseudocode representation of the **CreateProdActivity** method. This method has a series of verifications and validations that it needs to go through to maintain the data integrity between the lots and their respective activities. These can be data constraints, relative to the used quantities in the production activity, or simply identifier integrity conditions, among others.

V. Discussion

To better understand how the platform provides features to support the traceability of environmental indicators of lots and activities, Fig. 3 provides a hypothetical use case of a T&C business process where two production units (#01 and #02) with different characteristics in value chain operations, collaborate to create a lot of T-shirts. The diagram reading does not need to follow a linear timeline because many lots and activities may not be sequential.

The use case may be read as follows:

1) *Production Unit #01* receives two lots from a participant outside the platform consortium and issues **Registration** activities to register both lots (cotton and polyester).

2) *Production Unit #01* then issues a **Production Activity** that uses the newly registered lots to produce a yarn lot. The entire lot of polyester is used in this production as well as the cotton one. The system responds to this by deleting both the polyester lot and cotton lot from the state database caused by the update of the lots' quantity to 0. If a lot were not to be fully used, the remaining lot quantity would be updated.

3) Then, *Production Unit #01* issues a **Production Activity** that uses the entire lot of yarn to produce a lot of fabric to be sold and used by another production unit.

4) *Production Unit #01* only works with lots up to this stage, so it will send the lot of fabric to *Production Unit #02*. For this, it issues a **Transport** activity to ship the entire lot of fabric to *Production Unit #02*.

5) *Production Unit #02* receives the lot by issuing a **Reception** activity, indicating the amount that passes the quality assessment conditions set by the consortium or production unit for that type of product.

6) *Production Unit #02* then issues a **Production Activity** that outputs the produced lot of T-shirts by using the entire lot of fabric that it had previously received.

Other value chain operations may be issued, different from the ones in Fig. 3, but as long as the lots that are produced inside the system have a **Production** activity related to them or, on the other hand, lots that are produced outside the system firstly pass through a **Registration** activity, and there are **Transport** and **Reception** activities respectively when changing production units, the platform is trustworthy and compliant for traceability purposes.

A production unit may also partially or fully return a lot, due to the criteria defined when issuing the reception activity and this would imply a return to sender transport activity, which would add to the environmental score of the lot.

VI. Conclusion & Future Work

In this paper, a traceability problem in the T&C value chain has been described, and for that a blockchain-based solution has been presented. A smart contract has been defined with a set of transaction methods for properly recording the lifecycle data of each lot in the T&C value chain. The full stack architecture of the solution has also been defined.

Future work will involve implementing the front-end web application, where the API linking to the smart contract will be consumed. The integration of the blockchain data with external off-chain databases, or the integration of IoT devices to automatically capture the manufacturing process' data to optimize the system performance, are also suggestions for future work. On the consumer side, motivation heuristics design like gamification, could be a solution to promote a circular economy of the T&C value chain. Future work will also address a consumer targeted application.

Acknowledgements

This paper and research work have been developed in the context of Project "STVgoDigital: Digitalização da Cadeia de Valor do Setor Têxtil e Vestuário", specifically in its PPS1, "ID Têxtil Sustentável e Circular 4.0" (reference POCI-01-0247-FEDER-046086), funded by the European Regional Development Fund (FEDER-Fundo Europeu de Desenvolvimento Regional) through Operational Programme for Competitiveness and Internationalization (POCI).

References

[1] A. M. R. da Cruz, F. Santos, P. Mendes, and E. F. Cruz, "Blockchain-based traceability of carbon footprint: A solidity smart contract for ethereum," in 22st International Conference on Enterprise Information Systems (ICEIS), vol. 2, pp. 258–268, SciTePress, 2020.

[2] L. Alves, E. Ferreira Cruz, S. I. Lopes, P. M. Faria, and A. M. Rosado da Cruz, "Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: A review," Waste Management and Research, vol. 40, pp. 3–23, 2022.

[3] M. Muñoz-Torres, M. Fern´andez-Izquierdo, J. Rivera-Lirio, I. Ferrero-Ferrero, and E. Escrig-Olmedo, "Sustainable supply chain management in a global context: a consistency analysis in the textile industry between environmental management practices at company level and sectoral and global environmental challenges," Environ Dev Sustain, 23, 3883–3916, 2021.

[4] A. M. R. da Cruz and E. F. Cruz, "Blockchain-based traceability platforms as a tool for sustainability," in 22st Int'l Conf. on Enterprise Inf. Systems (ICEIS 2020), vol. 2, pp. 330–337, SciTePress, 2020.

[5] E. F. Cruz and A. M. R. da Cruz, "Design science research for is/it projects: Focus on digital transformation," in 15th Iberian Conf. on Information Systems and Technologies (CISTI), pp. 1–6, 2020.

[6] A. R. Hevner, S. T. March, J. Park, and S. Ram, "Design science in information systems research," MIS Quarterly, vol. 28, no. 1, pp. 75– 105, 2004.

[7] M. Bailey, S. R. Bush, A. Miller, and M. Kochen, "The role of traceability in transforming seafood governance in the global South," Current Opinion in Env. Sustainability, vol. 18, pp. 25–32, Feb 2016.

[8] K. Kraisintu and T. Zhang, "The role of traceability in sustainable supply chain management," Master of Science in Supply Chain Management. Chalmers University of Technology, G¨oteborg. Dep. of Tech. Mngmnt and Economics, Div. of Logistics and Transp., 2011.

[9] E. F. Cruz, A. M. Rosado da Cruz, and R. Gomes, "Analysis of a Traceability and Quality Monitoring Platform for the Fishery and Aquaculture Value Chain," in 2019 14th Iberian Conference on Information Systems and Technologies (CISTI), pp. 1–6, IEEE, June 2019.

[10] E. F. Cruz and A. M. R. da Cruz, "Using blockchain to implement traceability on fishery value chain," in Proc. of the 15th International Conf. on Software Technologies (ICSOFT 2020), pp. 501–508, July 2020.

[11] F. Miatton and L. Amado, "Fairness, transparency and traceability in the coffee value chain through blockchain innovation," in 2020 Int'l Conf. on Technology and Entrepreneurship (ICTE-V), pp. 1–6, 2020.

[12] S. Cakic, A. Ismailisufi, T. Popovic, S. Krco, N. Gligoric, S. Kupresanin, and V. Maras, "Digital transformation and transparency in wine supply chain using ocr and dlt," in 2021 25th International Conference on Information Technology (IT), pp. 1–5, 2021.

[13] M. Akhtaruzzaman Khan, M. Emran Hossain, A. Shahaab, and I. Khan, "Shrimpchain: A blockchain-based transparent and traceable framework to enhance the export potentiality of bangladeshi shrimp," Smart Agricultural Technology, vol. 2, p. 100041, 2022.

[14] K. Behnke and M. Janssen, "Boundary conditions for traceability in food supply chains using blockchain technology," International Journal of Information Management, vol. 52, p. 101969, 2020.

[15] R. V. George, H. O. Harsh, P. Ray, and A. K. Babu, "Food quality traceability prototype for restaurants using blockchain and food quality data index," Journal of Cleaner Production, vol. 240, p. 118021, 2019.

[16] P. K. Patro, R. W. Ahmad, I. Yaqoob, K. Salah, and R. Jayaraman, "Blockchain-based solution for product recall management in the automotive supply chain," IEEE Access, vol. 9, pp. 167756–167775, 2021.

[17] S. Figorilli, F. Antonucci, C. Costa, F. Pallottino, L. Raso, M. Castiglione, E. Pinci, D. Del Vecchio, G. Colle, A. Proto, G. Sperandio, and P. Menesatti, "A Blockchain Implementation Prototype for the Electronic Open Source Traceability of Wood along the Whole Supply Chain," Sensors, vol. 18, p. 3133, Sep 2018.

[18] A. Musamih, K. Salah, R. Jayaraman, J. Arshad, M. Debe, Y. Al-Hammadi, and S. Ellahham, "A blockchain-based approach for drug traceability in healthcare supply chain," IEEE Access, vol. 9, pp. 9728–9743, 2021.

[19] Y. Cao, F. Jia, and G. Manogaran, "Efficient traceability systems of steel products using blockchain-based industrial internet of things," IEEE Trans. on Industrial Informatics, vol. 16, no. 9, pp. 6004–6012, 2020.

[20] T. K. Agrawal, L. Koehl, and C. Campagne, "A secured tag for implementation of traceability in textile and clothing supply chain," Int'l Journal of Advanced Manuf. Tech., vol. 99, pp. 2563–2577, Dec 2018.

[21] T. K. Agrawal, V. Kumar, R. Pal, L. Wang, and Y. Chen, "Blockchain-based framework for supply chain traceability: A case example of textile and clothing industry," Computers & Industrial Engineering, 2021.

[22] B. Wang, W. Luo, A. Zhang, Z. Tian, and Z. Li, "Blockchain-enabled circular supply chain management: A system architecture for fast fashion," Computers in Industry, vol. 123, p. 103324, 2020.

[23] K. Pal and A.-U.-H. Yasar, "Internet of things and blockchain technology in apparel manufacturing supply chain data management," Procedia Computer Science, vol. 170, pp. 450–457, 2020. 11th ANT Int'l Conf / 3rd EDI40 Int'l Conf.

[24] F. R. Rinaldi, C. D. Bernardino, V. Cram-Martos, and M. T. Pisani, "Traceability and transparency: enhancing sustainability and circularity in garment and footwear," Sustainability: Science, Practice and Policy, vol. 18, no. 1, pp. 132–141, 2022.

[25] R. Baskerville, "What design science is not," 2008.

[26] Z. Nehai and F. Bobot, "Deductive Proof of Ethereum Smart Contracts Using Why3," apr 2019.