An architecture based on blockchain technology for packaging returns: a study in the wood panel industry

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Abstract. This article aims to propose a solution for the return of packaging in the wood panel industry. The proposed solution is an architecture based on blockchain technology that supports reverse logistics to minimize waste generation in landfills and reduce costs, and resource consumption. To achieve this goal, this work was conducted in two stages. Firstly, a literature review was conducted on the fundamentals of blockchain technology, its application in sustainable supply chain management, and how blockchain architectures are structured in the literature. Once the literature was mapped, it was possible to observe that existing blockchain architectures do not address manufacturing activities regarding the return and reuse of waste through reverse logistics. Thus, the second stage of this study involved the conceptual development of a solution based on blockchain architecture for the return of packaging, considering a real scenario of the wood panel industry. As a result, the proposed architecture supports the reverse logistics of packaging for the panel industry chain, enabling the establishment of a secure technological ecosystem for real-time data transmission and material traceability, promoting waste reuse. This solution highlights the financial incentive obtained for returned and reused waste, generated through smart contracts. However, the implementation of blockchain technology faces challenges such as low awareness of recycling, disbelief in its effectiveness, and a shortage of technical capacity in the market, representing significant obstacles to its adoption in Reverse Logistics and Closed Supply Chains.

Keywords: Reverse Logistics, Production Planning, Circular Economy, ESG, Internet of Things

1 INTRODUCTION

The growing societal awareness of the importance of environmental practices in industrial activities has been driven by concerns regarding the depletion of natural resources [1]. These concerns have been validated by ESG (Environmental, Social, and Governance) practices, which emphasize the urgency of integrating environmental,

social, and governance issues into corporate management [2]. This strategic concept is based on the reuse of materials and waste with a view to the importance of reverse logistics as a key activity [3] [4] [5], contributing to the reduction of environmental impacts [6], the mitigation of natural resource consumption [7] [8], and sustainable supply chain management. On the other hand, reverse logistics and supply chains face challenges in obtaining accurate and real-time information about materials across the logistics network [6]. This landscape requires organizations to adopt new technologies and approaches [9] in which waste returns rely on reliable reverse processes, driving circularity and countering the linear model of final disposal in landfills [10].

In this context, the potential resources of blockchain technology can pave the way for recycling practices and initiatives that address the reuse of materials, thus avoiding the waste of potentially useful residues [11]. The blockchain architecture is described to minimize the challenges of reverse logistics [6], in the literature has presented some solutions and architectures based on this technology, such as Life Cycle Assessment [12] for the complexity of product tracking along the supply chain and for the secure sharing of data for LCA and Green Logistics in Supply Chains [6] to identify the precise and real-time location of a material to be recovered through reverse logistics, among others to be discussed in this study.

Given the relevance of Brazil's forest production chain to the Brazilian economy, which has shown growth above GDP in recent years, and considering the sector's concern in seeking solutions to optimize the use of waste and natural resources, focusing on circular practices, especially in the concept of the 3R (Reduce, Reuse, Recycle) [13], this study considered a wood panel industry to develop a solution based on blockchain architecture for the reverse logistics of its packaging.

This proposal was created because the previous research did not find any solutions that took into consideration using blockchain technology to return and reuse waste in manufacturing processes using reverse logistics. The study's questions were shaped by this realization: *How can blockchain technology help with reverse logistics and facilitate the recycling and return of waste from a manufacturing company?* The goal of this study was to provide a blockchain-based solution that would enable the return of packaging to the wood panel industry to address this question. Before achieving this objective, it was important to comprehend the structure of blockchain-based solutions. A proposed architecture for the reverse logistics of packaging from the wood panel industry was presented in the second stage.

This paper is organized into seven sections, with the first serving as an introduction. The work's theoretical underpinnings are covered in the second section. The section that follows presents the methodology. Section four describes the wood panel industry, while section five presents the suggested solution. Finally, the study's conclusions are given, along with the outcomes and related discussions.

2 THEORETICAL REFERENCE

The theoretical framework of this research is predicated on an awareness of the foundations of blockchain technology, its development concerning sustainable supply chain management, and the architectures of blockchain-based solutions.

2.1 Blockchain and its evolution, considering sustainable supply chain management

Blockchain technology is considered a shared and immutable ledger in a decentralized and distributed data structure [12] [14] [15] [16]. Additionally, by reducing third-party costs and facilitating real-time asset tracking, it facilitates the recording of decentralized transactions in a business network [4] [17]. An essential component of the technology's security is the hash algorithm that encrypts data in the blockchain network [18], particularly in cryptographic-based digital transactions. This lowers the possibility of fraud and data tampering for blockchain network users and boosts information security [19]. The characteristics of this technology that guarantee the resilience of blockchain networks are its distributed design, transaction verification based on consensus mechanisms, and the immutability of records, which, in turn, are based on the fundamental concepts of blockchain technology [20]. Blockchain also allows the establishment of smart contracts, acting as an intermediary for contracts between interested parties [3]. These contracts are built on codes with complex logic that aim to verify and validate transactions within the network [21]. Table 1 presents a chronological analysis of studies on the application of blockchain in supply chain management, supporting sustainable practices.

Table 1. Evolution of Blockchain in Sustainable Supply Chain Management

Year	Articles	Evolution of Blockchain in Sustainable Supply Chain Management
2018	[22], [23]	Traceability and smart contracts are used in reverse logistics operations to monitor assets.
2019	[12], [24], [25]	Digital platforms and conceptual architectures have improved security and transparency in the supply chain.
2020	[6], [14], [26], [27], [28]	Deployable architectures reduce supply chain errors by integrating blockchain with IoT and big data.

2021	[1], [3], [4], [7], [17], [22], [29], [30], [31], [32]	Reverse logistics are optimized through the connection of blockchain technology with big data, RFID, and IoT. This makes it possible to monitor products and digitize processes to support recycling and sustainable practices. Blockchain platforms facilitate the traceability of materials and waste, promoting a more efficient and environmentally conscious supply chain.
2022	[18], [33], [34], [35]	The application of blockchain technology to logistics is emphasized, with a focus on smart contract enhancement and the use of artificial intelligence and smart sensors for digital transactions.

Industry 4.0's technological advancements have led to the application of blockchain, which was first introduced as a conceptual model [22]. This has developed into implementable architectures, which are discussed in the next section, to assist supply chains in managing sustainably through the digital transformation of their operations [12] [29] [17] [32]. When combined with IoT technology, blockchain can precisely gather data in real-time thanks to an unchangeable and decentralized data structure [28] [30] that makes material tracking easier [29] and allows for precise real-time location problem-solving of materials along supply chains [36]. It can also support decentralized visibility and information sharing [14].

2.2 Deployable architectures based on blockchain technology

According to [16], the blockchain architecture's multi-layered design offers a clear arrangement of its components and the various roles that they each play. The use and application for which this architecture will be used determine the number of layers and sublayers as well as the design of the blockchain architecture [14]. Table 2 lists the blockchain-based implementable solutions that were found in this study. By analyzing these architectures, structures arranged in layers and sublayers are presented, along with the use of cutting-edge technologies pertinent to recycling procedures [12] [6] [14] [15] [16].

Table 2. Blockchain-based architectures' structures

Solution	**Architecture structure**	
	Layers	**Sublayers**
Life Cycle Assessment [12]	- Infrastructure	- Hardware - Software
	- Blockchain Services	- Services - LCA
	- Applications	

Solution	Architecture structure	
	Layers	**Sublayers**
Green Logistics in Supply Chains [6]	- Users	
	- Physical	
	- Perception	
	- Network	
	- Blockchain	
	- Management	
	- Application	
	- User	
Architecture for fast fashion [14]	- Perception	- Sensors - IoT gateways
	- Blockchain network	- Services - Data
	- Application	
	- User	
Architecture for Healthcare [15]	- Healthcare Stakeholders	
	- Access	
	- Blockchain-Cloud Integration	- Blockchain Service - Cloud Storage
Platform for pallet management [16]	- Decentralized Pallet	- Stakeholders - Terminal
	- Perception	- Pallet identification - Cyber Networks
	- Network	
	- Decentralization	
	- Services	- Cloud Services - IoT Services
	- Application	

As we did not identify studies that present the use of blockchain architectures in manufacturing activities, including real-time tracking of materials and waste through reverse logistics, a new architecture was proposed that includes reverse logistics activities for real-time monitoring. location and quantity during the return of materials and waste to manufacturing.

3 METHODOLOGY

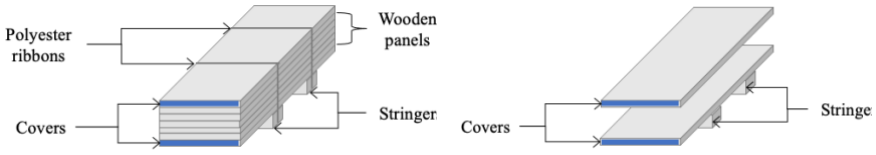
This study comprised two stages, the first being theoretical and the second being empirical. Theoretical research (1st stage), based on bibliographic research in the

Scopus and Web of Science databases, was conducted to substantiate the main themes covered in this study. Thus, studies that summarize the relationships and connections between blockchain technology and its implementation in sustainable supply chain management were mapped. The search for scientific articles in the databases considered the following expression: blockchain AND ("reverse logistics" OR "closed loop* supply chain" OR "green logistics" OR "reverse supply chain*" OR "green supply chain*" OR "circular economy" OR "sustainab* logistics" OR "sustainab* supply chain*" OR "economic sustainab*").

Once the studies on the topic were known, the second stage began, where a solution based on blockchain technology was developed for an industry in the wood panel sector called ALFA. To characterize the ALFA industry and its customer network, information was collected from Commercial Sales Management. To develop the solution, the architectures found and their structures were analyzed. After this analysis, a solution was proposed. The following section characterizes the scenario for which this solution was developed.

4 UNDERSTANDING THE WOODEN PANELS INDUSTRY CHAIN

The architecture was proposed in the context of a reconstituted wood panel industry, here called ALFA, with its linear supply chain and waste disposal in landfills. ALFA's portfolio consists of MDP (Medium Density Particleboard) and MDF (Medium Density Fiberboard) wood panels. Each package is made up of the following items: two covers, which are scrap wood panels and have the function of protecting the finished product, and stringers placed at the base of the packages to move them (see Fig. 1). The problem facing the company ALFA focuses on the impossibility of reusing packaging items allocated to customers as waste. This waste originates in the production process of the furniture industry during the activity of removing the packaging from wooden panels, which are subsequently discarded in landfills, even in good conditions for reuse. I understand the current scenario of this study.



(a) Packaged wooden panels (b) Reusable packaging items

Fig. 1. Packaged wooden panels and packaging items

5 BLOCKCHAIN ARCHITECTURE: THE CONCEPTUAL MODEL

The proposed blockchain architecture aims to change the current scenario to support a scenario with the return of packaging items (covers and stringers) via reverse logistics. As reverse logistics is the key activity in the process of returning waste to a state of reuse by manufacturing, the need for a layer responsible for manufacturing activities is evident. Based on this future scenario, the solution was proposed (see Fig. 2).

The proposed architecture is composed of four layers: Infrastructure, Blockchain-Cloud Integration, Manufacturing, and User. The infrastructure layer manages the collection, transmission, and storage of data, divided into Input (hardware) and Gateway (software). Input involves IoT, RFID, barcode, and GPS sensors to collect data at all stages of the product lifecycle. The Gateway is responsible for data pre-processing and connecting different information systems, such as warehouse planning and management, via the Internet. This structure allows for efficient integration between technological components and information systems in logistics operations.

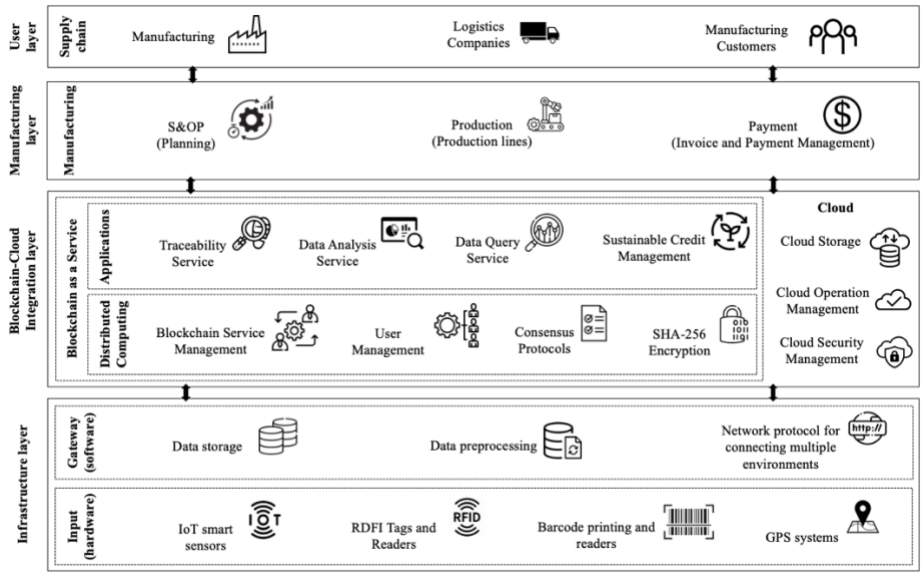


Fig. 2. Blockchain architecture for returning waste to Manufacturing

The Blockchain-Cloud Integration layer provides the services of processing and recording data relating to all phases of the product life cycle, collected by the Input sublayer and transmitted by the Gateway sublayer, and managing and providing the blockchain network as a service allocated in the cloud. This layer is composed of 2 sublayers: Distributed Computing that provides four blockchain services: (i) Blockchain Service Management, responsible for recording and processing data

provided by members of the supply chain, (ii) User Management which manages access and provision of digital signatures that are primary keys that allow users access to the blockchain architecture, (iii) Consensus Protocols, which aims to confirm the validation of a block generated by a node through consensus with the largest possible number of nodes in the blockchain network; and (iv) SHA-256 Encryption, which ensures that data sent to the blockchain architecture is protected by the SHA-256 algorithm. The Applications sublayer is made up of four applications: (i) Traceability Service that allows users to track product life cycle information in real-time (ii) Data Analysis Service which consists of processing and analyzing the data so that it can be used strategically in decision making, (iii) Data Query Service which ensures that information from Manufacturing and waste customers is recorded in databases in real-time; and, finally, (iv) Sustainable Credit Management, which is a service responsible for calculating the financial value credited to Manufacturing customers based on the return of waste in a good state for reuse. The credit calculation is carried out by a smart contract, named in this work as Sustainable Credit, and consists of the sum of the waste available for collection, multiplied by the unit cost of this waste, informed by the Manufacturing, and reduced by the freight cost of transporting the waste from the origin to the destination.

The Manufacturing layer comprises production planning activities that cover the reuse of waste received through reverse logistics, in addition to the activities of the department responsible for executing the payment of financial credits acquired by customers and generated by the Sustainable Credit smart contract. The User layer is made up of members of the supply chain who can access data shared in real-time in the blockchain architecture.

6 DISCUSSIONS ABOUT THE PROPOSED ARCHITECTURE

The proposed blockchain architecture for the return of packaging for the panel industry was inspired by the five architectures listed in Table 2, namely: Life Cycle Assessment [12], Green Logistics in Supply Chains [6] Architecture for fast fashion [14] Architecture for Healthcare [15] and Platform for Pallet Management [16].

The Infrastructure layer considered the Life Cycle Assessment [12] and the Architecture for fast fashion [14] architectures. The management of technological resources in this layer can be used to collect data [21] at all phases of the product life cycle [14], allowing reverse logistics and manufacturing to have an accurate and real-time view of the location and quantity of materials available for return [37].

The Blockchain-Cloud Integration layer observed the Architecture for Healthcare [15] and considered SHA-256 encryption [5]. The Applications sublayer was inspired by the services proposed in the architectures for Life Cycle Assessment [12], Architecture for fast fashion [14] and Green Logistics in Supply Chains [6]. The

Sustainable Credit Management proposal is a differentiator of this architecture, being carried out by a smart contract [38].

The Manufacturing layer was proposed for this architecture considering the context of the Panel Industry and it integrates with production planning activities where waste returns are reported and financial credits are recorded. And finally, the User layer, guided by the work of [12] [6] [14].

Thus, the blockchain architecture proposed in this work highlights the advantages of using a digital platform based on blockchain technology to enable secure exchanges of information about the return of materials and facilitate their traceability between interested parties [28]. Furthermore, the benefits in terms of management, traceability, and resilience to reverse logistics activities can be highlighted through their decentralized and secure nature, which protects the reliability and usability of information exchanged between the various members of the supply chain, according to [8]. In this way, the application of a blockchain architecture will serve as the necessary ecosystem for the reuse of waste [10], in this case study, of packaging items, mitigating the environmental impacts caused by the disposal of items that could be reused [31].

Therefore, the adoption of the proposed blockchain architecture can bring significant strategic benefits, supporting ESG practices, both for the company ALFA and for logistics companies and furniture manufacturers. The information exchanged about the number of covers and stringers supplied by furniture manufacturers and the expected receipt of these packaging items by ALFA is made available in the blockchain architecture. This information is received by Manufacturing and can be considered in the production planning process, in replenishing the ALFA company's raw material stocks, and, consequently, in reducing the consumption of natural resources [39]. Furniture manufacturers, in turn, benefit from the financial credits generated by the Sustainable Credit smart contract for eventual use following their strategy. Regarding logistics companies, the implementation of emerging technologies plays a crucial role in improving collection, transfer, storage, and distribution processes [35]. These benefits include: (i) optimization of vehicle fleet routing based on information automatically captured by sensors, allowing efficient strategic planning [40], in addition to fuel savings and reduction of greenhouse gas emissions [41]; (ii) improvements in the level of service, through the management of information that assists in transport planning and improving operational margins [42]; and (iii) increasing the quality of life of logistics operators, with a reduction in occupational stress [43].

7 CONCLUSIONS

Concern for sustainability and the effective management of natural resources has gained prominence globally, as reflected in the adoption of the ESG concept by companies. Within this context, reverse logistics emerges as a crucial area to promote sustainable practices. Blockchain technology, with its characteristics of transparency, traceability, and immutability, offers fundamental support to these processes. By enabling the implementation of decentralized smart contracts, blockchain facilitates the

transparent exchange of information and efficient waste management, contributing to the reduction of natural resource consumption and environmental conservation.

The integration of blockchain technology with ESG principles further strengthens sustainable supply chain management. Cryptography and smart contracts offer guarantees of privacy and reliability in reverse practices, improving companies' image and positively influencing consumer behavior. This synergy between blockchain, Reverse Logistics, and ESG principles promotes the sustainable development of organizations, making them more competitive and attractive to investors and consumers committed to environmental and social responsibility.

Despite the clear benefits, there are still challenges to be overcome, such as a lack of awareness about recycling, financial and technical limitations, and difficulties in integrating with existing systems. However, it opens up a vast field for future research that can explore sustainable business models based on blockchain technology integrated with other innovations, such as Generative Artificial Intelligence, especially concerning inventory planning and demand forecasting. This research can further boost the adoption of sustainable and efficient practices in companies, contributing to a more conscious and balanced future.

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