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# An Assessment on the Perception of the Adoption of Blockchain Technology - A Case Study in the Portuguese Textile Industry

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# Resumo

Esta dissertação tem como objetivo analisar tanto a fase de implementação da blockchain nas indústrias, como encontrar quais as características da blockchain mais valorizadas pelas empresas da indústria têxtil e da moda portuguesa. Estes objetivos são respetivamente alcançados neste documento através de dois estudos: uma revisão sistemática da literatura e um inquérito empresarial às empresas envolvidas no projeto STVgoDIGITAL, cujo objetivo é utilizar a blockchain para rastrear produtos ao longo da cadeia de abastecimento, como resposta ao Passaporte Digital de Produtos da União Europeia.

De acordo com os resultados obtidos na revisão sistemática, a indústria alimentar destaca-se como a mais forte investidora nesta tecnologia, uma vez que um número crescente de empresas dos sectores alimentar e agrícola vê a rastreabilidade dos produtos como um fator determinante para o seu sucesso num futuro próximo, contribuindo para o aumento do conhecimento dos consumidores sobre os alimentos que compram, para a mitigação do desperdício e para a eficiência na cadeia de abastecimento. Adicionalmente, as empresas agrícolas são ávidas utilizadoras da Internet-das-Coisas, algo que diversos estudos mostram ser uma ferramenta eficaz quando aliada à tecnologia blockchain.

Relativamente aos resultados obtidos no inquérito às empresas, as conclusões empíricas sugerem que a "transparência da informação" está entre as características mais valorizadas pelas empresas inquiridas e a "imutabilidade dos dados" está entre as características menos valorizadas. Adicionalmente, a maioria das empresas inquiridas acredita que a implementação de blockchain teria um impacto positivo na "rastreabilidade dos produtos". Por outro lado, este estudo também analisa as correlações entre o tipo de empresa (industrial, tecnológica e empresas com marcas), a dimensão e a escolha da adoção de blockchain e as características que foram avaliadas no inquérito. Os resultados sugerem que as marcas tendem a priorizar as características trazidas pelo blockchain acima de outros aspetos dos negócios.

# Abstract

This dissertation aims to analyze both the stage of blockchain implementation across industries and to find what blockchain features are most valued by companies in the Portuguese textile and fashion industry. These objectives are respectively achieved in this document with two studies: a systematic literature review and a business survey on companies involved in the STVgoDIGITAL project, whose purpose is to use blockchain to trace products through the supply chain, as a response to the European Union's Digital Product Passport.

According to the results obtained from the systematic review, the food industry stands out as the strongest investor among industries in this technology, as an increasing number of companies in the food and agricultural sectors view the traceability of products as a defining factor in their near future success, contributing to the increase of consumer knowledge over the foods they purchase, waste mitigation, and efficiency in the supply chain. Additionally, agricultural companies are avid users of Internet-of-Things, which some authors believe to be an effective tool when paired with blockchain technology.

Regarding the results obtained from the business survey, the empirical findings suggested that "information transparency" is among the highest-valued features in the inquired companies, and "data immutability" is among the lowest-valued features. Additionally, most of the inquired companies believe that blockchain adoption would positively impact the "traceability of products". Furthermore, this study also analyzes correlations between the type of firm (industrial, technological, and companies with brands), size, and choice of adoption of blockchain and the features that were evaluated in the survey. The findings suggest that brands tend to prioritize elements brought by blockchain higher than other business elements.

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# 1. Introduction

With the increasing popularity of Blockchain and with experimental solutions being developed around this technology, digital supply chain systems supported by blockchain technology are expected to solve several supply chain issues that have been arising in recent years, while also contributing to the digitalization of the supply chain (Sunmola, et al. (2021). The work of Yousuf & Svetinovic (2019) suggests that the emergence of blockchain technology has the potential to revolutionize the way in which supply chains operate and that it could be exploited to increase the efficiency and transparency of supply chain operations by enabling secure and transparent communication and data sharing. Additionally, the authors argue that blockchain has the potential to improve the traceability of products and services.

As this technology becomes more relevant, the question remains of how supply chains benefit from blockchain, and what stage of implementation are industries and countries currently in. Accordingly, the purpose of this thesis is to assess the evolution of blockchain implementation in a textile-based supply chain in Portugal. With this in mind, two objectives were defined for this study:

1 - Analyze the evolution of blockchain-based supply chain solutions in different industries and contexts.

2 - Assess the implementation of blockchain technology in the Portuguese textile and fashion industry's supply chain, evaluating its impact on efficiency, transparency, and traceability.

To achieve the defined objectives, two studies were conducted. Objective 1 is achieved with a systematic literature review, and Objective 2 is achieved with a business survey. Each objective contains two research questions that serve as guidelines for the studies. In Objective 1, the research questions are:

- RQ1: What is the progress, in the number of papers, of the creation or implementation of blockchain-driven supply chain solutions?
- RQ2: Which industries have adopted blockchain-driven solutions into their supply chain?

In Objective 2, the proposed research questions are:

- RQ3: Are the characteristics of information transparency, data immutability, and product traceability elements of high priority for a selection of companies in the textile sector?
- RQ4: What is the status of the adoption of blockchain technology in the Portuguese textile and fashion industry?

As such, this dissertation explores the potential of blockchain technology and its application in supply chains, by examining the key drivers and barriers of blockchain adoption. Consequently, this work draws from a range of research methods, including a systematic literature review and a business survey, to explore the potential of blockchain technology in supply chains.

The document is structured as follows. Chapter 2 provides a background on blockchain technology and includes a description of key blockchain concepts. Additionally, this chapter contains a review of related work that describes the state of the art of blockchain technology applications in various industries. In Chapter 3, a systematic literature review on papers that regard the terms "blockchain" and "supply chain" is presented, detailing the techniques and systems used for its development, as well as the results that were generated. In Chapter 4, a business survey was conducted to evaluate blockchain implementation in companies integrated into the textile and fashion industry of Portugal. Lastly, in Chapter 5 a discussion of the findings of this research is presented, and Chapter 6 provides the final conclusions of the dissertation.

# 2. Blockchain technology and real-world use cases

In this chapter, a background on the blockchain is provided, where the technology and its components, and key concepts are explained by providing a comparison between blockchain transactions to traditional transactions. In particular, this chapter overviews the blockchain application in a business and institutional context, and the application of Blockchain in the Portuguese textile and fashion industry. Additionally, it includes related work that details different research efforts where blockchain implementation is assessed in either the textile industry or any other industry.

## 2.1. Background

Although blockchain was invented in 1991 and originally used for times-tamping digital documents (Haber & Stornetta, 1991), it was popularized only in 2008 by Satoshi Nakamoto, the unknown person/entity behind the invention of the cryptocurrency Bitcoin (Nakamoto, 2008). Bitcoin's main novelty is that it is supported and enabled by blockchain technology. Bitcoin users rely solely on the mechanisms of the blockchain itself, which provide immutable, verifiable information and execute secure transactions, whereas people with bank accounts rely on banks and financial institutions to manage regulation around currency and money.

However, blockchain is applicable to a wide range of activities. Casino, et al. (2018) describes blockchain as a Distributed Open Ledger Technology (or DLT), which implies that the technology is a distributed data structure that is replicated and shared with every user of the network. This allows users to have a distributed P2P (peer-to-peer) network where members can interact with each other directly and trade assets without the need for an intermediary authority (Christidis, et al. (2016)). The architecture of blockchain consists of a digital chain of blocks that contain specific information. Each block contains:

- **Data** – the data each block contains depends on the type of blockchain that is being used. For example, Bitcoin's blocks contain information on transactions, such as information on the sender, the receiver, and the amount of bitcoin traded;

- **Hash** – a hash is a code that works as a barcode or a fingerprint identifying each block in a unique manner. Should any information inside the block change, so does the hash, which makes it easy to detect whenever there are changes to the blocks;

**A hash of the previous block** – each block also contains the hash of the previous block, creating the chain effect. If a given block's information is tampered with, its hash will change, which will make the next block's hash of the previous block change, making its own hash change, and so on until the end of the chain.

### 2.1.1. Key Concepts of Blockchain Technology

The key concepts of blockchain technology are directly correlated to the transactions that are made in a blockchain. These concepts are easier to understand when a direct comparison is made between blockchain transactions and traditional transactions. For example, an ordinary online money transaction without blockchain occurs as follows: Person A wants to send 100€ to Person B. Person A uses a 3$^{rd}$ party element to wire the transaction amount, usually an institution such as a bank. The bank takes an average of 3 business days to make the transfer and charges a fee for this service. There are three aspects of this traditional transaction that blockchain technology has the potential to dismiss: the need for a 3$^{rd}$ party institution; the time it takes to wire the transaction amount; and finally, the service fee. For this to happen, the three key concepts of blockchain first need to be explained.

Out of the 3 key concepts of blockchain technology, 2 can be found in its definition - **distributed** and **open ledger**, - and the third key concept is **consensus**.

**Open Ledger:** A ledger is a record of transactions. Most networks have ledgers that record different types of transactions between users. In a public blockchain network, however, this ledger is organized in a chain-like structure and is open to every node (computer connected to the blockchain) of the network, allowing everyone to have access to each other's information on transactions and funds, which is a driving factor that contributes to the transparency feature of blockchain technology.

**Distributed:** The second key concept of blockchain is the fact that it is distributed, meaning that every node of the network has a copy of the open ledger, instead of a centralized trusted party that holds the ledger. However, by removing the centralized ledger, a new problem emerges. Since every node has a copy of the ledger, a mechanism is necessary to ensure that every copy is synchronized and updated appropriately, to guarantee that all participants of the network see the same ledger copy. This leads to the third key concept of blockchain, consensus.

**Consensus:** When building a new blockchain, the creator is required to choose a consensus mechanism, which is a set of "methodologies used to achieve agreement, trust, and security across a decentralized computer network"[1]. Nguyen, et al. (2019) classify it as the backbone of a blockchain network, playing a key role in ensuring the network's security, integrity, and performance.

While the "open-ledger" and "distributed" concepts of blockchain are simple (but imperative) architectural features of this technology, the "consensus" concept is more complex, and its applicability changes depending on the type of blockchain and its purpose.

Consensus is essential to the blockchain because a consensus mechanism is how a given blockchain achieves Byzantine Fault Tolerance[2] (BFT) (Binance Academy, 2022). BFT is a concept that derives from the Byzantine Generals' Problem, a logical dilemma conceived in 1982 that employs an example of four Byzantine generals attempting to agree on a strategy to illustrate the decision-making process of a decentralized system. The generals need to either attack or retreat, but the strategy only works if all generals agree to it and act on it in a synchronized manner. The generals are only able to communicate through a messenger, which leads to the central issue of the dilemma that messages could get delayed, destroyed, or lost. If this dilemma is applied to the blockchain, each byzantine general represents a node of the network, and the majority of the nodes need to agree on a decision of the blockchain.

In this regard, Byzantine Fault Tolerance is a property of a system that is able to withstand the failures associated with agreement in the blockchain, so that the network keeps operating even if certain nodes fail. There are several possible solutions to this dilemma

[1] Source: https://www.investopedia.com/terms/c/consensus-mechanism-cryptocurrency.asp
[2] Source: https://academy.binance.com/en/articles/byzantine-fault-tolerance-explained

and there are many different approaches that a blockchain can take to achieve agreement and trust. They are called consensus mechanisms.

Most existing consensus mechanisms are developed for cryptocurrency and the two most predominant ones are proof-of-work (PoW) and proof-of-stake (PoS). PoW relies on "miners" (which are special nodes within the network) to validate transactions in the blockchain. Whenever users intend to make a new transaction, miners compete to validate it and to find the key that connects it to the rest of the ledger, thus continuing the chain of transactions. The first one to do so is rewarded with an agreed-upon amount of the digital currency used in their specific network. This method of consensus, however, consumes a great amount of computing power and ultimately drives miners to consume too much energy and possibly cause the deterioration of the computer.

Taking this into consideration, proof-of-stake was created. PoS detects a transaction and chooses a node called "validator"[3] (as opposed to "miner") that will validate it and find the key. If the other validators approve of the transaction, the first validator will be rewarded, just as in PoW. In order to become validators, these nodes first have to make a payment to the network, to show that they have a "stake" in the blockchain. The higher the stake, the higher the chances of being chosen to validate the next transaction. Unlike PoW, PoS does not require several nodes to use their computing power all at once, which saves up a considerable amount of energy over time.

Additionally, blockchains can be public or private. Most known blockchain networks, such as Bitcoin and Ethereum, are public, meaning that any individual with a computer can create an account and join the network. In public (or permissionless) blockchains, participants can read and write transactions (provided that the consensus protocol is followed). In private (or permissioned) blockchains, which are usually governed by a consortium of private entities or a single entity, access is limited to authorized participants only and there are often levels of confidentiality and access within the blockchain. As such, private blockchains are a better match for industries seeking to develop blockchain-based supply chain solutions.

[3] Source: https://www.investopedia.com/terms/p/proof-stake-pos.asp

### 2.1.2. Blockchain Technology in a business context

Blockchain is a technology that allows companies to fully trace all types of transactions in a secure and transparent manner. As such, there is a substantial amount of untapped potential in the application of blockchain in a business context, especially in supply chains. Supply chains currently rely on different systems and software, such as Enterprise Resource Planning systems (or ERPs), websites for business-to-business (or B2B) commerce, systems for working with subcontractors or suppliers, and Internet-of-Things (IoT) platforms, to name a few. In other words, companies that intend to integrate blockchain into their supply chains usually take these existing systems into account. Some studies indicate that ERP systems can be improved by blockchain, and that, in theory, IoT is compatible with – or even beneficial to – blockchain-based supply chain solutions.

Over the past two decades, the Portuguese textile industry has experienced a significant transformation, becoming a leading player in the global market. According to data from the Portuguese Textile and Clothing Association (ATP, 2023), the industry has seen a steady increase in exports, with an annual growth rate of 4% since 2000[4]. In 2020, the industry exported a total of €5.5 billion worth of goods, making it one of the most significant export industries in the country.

According to ATP's RoadMap of 2019, the Portuguese textile industry's success can be attributed to its ability to adapt to changing consumer demands, technological advancements, and sustainable production practices. The RoadMap also suggests that in recent years, the industry has shifted its focus to the production of high-quality and sustainable textiles, with a particular emphasis on eco-friendly materials and circular production processes. Furthermore, the industry has also invested heavily in research and development, leading to the creation of new, innovative textiles that meet the demands of a constantly evolving market.

It is important to reiterate that the consensus mechanisms previously mentioned were created purposefully for public cryptocurrency blockchains, which insinuates they are not as well suited for private blockchains, and that industries that want to implement blockchain in their supply chain tend to find other solutions to achieve consensus in the network.

[4] Source: https://atp.pt/pt-pt/estatisticas/estatisticas-2020/

Private blockchains usually look to other methods to find consensus within the network. The Hyperledger Foundation[5], hosted by the Linux Foundation, is an open-source project created for the development of enterprise-grade blockchains, and currently has 16 projects under its wing (About Hyperledger Foundation, 2022). Many projects of the Hyperledger use different consensus mechanisms depending on the network's needs and features, from the most popular PoW and PoS to Proof-of-Authority, Kafka, Solo, among others; while other projects do not offer any consensus protocol[6] (Anwar, 2021), and some even offer blockchain interoperability, referring to the ability of multiple blockchains communicating with each other, according to the work of Belchior, et al (2022).

Some are considering the adoption of a DAG (Directed Acyclic Graph) consensus mechanism (Cao, et al. (2019)), which businesses have been using long before the blockchain was created. Others have been developing solution models. For example, Hader, et al. (2022) proposed a model for the improvement of traceability and information sharing in the textile supply chain called Bigchaindb-TSC (Blockchain-based big data framework for textile supply chain) embedded with Tendermint, a powerful open-source software, as a consensus mechanism.

On March 30th, 2022, the European Commission presented a package of European Green Deal proposals to make sustainable products in the EU the norm and to boost circular economy practices in European companies[7] (European Commission, 2022). In this strategy, some specific measures were defined, one of which is the creation of a Digital Product Passport (DPP).

A Digital Product Passport is a tool that gathers data on a product and its supply chain and shares it across the entire value chain, enabling all participating actors of the chain, including consumers, to have access to information on specific materials and products. The DPP is meant to be applied not only in the textile industry (which is a major objective of the Green Deal), but also construction, vehicle batteries, consumer electronics, packaging, and food[8] (Stretton, 2022).

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[5] Source: https://www.hyperledger.org/about
[6] Source: https://101blockchains.com/hyperledger-fabric-vs-aries/
[7] Source: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013
[8] Source: https://www.circularise.com/blogs/digital-product-passports-dpp-what-how-and-why

According to the European Commission, the implementation of digital product passports in these value chains is designed to support:

- **Sustainable product production** - enable the transition to a circular economy and therefore boost material and energy efficiency, extend product lifetimes, and optimize product use.
- **Businesses to create value through circular business models** - thanks to the improved access to data with digital product passports, more businesses can implement service and repair-based business models.
- **Consumers to make more informed purchasing decisions** - once they are provided with information on the total impact of their buying behaviors.
- **Verify compliance with legal obligations** - the digital product passport will also act as a record of the standards a product complies with and provides auditors with data to evaluate this.

While data requirements for DPPs are still being determined, this tool requires the collaboration of the entire supply chain. The information storage and access in a DPP work as follows:

The DPP must be connected to a unique product identifier (i.e.: bar code, QR code) through a data carrier, which is physically present on the product, packaging, or any documentation accompanying the product. The data in the DPP refers to the product model, batch, or item, and its access is regulated in accordance with already defined access rights. According to Adisorn, et al. (2021) manufacturers would likely be the main suppliers of product information. If implemented, all actors in a supply chain would have free access to information in DPPs based on their access rights group.

In this context, blockchain technology could play a role in DPPs. The implementation of a data transfer infrastructure is a crucial task in DPP implementation, enabling information flows in a seamless and transparent manner between the actors in the supply chain. One of the major obstacles to DPP implementation is the lack of an infrastructure in companies that allows for an open, standard, searchable, and interoperable data format. In short, companies require a decentralized system that meets these requirements. A distributed ledger such as blockchain poses a very suitable match for this issue, as blockchain allows for a secure transfer of vast amounts of data.

## 2.2. Related Work

The use of blockchain technology in supply chains addressed in the literature focuses mainly on analyzing its implementation across economic sectors. This analysis is usually coupled with the assessment of either readiness for implementation, obstacles that organizations face with blockchain implementation, key factors that lead to the success of the implementation, or technologies that are compatible with blockchain technology. As such, in this subchapter, studies that assess blockchain implementation across different industries were reviewed. Section 2.2.1 presents papers with focus on industries other than textile, and section 2.2.2 presents papers with focus on the textile industry.

### 2.2.1. Blockchain Applications in the Industry

For example, in the healthcare industry, Balasubramanian, et al. (2021) proposes a blockchain readiness framework with key stakeholders; dimensions of individual stakeholder readiness (including motivational, engagement, technology, and structural readiness); key relationships between stakeholders for blockchain adoption; and key facilitating conditions. This study has found that government readiness is significantly impactful in driving blockchain initiatives and that lack of clarity on blockchain regulation and issues pertaining to trust and security negatively affect the readiness of stakeholders.

In the tourism sector, Irannezhad, et al. (2021) conducted a multiple case-study approach on early use cases of blockchain in tourism, aided by literature on technology acceptance management, with the objective of examining the impacts, opportunities, and challenges of the adoption of this technology in tourism. This study concludes that the main advantages of blockchain implementation include the enablement of smart contracts; the elimination of intermediaries; the providence of transparency, authenticity, and security; the creation of seamless inventory tracking; and shortened waiting time at border control. Additionally, the study expects blockchain implementation in tourism to have the potential to help with uplifting developing economies.

Another study, by Erol, et al. (2020), aimed to discover in which industries is blockchain implementation more feasible, from logistics and supply chain to energy and automotive. A decision model was constructed to select a set of indicators with the purpose of identifying the feasibility of blockchain adoption in various industries. Some of the indicators are the existence of regulations, the level of technology maturity, the proportion of digitized assets, and the need for building trust, among others. Following these indicators, the study concluded that logistics, supply chain, finance, and health industries are the most feasible ones for blockchain implementation.

In the food industry, Kohler & Pizzol (2020) analyzed and compared six cases of blockchain implementation in food supply chains, where the focus of the comparison is not on the concept used for implementation, but rather on the real-life results derived from the implementation. After choosing which cases to study, the authors applied a technology assessment framework, which states that any technology is composed of four components: knowledge, organization, technique, and product. This study analyzes each case through the lens of these components. The technique component addresses the tools used to implement blockchain, from the blockchain technology itself to data handling, data storage, and tokenized incentives. The knowledge component consists of what knowledge software developers and actors of the supply chain need to have to ensure blockchain implementation. This includes knowledge of programming language, how to use specific platforms and apps, how to link software to the blockchain, etc. The organization component analyzes the relationships between the involved stakeholders and finally the product component is a result of the previous components, either in the form of a user program, mobile app, management platform, or QR code, among others. Not unlike the previous studies, the results of this study indicate that blockchain implementation leads to increased transparency, traceability, and trust. Additionally, it highlights the synergy between blockchain and the different technologies associated with businesses, including ERP systems and IoT devices.

In the energy sector, Mika & Goudz (2021) suggested a framework of a service model for the trade of electricity from renewable sources between low capacity "prosumers" (individuals that produce and consume their own energy) in Germany. The authors believe that the expansion of renewable energy can be aided by the implementation of blockchain in the medium and long term, and that legal and regulatory hurdles pose challenges in the short term. Similarly, a study by Brousmiche, et al. (2018), which addresses the energy sector in Lille, France, proposes the creation of a local energy marketplace built on a blockchain platform that combines Ethereum's protocol and Tendermint consensus engine.

### 2.2.2. Blockchain Applications in the Textile Industry

Regarding studies that focus on the textile sector, in 2018, Fu et al. proposed an environmentally sustainable solution for the fashion apparel manufacturing industry based on blockchain technology (Fu, et al., 2018). This solution incorporates de Emission Trading Scheme[9] (ETS - a cornerstone of the EU's policy to combat climate change), and an "emission link" system that exposes the carbon footprint of the manufactured pieces.

A study by Pérez et al. (2020), addresses the traceability of ready-to-wear clothing, by introducing recent traceability schemes for the apparel industry along with a framework for ready-to-wear clothing that ensures transparency, authenticity, reliability, and integrity in the supply chain. The authors included a case study of a woman's shirt from an apparel and fashion company, where blockchain technology was used to trace the shirt's path along the supply chain. This study also proposes different blockchain actors for each product stage.

In 2021, Agrawal et al. proposed a blockchain-based framework for traceability in multi-tier textile and clothing supply chains, based on the premise that consumers find it difficult to access product data that enables ethical buying practices (Agrawal, et al., 2021). This framework conceptualizes the interactions between supply chain partners at the organizational level and the use of smart contracts and consensus rules for transactions at the operational level. The authors suggest that their proposed system has the potential to increase trust between partners and successfully authenticate all transactions.

Nazam, et al. (2022) analyzed the key barriers that halt the adoption of blockchain-related practices in the textile supply chain. To achieve this, the authors conducted an extensive literature review and organized panel discussions with experts when identifying barriers and applied a fuzzy analytical hierarchy process (Fuzzy AHP) to prioritize them. The barriers are organized into five categories, and each category was ranked according to the dimension of their impact in the following order: Technological and System Barriers, Human Resources and R&D Barriers, Socio-economic and Environmental Barriers,

[9] Source: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

Organizational and Individual Barriers, and Governmental and External Stakeholder Barriers. These categories pertain to barriers such as technology immaturity, security risks, lack of expertise, negative perception of IT among workers, lack of key departments and of financial resources, poor long-term economic behavior, lack of organizational policies, and lack of government interest in blockchain-based solutions, among several others within the given categories.

A study by Shou & Domenech (2022) attempts to promote the union of blockchain and a Life Cycle Assessment methodology (or LCA), by arguing that, although LCA has and is being used to assess the environmental impact of the fashion industry, its results are constrained by the lack of reliable data, which blockchain technology would help improve. The study includes the proposal of a protocol for the integration of LCA and blockchain to assess circular practices, by using leather handbags as a case study.

# 3. Literature Review

A systematic literature review offers several advantages, including a comprehensive analysis of existing research, identification of research gaps, and synthesis of evidence. In this chapter, a systematic literature review is presented in order to achieve Objective 1 - analyze the evolution of the application of blockchain in supply chains across industries. This systematic literature review was conducted to analyze papers that mention the topics of blockchain technology and supply-chain.

## 3.1. Methodology

The resulting data of the systematic literature review was divided into three sections (representing three phases of analysis): General Analysis, Review of Abstracts, and Detailed Analysis. The review methodology is detailed in Figure 1, which deconstructs the steps that were followed to select the final set of papers. The three phases of the analysis indicated were performed at different stages of the systematic literature review, and each aims to provide a summary of the progress of papers in terms of numbers, topics, and areas of focus. The choice for the structure of this review was inspired by the systematic literature review of Pedreira, et al. (2021), which includes the analysis of academic articles through 3 phases. Additionally, this study aims to identify whether topics such as traceability, data transparency, security, privacy, efficiency, optimization, IoT, and sustainability are current trends for blockchain-driven supply chain solutions. For this study, it was assumed that the current trends of blockchain and supply chain could be assessed by overviewing the progress of published papers over time (from 2016 to June 2022).

As such, for the systematic literature review, two research queries were formulated:

- RQ1: What is the progress, in the number of papers, of the creation or implementation of blockchain-driven supply chain solutions?
- RQ2: Which industries are most willing or capable of adopting blockchain-driven solutions into their supply chain?

After defining the research queries, the keywords “Blockchain" and “Supply chain” were selected for this study and, in order to search and extract the papers that best suited the review's objectives, the search engines Scopus and the digital library of the Institute of Electric and Electronic Engineers, called IEEE Xplore, were used. With these elements defined, 2994 papers were extracted from the chosen search engines (2113 from Scopus and 882 from IEEE Xplore) and uploaded to StArt (State of the Art through Systematic Review), a software that helps in the organization and sorting of academic papers for systematic literature reviews. Once the papers were uploaded, a set of exclusion criteria (table 1) was applied (exclusion criteria (1) and (2)) which resulted in the exclusion of 940 duplicate papers and 24 papers that were unusable for the study due to a lack of information regarding either the authors or the abstract.

| | |
|---|---|
| **(1)** | Paper is a duplicate |
| **(2)** | Paper is unusable (no abstract or author information) |
| **(3)** | Paper has a score of less than 60 |
| **(4)** | Paper considered not relevant for this study |
| **(5)** | Paper is not in English or Portuguese |
| **(6)** | Paper required payment or a special license to access |

Table 1 - Exclusion criteria for the systematic literature review.

Then, the exclusion criterion (3) was applied, thus excluding 1922 papers that had a score under 60. For this criterion, the score of each paper was calculated using the following rules:

- Three keywords were added to the original ones. The added keywords are "distributed ledger", "industry" and "private blockchain", to emphasize the focus on the use of private blockchains or other DLTs in companies within a specific industry context.
- The point distribution was calculated by attributing papers 5 points for every keyword in the title and 3 points for every keyword in the abstract.

| **Primary Keywords** | **Secondary Keywords** |
|---|---|
| Blockchain | Distributed ledger |

| | |
|---|---|
| | |
| | Industry |
| Supply-chain | |
| | Private Blockchain |

Table 2 – Keywords of the systematic literature review.

The minimum score chosen was 60 points given that the objective of this systematic literature review was to arrive at under 40 papers for the detailed analysis, to ease the review process.

After applying the exclusion criterion (3), 108 papers remained, which were used for the Abstract Analysis. After this analysis, 76 papers were excluded for matching criteria (4), (5), and 6, thus leaving 37 selected papers for the Detailed Analysis. Considering this, the following sections detail the 3 phases of analysis mentioned.

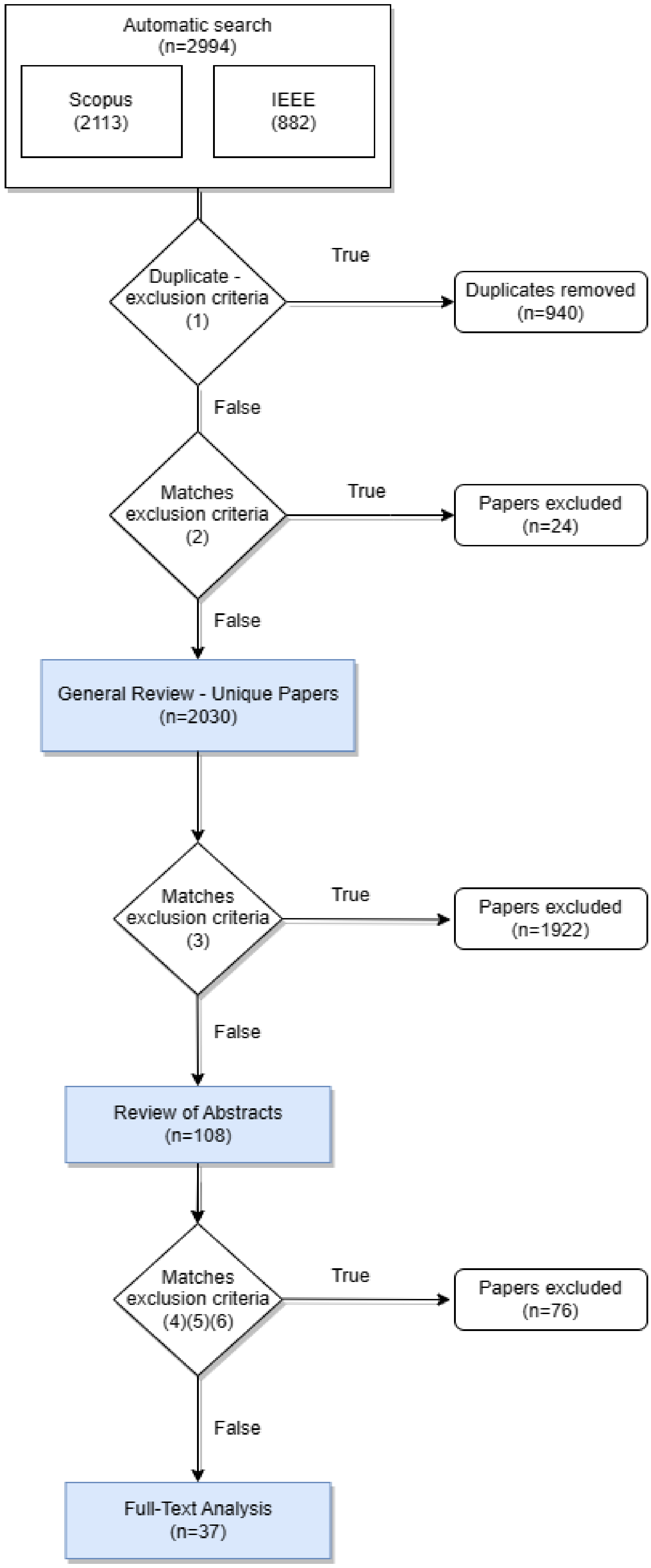


Figure 1 - Systematic Literature Review Methodology.

## 3.2. Results of the systematic literature review

The following sections showcase the results found during the three phases of analysis of the systematic literature review. Each section represents a phase of analysis (General Analysis, Review of Abstracts, and Detailed Analysis) and the resulting data was converted to graphs and tables.

### 3.2.1. General analysis

The general analysis consists of a quantitative evaluation of 2030 unique papers, from which results were obtained for the yearly progression of the publishing of papers on the topic of "blockchain + supply chain".

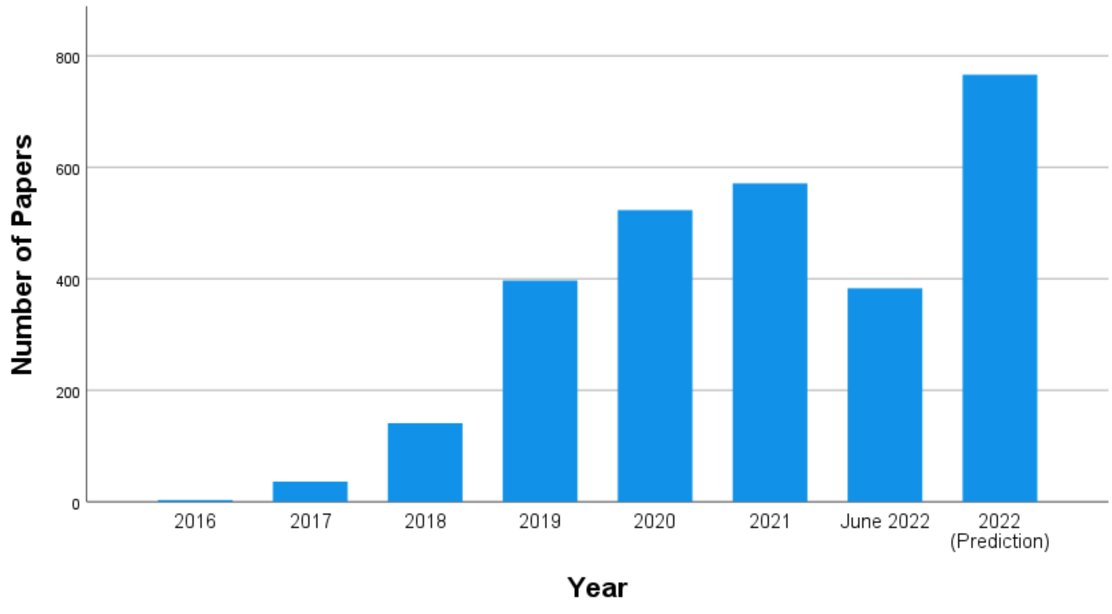


Figure 2 – Yearly evolution of number published papers on "blockchain" and "supply chain."

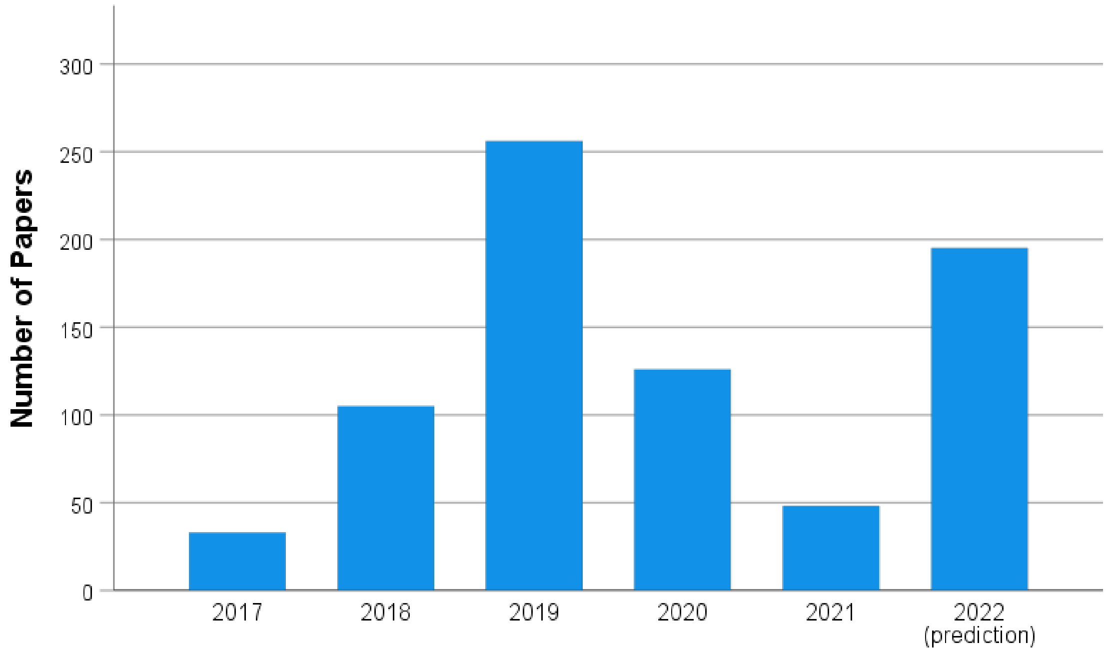


Figure 3 - Yearly variation of the number of published papers on "blockchain" and "supply chain."

Figure 2 presents the number of published papers every year since 2016, with respect to the inclusion of the terms "blockchain" and "supply-chain". The year 2022 has been divided into 2 variables, where the variable "June 2022" details all the papers published from January until June of 2022, and the "2022 (Prediction)" presents a rough prediction of the number of published papers during the whole year of 2022, based on the temporal behavior of these type of papers. This figure indicates that even though blockchain technology was first revealed in October 2008, papers on this subject only started to be published in 2016. In that year, only 3 papers were published on blockchain and supply chain, and over the next few years, the number of published papers skyrocketed to almost 600 in 2021. As of June 2022, the number of published papers in that year is close to 400 (almost as much as the entire year of 2019), inferring a projection of nearly 800 published papers by the end of the year.

Figure 3 displays the yearly variation in the number of published papers, with respect to the inclusion of the terms "blockchain" and "supply-chain". Similar to Figure 2, there is a variable that presents a projection for the yearly variation of papers in 2022, as compared to 2021. Since 2016 the growth rate of papers has remained always positive, with 2019 being the year of highest growth. Although the growth rate diminished from 2019 to 2021, almost 400 papers were published in the first half of 2022, which is why a growth rebound by the end of the year was projected, with a near total of 800 published papers.

### 3.2.2. Review of Abstracts

The review of the abstracts was conducted as follows. Every paper that had a score of 60 or higher has been selected and its abstract analyzed. In Figures 4 to 6, the areas of focus represented are food, textile, automotive, health, financial, renewables, luxury goods, and retail, as well as a "multi-sector" variable (for papers that focus on more than one industry), a "no specific sector focus" variable (for papers that analyze the general adaptability of the blockchain-driven supply chain within companies, regardless of their economic activity), and lastly a "geographic" variable, for papers that approached the subject by analyzing the country or countries of application rather than the industry where the technology was applied.

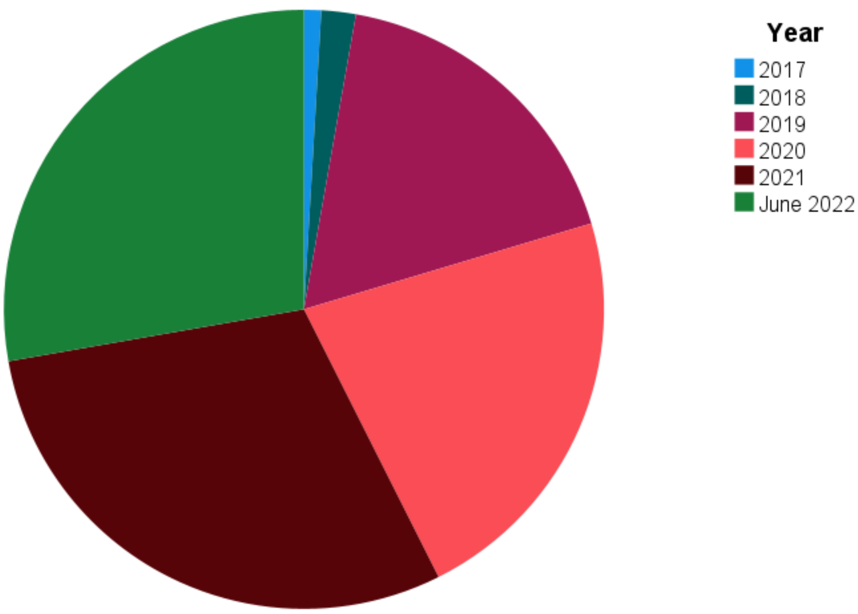


Figure 4 - Number of published papers by year on the topics of blockchain and supply chain.

Figure 4 presents the number of published papers per year that have a score of 60 or higher. It can be concluded that the number of papers grew substantially from 2017 until

June 2022, with only 3 papers being published between 2017 and 2018. The year of highest growth was 2019, and 30 papers were published from January to June 2022.

Figures 5 and 6 demonstrate an analysis of the area of focus of the selected papers. Figure 5 indicates that out of the 108 published papers, 53 have no specific industry focus, 52 papers focus on one or more industries, and 3 focus on one or more countries. It may also be deduced that the food industry is the most popular area of study for this subject, followed by "multi-sector" focused papers, which represent roughly 17,5% of all papers in this analysis. Furthermore, all other industries are individually represented in 3 or fewer published papers.

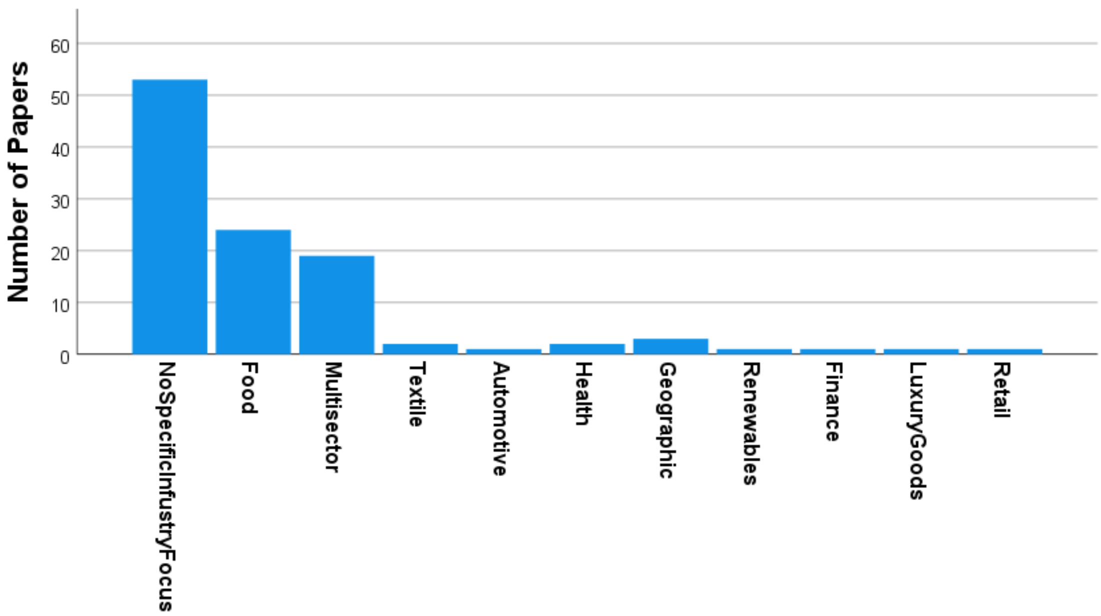


Figure 5 - Number of published papers by area of focus.

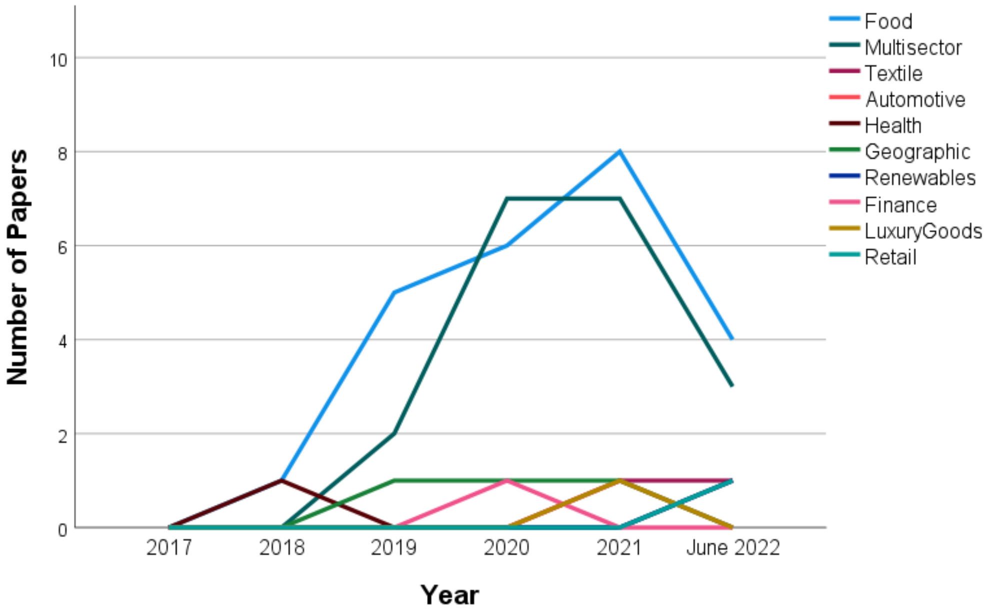


Figure 6 - Yearly evolution of the number of papers by area of focus.

Figure 6 indicates that there were no papers published in 2017 with a specific area of focus, and only two in 2018, one focused on the health sector and the other on the food sector. Food and multisector-focused papers had a similar growth trajectory throughout the years, while the textile, automotive, health, renewables, financial, geographic, luxury goods, and retail variables had no more than one paper published per year.

### 3.2.3. Detailed Analysis

Before starting the detailed analysis, all papers that met exclusion criteria (4), (5), and (6) were excluded, leaving 37 selected papers on which a thorough analysis was conducted. In this section of the systematic literature review, the goal was to identify two main trends: the yearly evolution of the number of papers published in relation to the areas of focus; and the mentions of the following topics: Data Transparency and Traceability, Security and Privacy, Efficiency and Optimization, Internet-of-Things, and Sustainability. Regarding the selected papers, Figure 7 shows the yearly evolution of the number of papers published, categorized by area or areas of focus. The analysis of Figure 7 leads to the following conclusions:

- The overall number of papers grows steadily each year.

- Most papers included in this list were published between 2020 and 2021, with no more than 2 papers being published in 2018.
- 16 out of the 37 papers focused on multiple sectors simultaneously.
- The food sector appears to be the one with the most attention in the academic research of blockchain-driven supply chain solutions, representing around 40% of the selected papers.
- The health, textile, and automobile industries are the least mentioned in the selected papers. No more than one paper has been published per year, regarding these industries.
- Among the selected papers there are three published papers that analyze blockchain application in supply chain management with a geographic approach, either by comparing the efforts of adopting blockchain by companies in two different countries (comparisons of Germany with Russia, USA with India) or with a deep analysis on a single country's experience (an approach on several manufacturing industries in Australia).

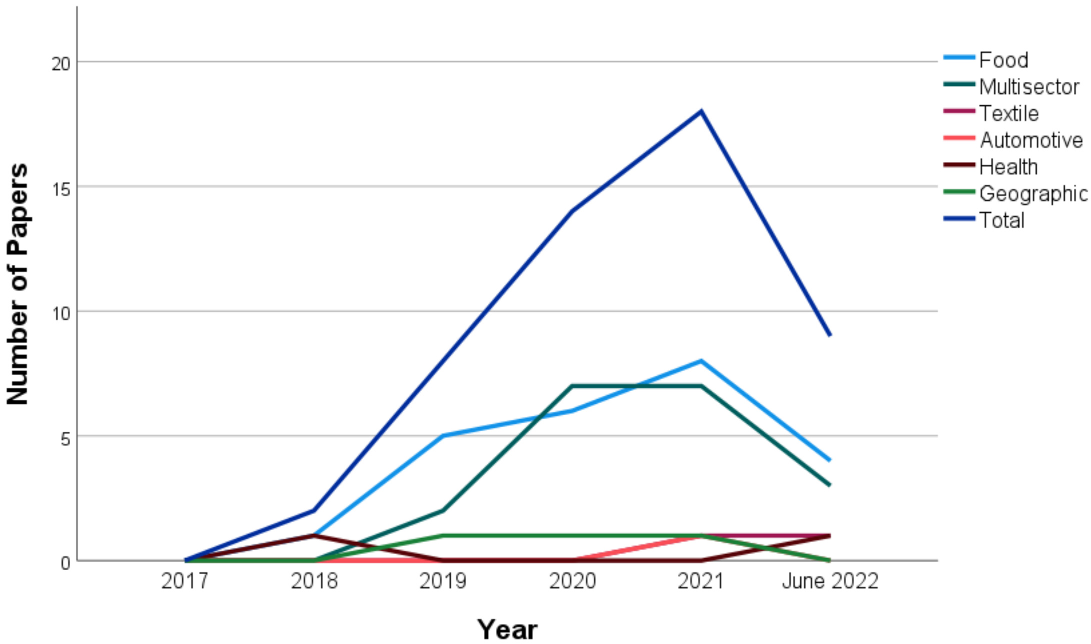


Figure 7 - Number of papers per area of focus, per year.

Regarding the selected papers that mention the topics described above, Figure 8 shows the number of papers per mentioned topic. For example, the "Internet of Things" topic has been mentioned in 18 out of 37 papers.

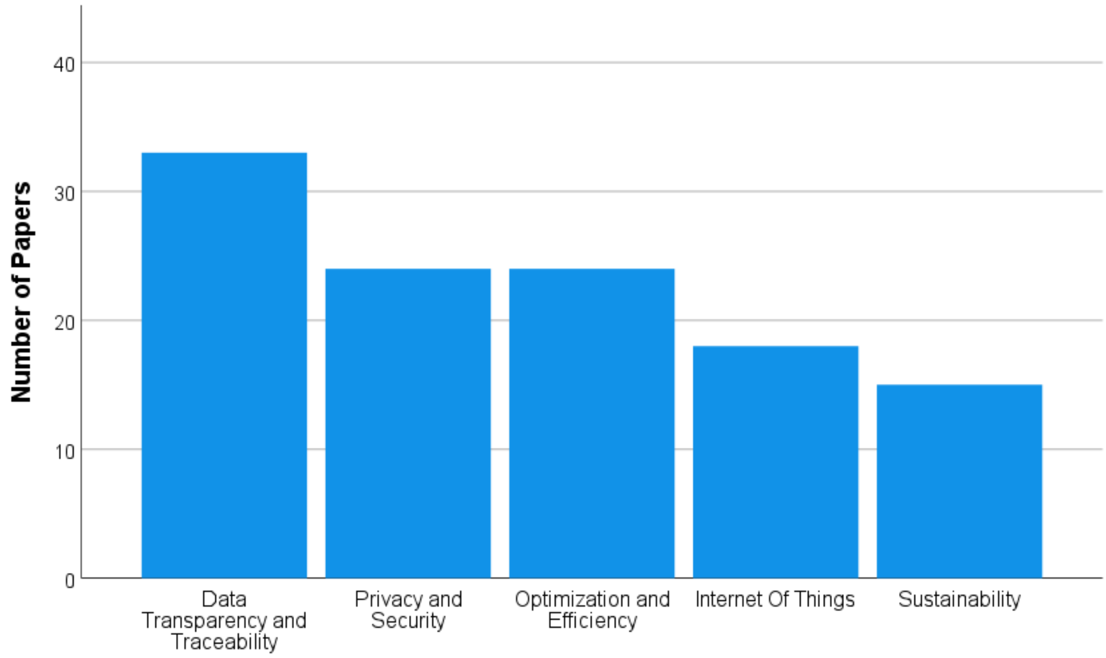


Figure 8 - Number of papers per mentioned topic.

In order to establish a relationship between the "topic" and "area of focus" variables, a scoring system was created in Figure 9, where each paper is attributed one point for every topic that is mentioned. Papers that mention all five topics received a score of 5, papers that mention four topics received a score of 4, papers that mention three topics have a score of 3, and so on until zero topics are mentioned.

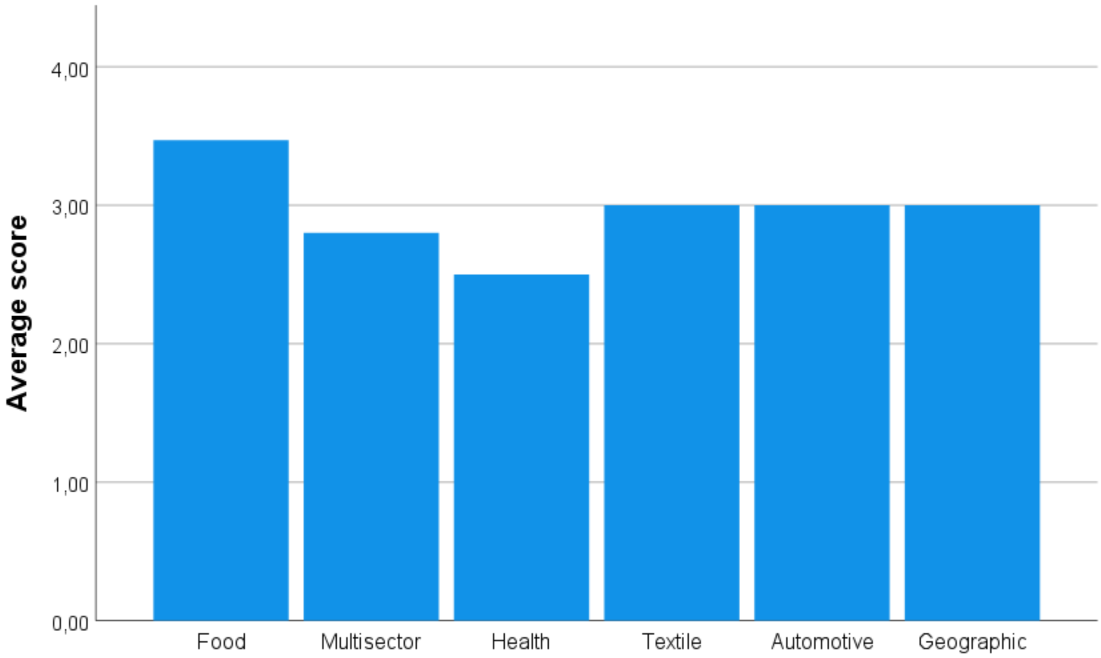


Figure 9 - Score of selected papers per area of focus.

In Table 3, a relationship was established between topic 1 (Data Transparency and Traceability) and the other topics. This table presents the number of papers matching topic 1 and one topic from 2 to 5. Topic 1 is a fixed topic for this comparison since it is present in almost every selected paper.

| | | 1- Data transparency and Traceability | |
|---|---|---|---|
| | | "Paper does not mention topic" Count | "Paper mentions topic" Count |
| 2- Privacy and Security | No | 3 | 10 |
| | Yes | 1 | 23 |
| 3- Optimization and Efficiency | No | 2 | 11 |
| | Yes | 2 | 22 |
| 4- Internet of Things | No | 2 | 17 |
| | Yes | 2 | 16 |
| 5- Sustainability | No | 3 | 19 |
| | Yes | 1 | 14 |

Table 3 - Count of mentions of topics 2, 3, 4, and 5 in relation to topic 1.

Finally, Figure 10 presents a more detailed description of the selected papers, which have been categorized by the topic mentioned and area of focus.

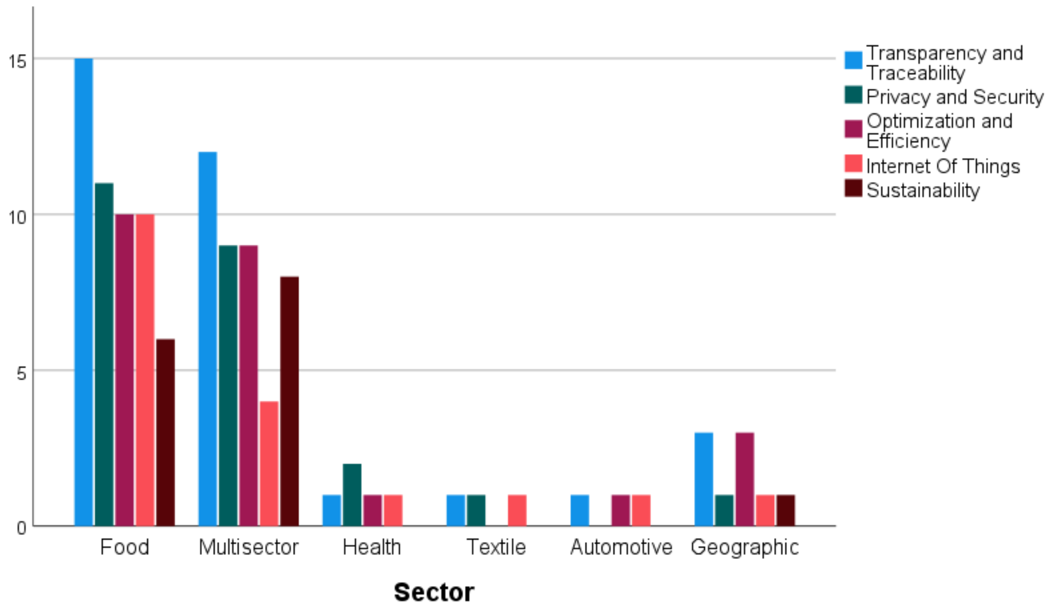


Figure 10 - Number of papers per mention of topic, by area of focus.

In this section, the following conclusions have been drawn:

- Almost half of the selected papers (around 45%) mention at least 3 of the 5 topics
- 7 selected papers mention the 5 topics and only 1 paper fails to mention any topic;
- "Data Transparency and traceability" is the most mentioned topic, appearing in 33 papers, followed by "Security and Privacy" and "Optimization and Efficiency", which are mentioned in 24 selected papers each;
- "Sustainability" is the least mentioned topic, appearing in 15 selected papers;
- "Data Transparency and Traceability" is most commonly mentioned alongside "Privacy and Security" and "Optimization and Efficiency". These topics are both mentioned in 23 papers and 22 papers, respectively;
- All 10 papers that mention at least 4 out of the 5 topics are either focused on the food industry or explore multiple industries at once;
- 10 out of the 18 papers that mention "Internet-of-Things" are focused on the food industry;
- More than half of papers that mention "Sustainability" explore multiple industries at once. Most of the other half is focused on the food industry.

- 10 out of the 18 papers that mention "Internet-of-Things" are focused on the food industry;

- More than half of papers that mention “Sustainability” explore multiple industries at once. Most of the other half is focused on the food industry.

## 3.3. Discussion

In this section, the proposed research queries of the systematic literature reviewed are answered according to the results obtained.

**RQ1:** What is the progress, in the number of papers, of the creation or implementation of blockchain-driven supply chain solutions?

In section 3.2.1 (General analysis), it is indicated that there is a sharp increase in the study of blockchain when applied to supply chains, with 36 papers being published in 2016 and 2017, and almost 600 papers being published only 5 years later, with no sign of stopping anytime soon. Even if blockchain applicability outside of cryptocurrency is still in its infancy, some companies have started developing supply chain solutions based on this technology. For example, Hemphill (2020) shows that multinational enterprises such as IBM, Walmart, Merck, and KPMG are testing blockchain solutions as a part of a program to improve food and drug safety and security through the traceability of units and information transparency.

Further efforts have been made across other industries to implement blockchain-based supply chain solutions. In France, a company called Suez Groupe has created the circular economy blockchain CircularChain[10] for the agricultural sector, to encourage the reuse of materials, provide transparency in the transactions of materials between companies and record all the steps required to process secondary raw materials, thus promoting trust between all involved entities (CircularChain, n.d.). A similar solution was proposed by Pinto, et al. (2021) for the pulp and paper industry of Portugal. The proposed model envisions the integration of a scalable and modular blockchain platform with the intention of promoting the circular economy of waste and taking advantage of the existing industrial symbiosis regarding recycled materials.

Although not connected to the supply chain, other blockchain projects have emerged in the past 5 years. One example of this is DApp (Decentralized App) Edu-Coin, a Proof-of-

[10] Source: https://www.suez.com/en/circularchain

Stake blockchain platform used for the rating of professional educators, recruiters, and universities (Nair, et al.). Users that enter the network can make a claim for the validation of their profile or project, which is then collectively assessed by validators of the network that are later awarded units of Edu-Coin for their work in the blockchain.

**RQ2:** Which industries are most willing or capable of adopting blockchain-driven solutions into their supply chain?

In sections 3.2.2 (Review of Abstracts) and 3.2.3 (Detailed Analysis), it is indicated that a large portion of selected papers do not focus on a specific industry, but rather on supply chain management. However, out of the industries that are mentioned in the selected papers, the food industry stands out with the highest number of published papers on this subject. One reason may be that is the industry's significant use of a specific technology – the Internet of Things. Blockchain-driven supply chain solutions usually require companies to have existing technology that can be combined with blockchain. Most companies working in supply chains that are interested in adopting blockchain choose to do so by combining blockchain with already implemented technologies. One very common technology combination that the selected studies on the food industry mention are the combination of blockchain and IoT. Farooq, et al. (2020) argue that IoT in agriculture is a highly promising technology, where devices that measure soil quality levels, temperature, sunlight exposure, and water levels are constantly communicating with each other to create a network that optimizes the agricultural process. Blockchain experiments and theoretical solutions in the food supply chain are mostly focused on the traceability of products, from production to consumption. The inclusion of blockchain-driven food traceability solutions in IoT systems could create the following benefits:

A traditional IoT system uses a centralized server for data storage, transmitting, and sharing, while blockchain technology uses a P2P (peer-to-peer) distributed network, which is much harder to attack or tamper with. Additionally, blockchain allows users to upload data anonymously, which is in turn verified by a pre-established consensus mechanism that assures the validity of the information. The point of anonymity and the principle of consensus is to protect the data privacy of the user (individual or collective). According to Xu, et al. (2020), the combination of blockchain and IoT devices can prevent all parties from creating wrong records of information and tampering with the data source. This makes the channels of communication and data transaction more reliable and the information itself more trustworthy, ultimately providing consumers with a tool that effectively tracks the source of products. Furthermore, Feng, et al. (2020) argue that the efficiency of communication and reliability of information that comes from such a combination can contribute to a decrease in economic loss and product waste.

However, Feng, et al. (2020) also concluded that the joining of IoT and blockchain could lead to some challenges. At a **technical** level, studies have shown that design limitations in the IoT system could condition the choice for a consensus algorithm, or limit transaction capacity, data accessibility, and capacity for scalability. Blockchain nodes require frequent data exchange, but the computing capacity of IoT systems is lower than what is required by the blockchain, creating excessive energy consumption, high latency in the network, and eventually bottlenecks throughout the blockchain. There are also **infrastructural** issues in this regard, as blockchain systems heavily benefit from the full integration of all participants in the supply chain. The general rule is that the more actors are integrated into the blockchain, the better it works. However, the process of integration is difficult and slow, especially when actors don't agree on which information to share with each other or have a lack of resources and/or knowledge to implement a distributed ledger. Additionally, Sumnola, et al. (2021) argues that blockchain is not standardized to a point where the integration of the technology is facilitated, which leaves potential users worried about committing to a blockchain-driven solution.

# 4. Business Survey

This chapter details a survey that was conducted on a group of 30 Portuguese companies in the Textile and Fashion Industry, roughly half of which are currently participating in a consortium of a publicly funded Portuguese project called STVgoDIGITAL[11] (Citeve Tecnologia Têxtil, n.d.). The STVgoDIGITAL project started in June 2020, and it aims to accelerate the digital transformation of the national textile industry by stimulating companies to adopt 4.0 Industry technologies, thus elevating the productivity and efficiency of every firm, as well as the supply chain as a whole. The project is organized by the Textile Cluster: Technology and Fashion, an industrial organism whose main objective is to contribute to collaboration and information sharing within the textile supply chain, in order to boost companies' competitiveness for innovation and internationalization, so as to achieve collective efficiency.

The following subchapters explain the methodology used to construct the survey, the data analysis required, the results found, and a discussion of the results.

## 4.1. Methodology

The ultimate goal of this study is to analyze the companies in the STVgoDIGITAL and to understand their perspectives on blockchain as a tool that can be applied to the supply chain. Blockchain-based supply chain solutions allow companies to share information in a transparent manner, trace products, and have their data immutable. The companies that integrate the STVgoDIGITAL project were chosen for this survey because the project includes the implementation of blockchain-based solutions into an existing supply chain, which falls directly into the scope of this dissertation. Additionally, the location of the companies made it convenient to address them. The other companies outside the STVgoDIGITAL project were chosen for this survey due to them being actors in the same supply chain as the companies that integrated the project.

[11] Source: https://www.citeve.pt/artigo/stvgodigital

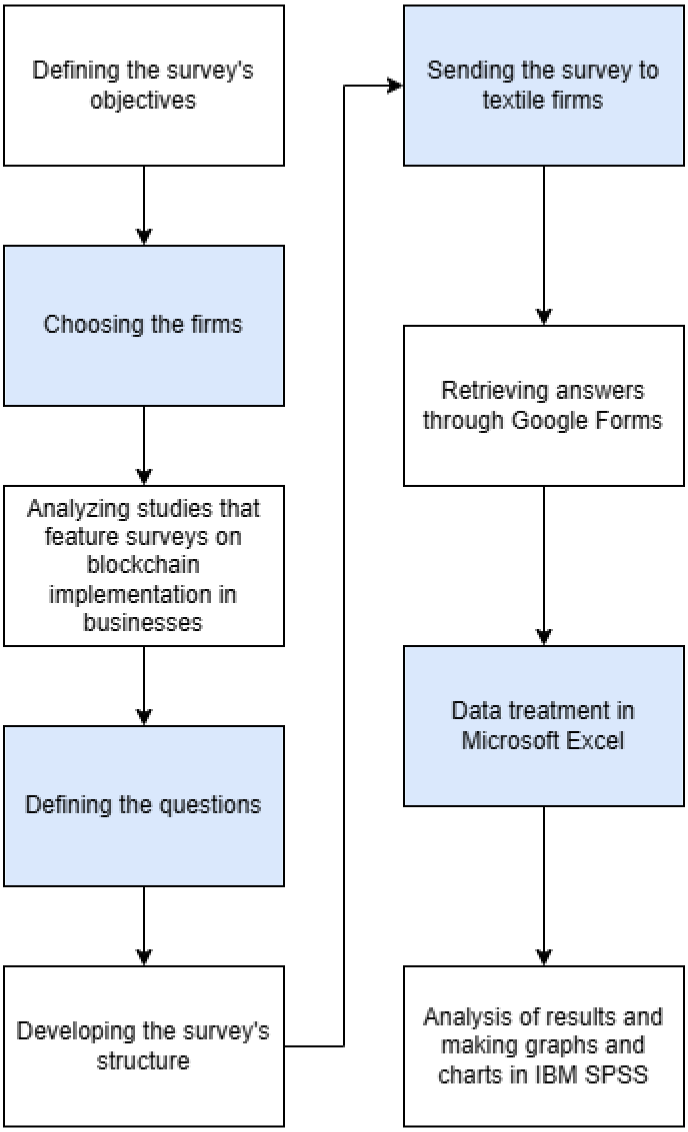


Figure 11 - Business survey chronological process

The objective of this survey is to gather data that can answer the following questions:

Q1 – Are information transparency, data immutability, and traceability of products elements of high priority for the inquired companies?

Q2 – Out of the inquired companies that adopted blockchain, which main advantages have they found?

Turilli and Floridi (2009) argue that "Transparency" is a term that has two different, even opposite, meanings. In the field of information management and business ethics, transparency refers to information visibility, which means the possibility of freely accessing information and behaviors that have been intentionally revealed. Contrarily, in the field of

IT and computer science, it refers to information invisibility. For this study, it was assumed the former definition of the term "transparency".

In total, there are 23 entities participating in the STVgoDIGITAL project: 16 private companies and 7 non-corporate entities from the ID&I program (Investigation, Development, and Innovation). These 7 non-corporate entities were not included in the questionnaire because they are not directly and commercially involved in supply chain processes, meaning that their incentives are non-profit and therefore not of interest to this study. However, these entities still play a crucial role in the development of the project by bringing know-how and a specialized and motivated workforce, in the form of masters and doctorate students looking to gain "real world" experience.

The STVgoDIGITAL project was created as a response to the EU's Digital Product Passport policy, where all manufactured products are intended to be accompanied by a digital passport that exposes its carbon footprint, waste, and countries where they were manufactured. The project is structured into 6 PPS (Product, Process, or Service that is created or undergoes major changes during the project), each having its own objectives, but working towards a common purpose: to create a digital ecosystem that simplifies processes and the supply chain, using technologies of information and communication as facilitators. PPS 1 and PPS 2 both focus on the supply chain but with different objectives: PPS 1 focuses on the ID of textile products to ensure transparency of information, traceability of the product, and availability of all that information to the end consumers, while PPS 2 focuses on the intermediation of all acting agents in the supply chain. PPS 3 aims to satisfy the part of the market that searches for increasingly personalized or even unique textile products. PPS 4 focuses on matters of the "Industry 4.0 worker", dealing with interconnectivity, agility, safety, and comfort at work. PPS 5 is tasked with the creation of an AI-driven resources platform, mainly for quality control purposes. Lastly, PPS 6 has broader objectives, mainly to ensure that every task of communication, promotion, marketing, and results demonstration is completed in a way that guarantees that the consortium acts as a whole rather than an array of individual actions.

The questionnaire was first aimed at the private companies participating in PPS 1, given that it is the only one that addresses the supply chain with blockchain-based traceability solutions. However, since the project is still in its early stages, and very few of those companies have used or are using blockchain, it would not be possible to build a questionnaire that focused solely on blockchain usage in the supply chain. As such, it was decided that other textile companies in the same economic context would also be inquired.

21 industry companies, 4 companies with brands, and 5 tech companies were asked to answer the survey. Even though the survey was the same for every firm, 2 extra questions were asked to companies with brands and another 2 to the tech companies, with the objective of finding out if there is a relationship between the companies' economic activity and their perspective on blockchain.

## 4.2. Survey Structure and Questions

The survey is divided into 5 parts. The first part contains most of the multiple-choice questions and briefly characterizes the firm and subject being inquired. The second part asks about the familiarity and experience that the subject has with blockchain. One of these questions aims to divide the subjects into the remaining 3 parts. When asked: "Has your firm considered the adoption of blockchain in its processes, products, or services?", three possible answers are given, creating 3 groups of companies: companies that have not considered blockchain adoption, companies that considered blockchain adoption but have never actually adopted it, and companies who are or have already adopted blockchain into their activity.

The third part (for companies that are adopting or have adopted blockchain) questions subjects about the conditions in which the adoption of blockchain had occurred, as well as a short series of scale-based questions about their perspectives on blockchain usage. In part 4, regarding companies that have considered but never adopted blockchain, they were asked about their perceived influence of blockchain integration into their supply chain. In the last part of the survey, companies that have never considered blockchain adoption were asked how valuable they believe that blockchain will be in their company's and industry's future, and how willing they are to adopt technologies that would contribute to information transparency between business partners and data immutability, regardless of the type of technology.

Regarding the extra questions created for companies with brands, they were asked how important they consider that the information provided by traceability technology (carbon footprint and digital "roadmap" of products) is to the end consumer, and if that aspect of the consumer's needs is marketed to. On the other hand, tech companies were asked how important they believe blockchain will be to the future of their industry and how interested their customers are in the technology.

The first thing that was considered before making the questions was to decide on their format. Depending on the type of answers desired, different types of questions were created. Simple multiple-choice questions were used to identify the basic characteristics of the firm and the person answering the question, such as the firm's activities in the industry, the age, and size of the company, the type of technology that is currently used by them, as well as the position occupied by the person who answered the questionnaire.

In order to identify companies' knowledge and perception of blockchain, several studies were analyzed for guidance. The work of Murabik (2022) provides an example of a survey with scale-based questions on the importance of information transparency, and data and information immutability (two key benefits of blockchain) in supply-chain management, particularly as elements to maintain a strong partnership. This question was adapted by using these two elements and four others so that the inquired companies would have to answer by prioritizing each element in relation to the others. On another occasion, the same logic was applied to a question by Paul, et al. (2022), where in that study the inquired subjects were asked about the influence of RFID-integrated blockchain-driven circular economy in the security, accuracy, decentralization, and process integrity of a given supply chain. This question was adapted to ask about the degree of influence that blockchain-driven supply chain solutions would have on information transparency, SC (supply-chain) efficiency, SC decentralization, the integrity of operations, traceability of products, and ecological footprint. Once again, companies were asked to order these elements according to what they believed would receive the strongest impact. Additionally, scale-based questions were used to assess companies' degrees of general knowledge of blockchain technology.

Finally, to address specifics of blockchain usage, subjects were asked open-answer questions where they had to identify the internal and external processes in which they are using or have used blockchain, excluding processes where blockchain was applied in the context of the STVgoDIGITAL project. Additionally, companies that have used blockchain are asked about their perspective after using the technology. This last question was also influenced by the literature on blockchain in the supply chain. While studying the factors that affect the adoption of blockchain, Chengyue (2021) conducted a survey on a group of individuals working in companies in retailing, e-commerce, manufacturing, and construction – that use blockchain. These companies were asked about the perceived usefulness, ease of use, innovativeness, knowledge, trust, and risk of blockchain, as well as their intention of using blockchain in the future. The developed questionnaires can be found in the following links:

Questionnaire for industry companies:

https://forms.gle/3xwYebVgDubykpgT7

Questionnaire for tech companies:

https://forms.gle/YkCvrDrZwFzhMUwC8

Questionnaire for companies with brands:

https://forms.gle/9Y3qrEQaXxvgpzii8

## 4.3. Survey Results

To analyze the questionnaire data, the answers were extracted from Google Forms and converted into a Microsoft Excel file for data treatment. This treatment depended on the type of question (scale-based, multiple choice, prioritizing). Variables of scale-based questions required a number code to represent each one. In multiple-choice questions, variables were transformed into columns and each answer was labeled into a "0" or "1", to indicate whether that variable was chosen ("0" for non-chosen variables and "1" for chosen variables).

Regarding questions that required the subject to prioritize between elements, the variables were also transformed into columns, and additionally given scores based on how they were prioritized by subjects. In all questions of this format, subjects had to choose how they would prioritize between variables. Depending on the order of prioritization, variables were given points between 1 to 6 points per answer (1 point for lowest priority and 6 points for highest priority). After data treatment, the IBM SPSS tool was used to read the data from the Excel file and to easily create visuals (graphs and charts) that illustrate correlations between variables and help establish relationships between companies' needs and blockchain's features.

### 4.3.1. Characteristics of subjects and companies

Starting with the descriptive questions of part 1, the inquired companies were asked about their most immediate characteristics. The data presented in the following figures detail those characteristics.

In Figures 12 and 13, it is shown that the majority of the companies (around 53%) have between 50 and 249 employees, placing them in the medium category of SMEs (small and medium enterprises), and around 23% have more than 250 employees, which classifies them in the category of large enterprises. The overwhelming majority of the companies (more than 80%) have more than 20 years of economic activity, while the remaining are evenly distributed between 6 to 10 years and 11 to 20 years of economic activity.

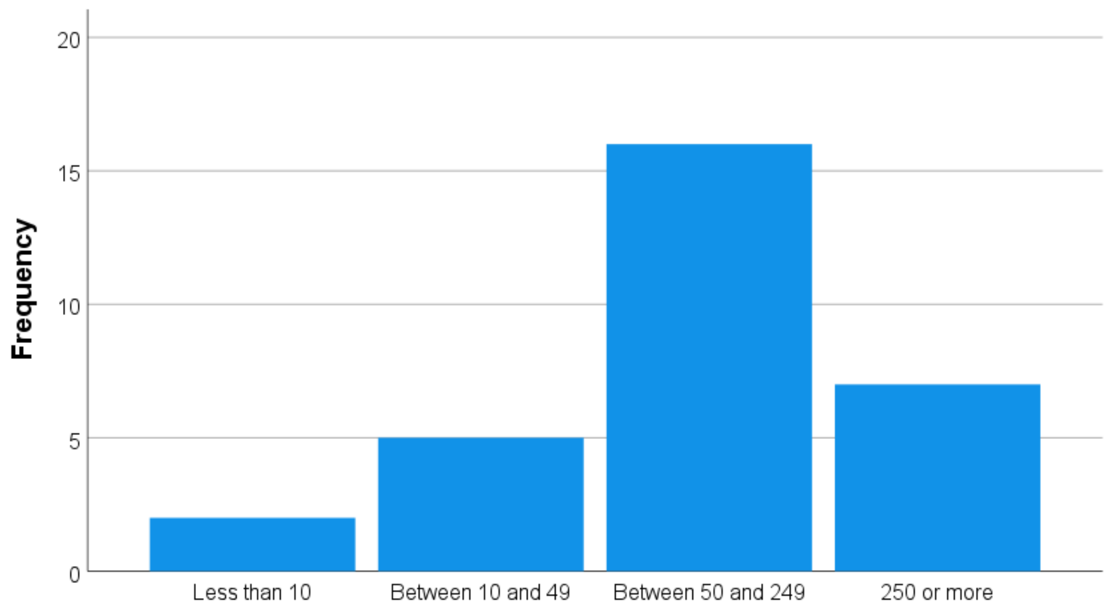


Figure 12 - Number of employees in inquired firms.

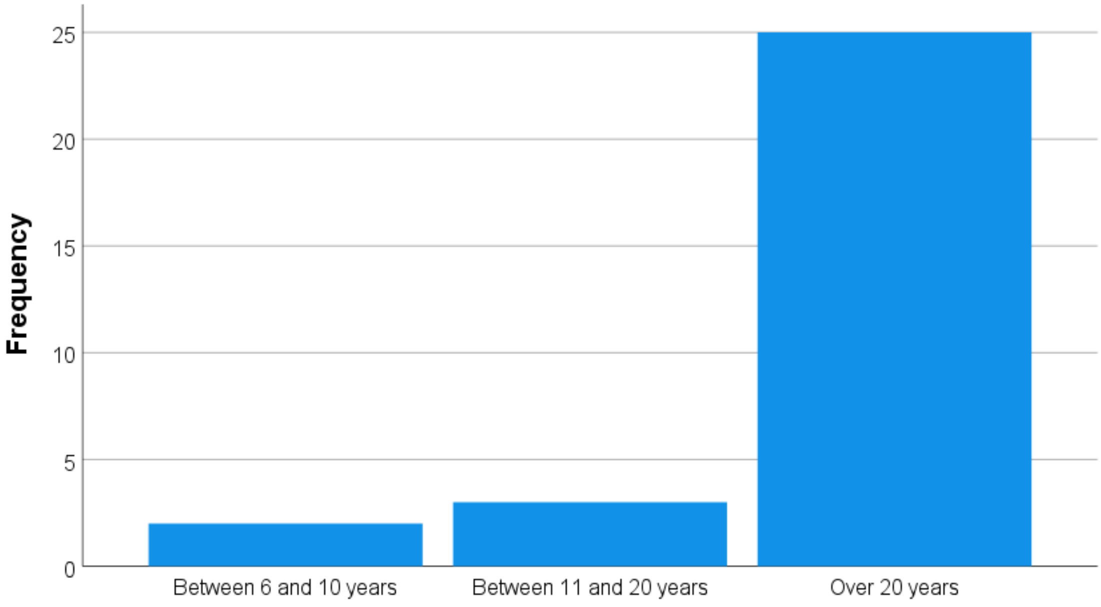


Figure 13 - Age of inquired firms.

Figures 14 and 15 detail the position of the inquired subjects, as well as the department they work in. Looking at the subjects individually, 16 out of 30 work in administration, which includes every CEO, CFO, and general manager that answered the questionnaire, as well as some of the team and department managers. The next most common departments are innovation and sustainability, respectively. The most common job position of the subjects is department manager, followed by team manager and CEO.

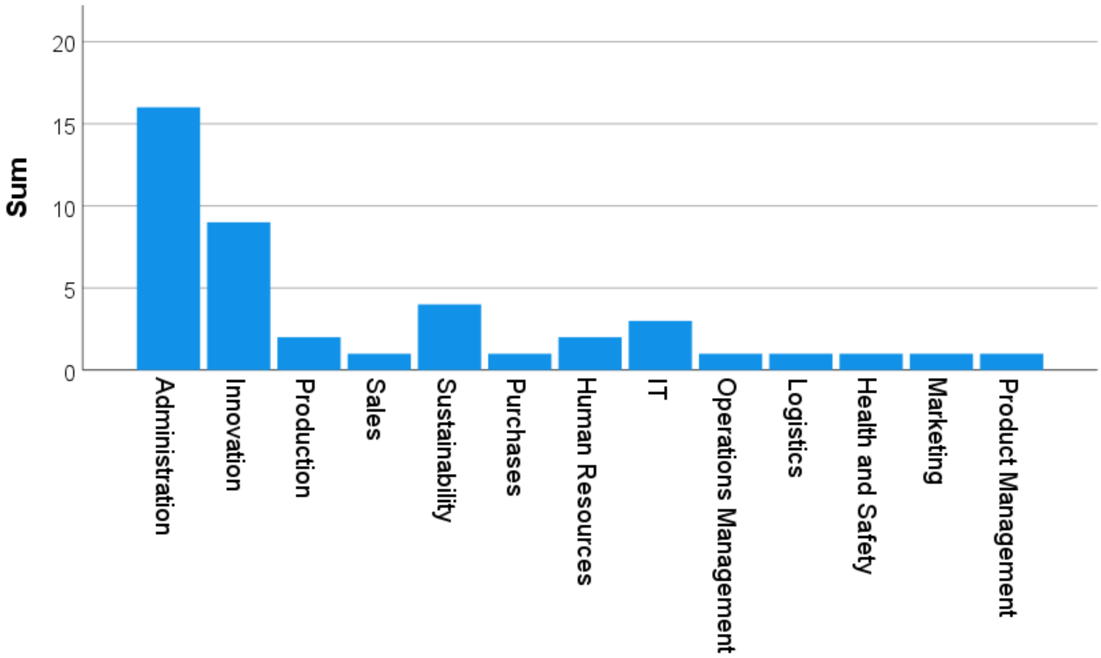


Figure 14 - Department of inquired subjects.

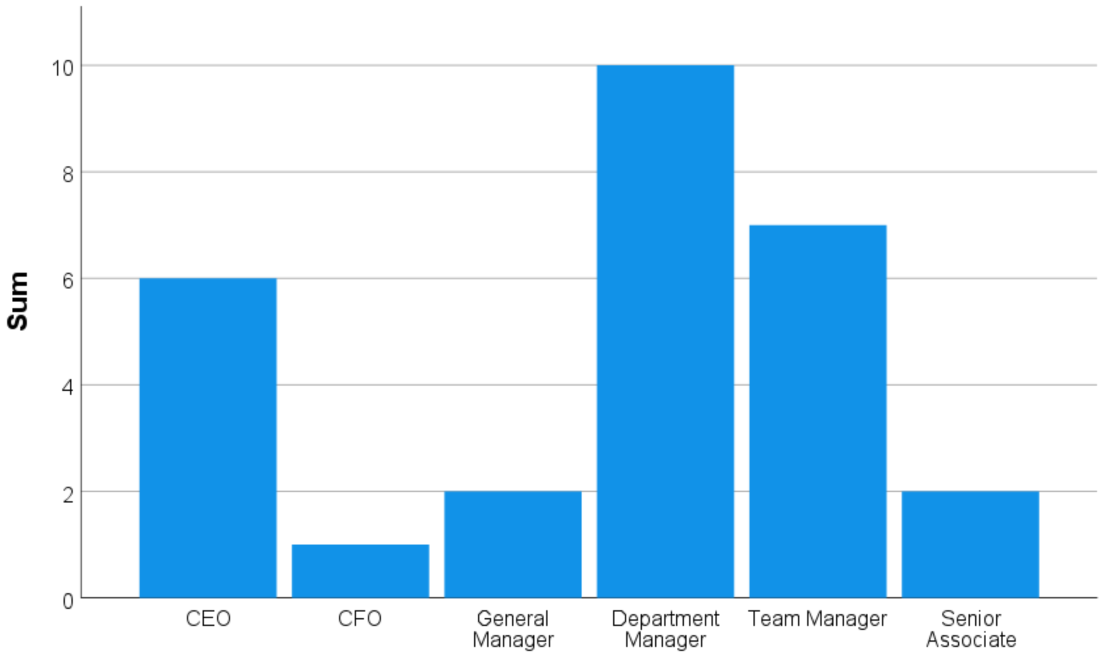


Figure 15 - Job titles of inquired subjects.

In Figure 16, each variable refers to a process that comprises either the manufacturing side of the textile and fashion industry, commercial activities, or software development and implementation operations.

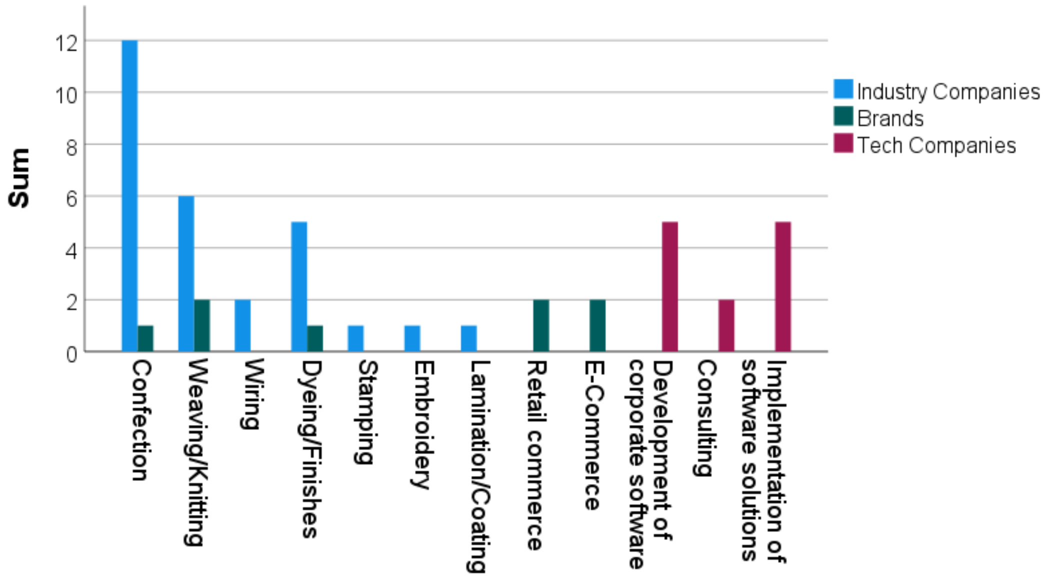


Figure 16 - Firms' main economic activities by type of firm.

From this figure, the following conclusions can be drawn:

- Most industrial companies specialize in confection, weaving/knitting, or dyeing/finishes;
- Some companies with brands also specialize in manufacturing activities, but also perform e-commerce and retail commerce activities;
- Tech companies naturally specialize in software development and implementation for textile and fashion companies, as well as consulting services.

Figure 17 indicates which technologies are most used by each firm. The main technology used by the inquired companies is an ERP (Enterprise Resource Planning) system, more than 85% of inquired companies have this type of technology. Variables F to I, which represent websites or other software for online transactions, CAD (Computer Assisted Design), 2D/3D Edition Software, and specific supplier or subcontractor management software are relatively similar in popularity within the inquired companies (used by a third of companies).

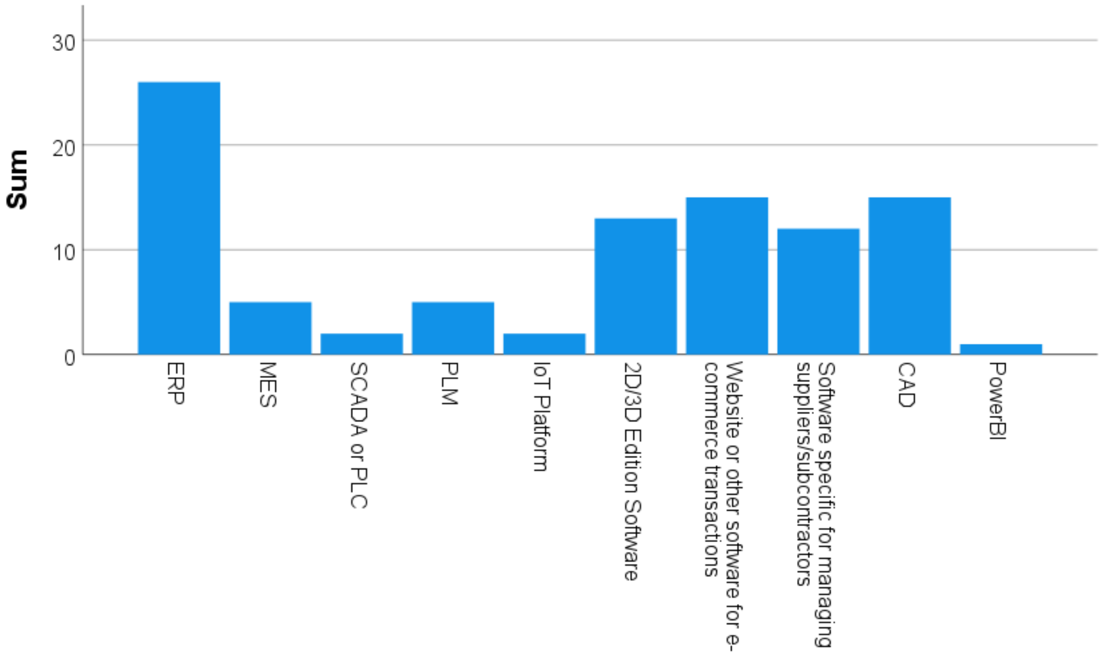


Figure 17 - Technologies used by inquired firms.

Faccia, et al (2021) argue that ERP systems can be significantly improved by combining them with blockchain. ERP systems are planning software that aims to streamline daily processes such as procurement, risk management, project management, accounting, and supply chain operations, among others. In some cases, ERP systems are equipped with software that evaluates and reports performance and budgets, enabling them to make accurate predictions for the company. However, although efficient and commonly widespread, Mahmood, et al. (2020) shows that ERP systems tend to have some issues related to top management, training and development, security risks, the taxonomy of issues, and many others, which occur due to inadequate flexibility of the systems, unclear definition of the production processes and high maintenance costs.

As such, Faccia, et al. (2021) shows that there are several benefits of ERP and blockchain integration, specifically regarding:

- **Data transparency** – Often, the supply chain is lengthy, and its processes fragmented, but BCT offers high visibility over shared and stored data at every step of the process for everyone that has an ERP system, as well as a more effective tracking of product status.
- **Trust** – BCT promotes trust among actors in the supply chain. It is a benefit that comes directly from the increased visibility for everyone's eyes, minimizing the risk

of corruption or data tampering. This makes it so that firms do not need to trust other firms, but rather the system in which they all operate.

- **Authentication and verification** – Blockchain technology enables ERP users to set up a multi-factor identification process to filter out any outside presence within the network.
- **Smart contract implementation** – smart contracts allow for easy verification of transactions. By pre-defining the terms of a smart contract, it will initialize itself as soon as all of the rules are met for transactions, making B2B commerce much easier, safer, faster, and less bureaucratic, which also leads to a decrease in the costs of commerce, especially with clients and suppliers that are located outside of the country or continent.
- **Market forecasting/predictions** – by compiling existing, transparent, and accurate real-time data, BCT helps with accurate forecasting reports of market behavior.

### 4.3.2. Companies' familiarity with blockchain and perspective of the value of blockchain elements

The question in Figure 18 marks the start of the second part of the questionnaire. Here, subjects were asked how familiar they are with blockchain on a scale of 1 to 10, 1 being "does not know what blockchain is" and 10 being "is completely aware of blockchain technology and its applications". Although only 2 of the inquired companies adopted blockchain, most of them selected their knowledge of blockchain between 7 and 8. The majority of answers situate companies' familiarity with blockchain on a scale of 5 or higher. By observing the behavior of this graph from left to right, a slight trend can be detected, where companies that are more familiar with blockchain are more likely to adopt it.

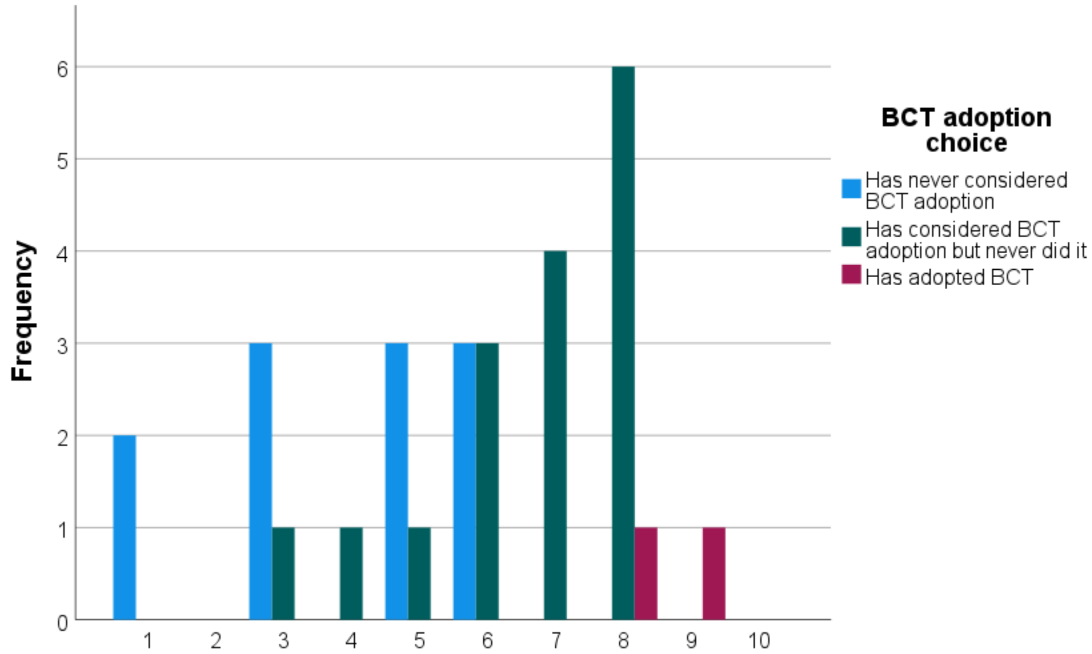


Figure 18 - Subjects' familiarity with blockchain and BCT adoption choice.

The variables in Figure 19 detail the inquired companies' priorities of which elements have a higher positive contribution to a strong partnership between companies. The inquired companies were asked to prioritize each of the variables, from more to less important. The most important in each answer received 6 points and the least important 1 point, with there being a 1-point difference between each degree of importance. The chart above shows the average points of each variable, by type of firm.

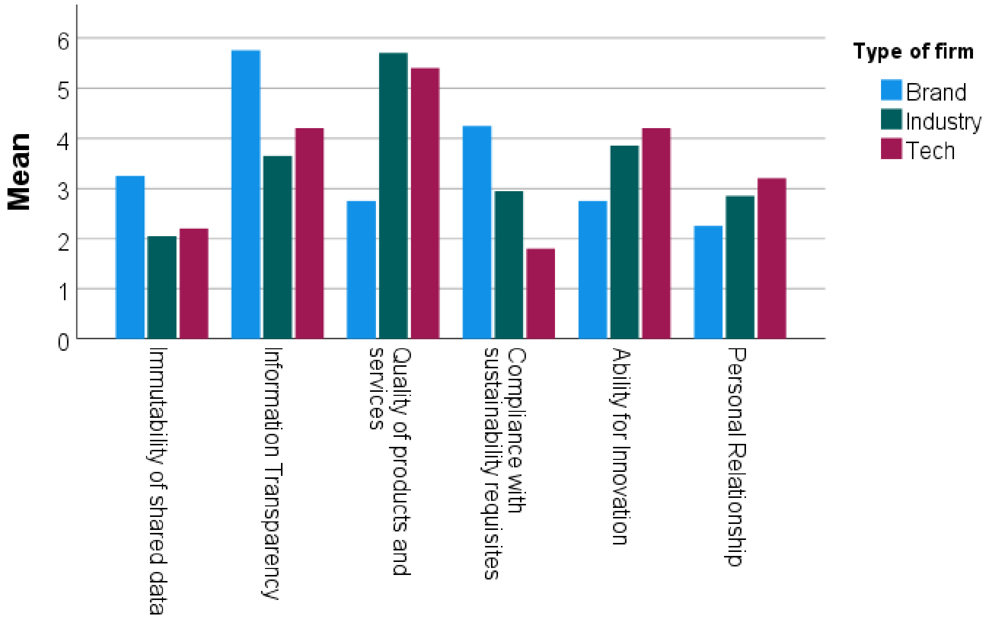


Figure 19 - Elements that contribute to a strong partnership by type of company.

From Figure 19, it can be inferred that the top priority of most inquired companies is "quality of products/services". Industry and tech companies have very similar choices when prioritizing these elements. "Information transparency" and "ability for innovation" have almost the same distribution in these types of companies, coming as 2nd and 3rd priorities. Also, for industry companies, "compliance with sustainability requisites" comes in 4th place, before "personal relationship", and "immutability of shared data" last. In tech companies' case, "compliance with sustainable requisites" comes last, after "personal relationship" and "immutability of shared data", respectively. Lastly, for companies with brands, after "information transparency", the top priority is "compliance with sustainable requisites", followed by "immutability of shared data". Elements C and E, representing "quality of products/services" and "ability for innovation", respectively, have the same scores, with "personal relationship" being the least important element.

In Figures 20 and 21, the same variables and calculation of averages as in Figure 18 were used, but the answers were categorized according to companies' blockchain adoption choice and size, respectively. In the scenario of Figure 19, it can be noticed that contrary to what would be expected, companies that have adopted blockchain chose "Immutability of shared data" and "Information Transparency" (two major benefits of blockchain) as the least important factors in a strong partnership. It can also be concluded from the graph that for companies that never considered blockchain adoption and that have considered but never adopted it, the results are quite similar, as the three most valued elements – "Quality of products/services", "Information Transparency", and "Ability for Innovation" – are the same for both categories.

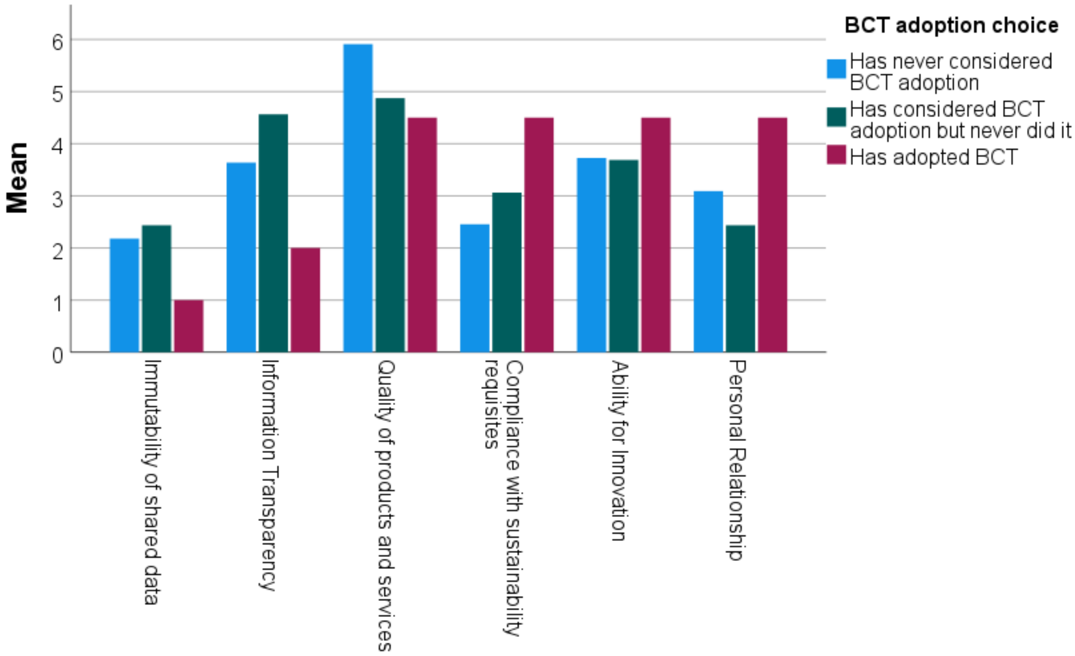


Figure 20 - Elements that contribute to a strong partnership, by BCT adoption choice.

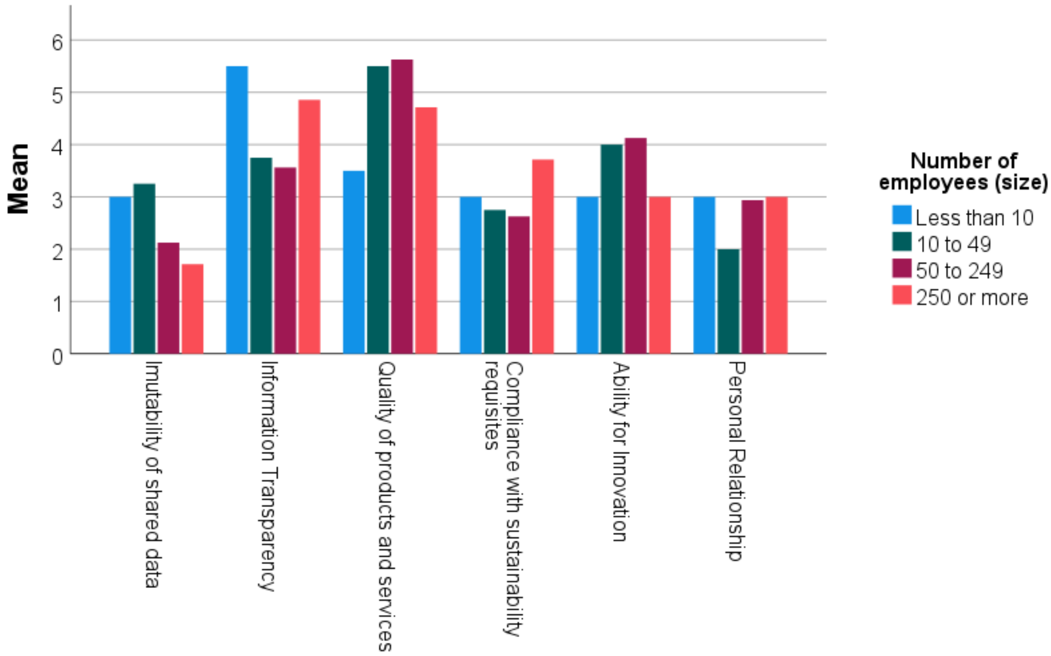


Figure 21 - Elements that contribute to a strong partnership, by company size

In Figure 21, an attempt was made to establish a relationship between priority factors in a strong partnership and the firm's size. In this figure, it can be assessed that, on average, the smallest companies, with under 10 employees, and the largest companies, with 250 or more employees both have the "Information transparency" element as the first priority in a strong partnership, immediately followed by "Quality of products and services". As for the remaining companies, "Information Transparency" comes as the third priority in this scenario, after "Quality of products and services" and "Ability for innovation". It can also be noticed that the least prioritized elements tend to be "Immutability of shared data" and "Personal relationship".

The last question of part 2 was "Has your company ever considered the adoption of blockchain?", to which three answers were possible:

1 – "The company has never considered blockchain technology adoption."

2 – "The company has considered but never adopted blockchain technology."

3 – "The company has adopted or is in the process of adopting blockchain technology."

11 companies chose answer number one, 17 companies chose answer number two, and 2 companies chose answer number three. This question helped divide the companies into

three categories, with each one of them representing a part of the questionnaire. Figure 22 summarizes this process:

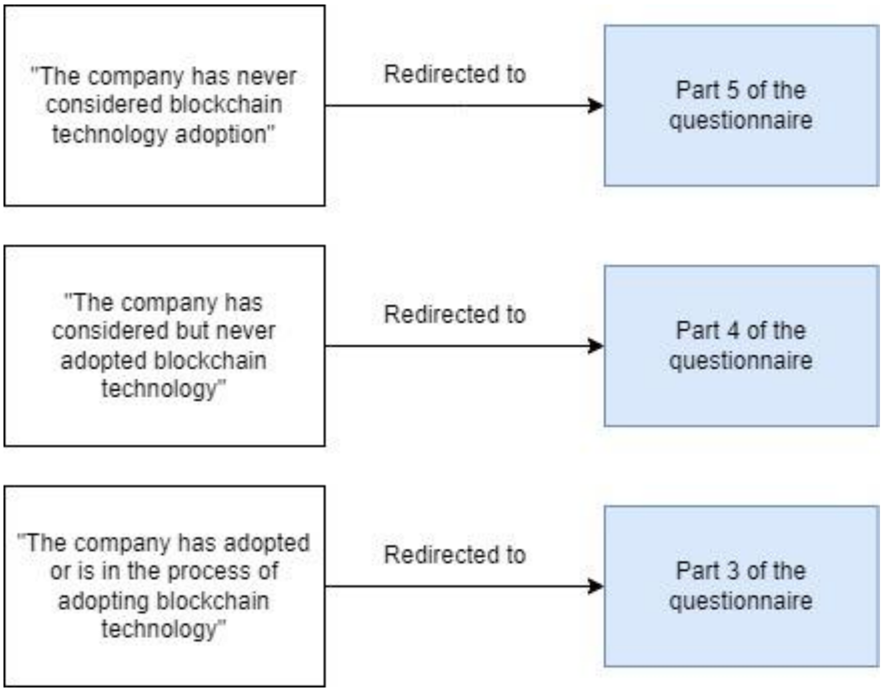


Figure 22 - Process of redirecting companies to specific parts of the questionnaire, depending on their answer to whether blockchain adoption was considered.

This choice of separation of the companies aided in the process of identifying correlations and theorizing relationships between companies' needs and choices and their perspectives on blockchain technology. Given that only 2 companies chose the third answer, questions in part 3 of the questionnaire and respective findings were grouped up with questions specific to tech companies and brands, to simplify the structure of this document.

### 4.3.3. Companies that considered blockchain adoption but did not go through with implementation.

Part 4 of the survey starts with questions on companies that considered the adoption of blockchain but never went through with it, where they were asked to give their opinion on which factors would be most positively impacted if blockchain was to be implemented into their supply chain, as is represented in Figure 23. The factors available for choosing are in the variables of the x-axis of the graph. The calculations for the values of this graph were conducted in the same manner as the ones in Figures 19 to 21. The answers provided the following data:

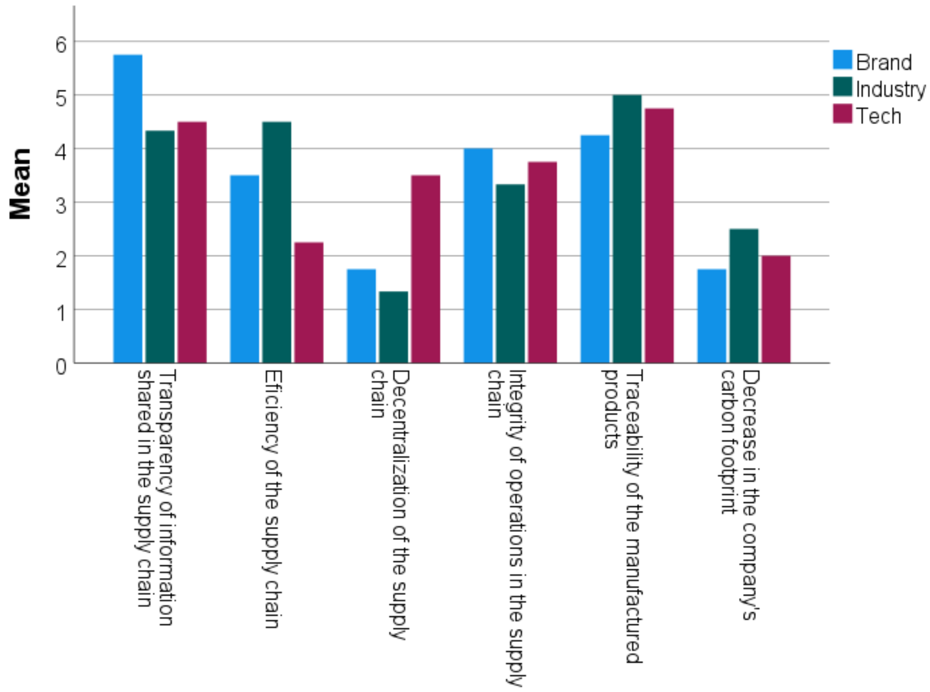


Figure 23 - Perceived positive impact of BCT in elements of supply chains, by type of firm

It can be concluded from this figure that companies with brands consider that blockchain implementation in their supply chain would most positively impact information transparency, followed by product traceability, the integrity of operations, and efficiency. From industry and tech companies' perspective, the most positively impacted factor would be the traceability of products, followed by efficiency, data transparency, and integrity of operations. Additionally, industry companies and companies with brands both consider the decentralization of the supply chain to be the least positively impacted factor, after the "Decrease in the company's carbon footprint" factor. Lastly, tech companies consider that a decrease in companies' carbon footprint and efficiency in the supply chain are the two least positively impacted factors.

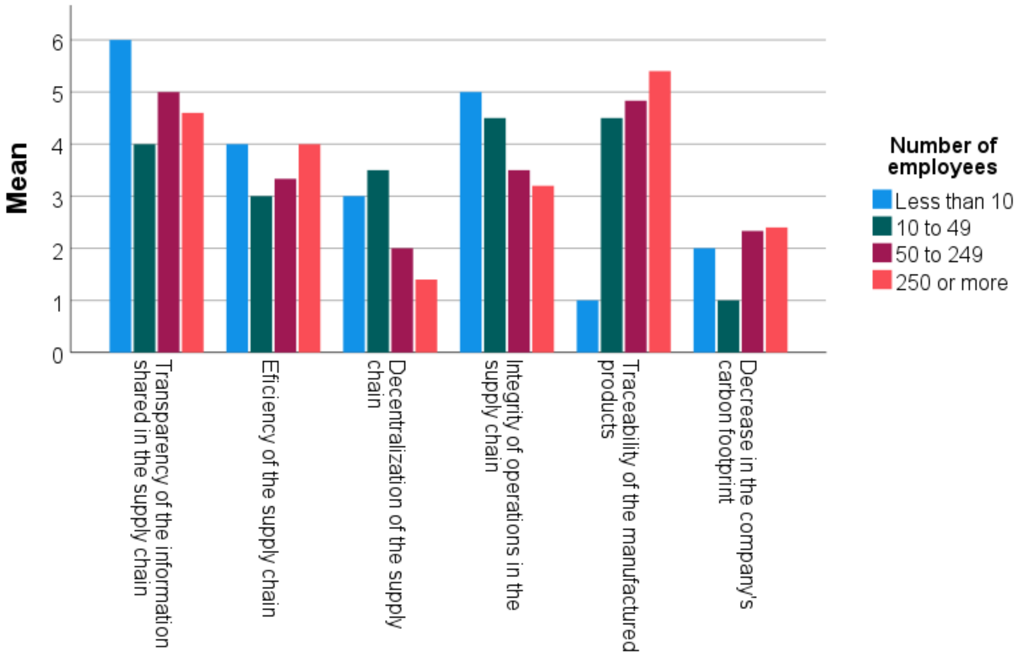


Figure 24 - Perceived positive impact of BCT in elements of supply chain, by size (number of employees)

In Figure 24, an attempt was made to find a relation between perceived positive impact and company size by looking at the number of employees. The conclusions found are the following:

- Companies with the lowest number of employees (less than 10) consider "transparency of information (…)" to be the most positively impacted element, followed by "integrity of operations (…)", and "efficiency of the supply chain". The element considered to be the least positively impacted by these companies is the "traceability of manufactured products". On the other hand, larger companies (with any number of employees ranging from 10 to over 250) consider traceability to be one of the most positively impacted elements, if not the most, when it comes to large enterprises.
- After product traceability, large enterprises consider the most positively impacted elements to be information transparency, efficiency, the integrity of operations, decrease in carbon footprint, and finally decentralization of the supply chain.
- For most companies, "Decrease in company's carbon footprint" and "Decentralization of the supply chain" have the least to gain from blockchain adoption.

### 4.3.4. Companies that have implemented blockchain, companies that never considered blockchain adoption and specific questions for tech companies and brands.

This subsection of the paper relates to Parts 3 and 5 of the business survey, which contain questions directed toward companies that have either implemented blockchain (Part 3) or that have never considered that option (Part 5). Additionally, questions specified towards the brands and tech companies that participated in the survey were formulated.

#### 4.3.4.1. Companies that have implemented blockchain

Regarding blockchain implementation, only 2 out of 30 surveyed companies have stated that they implemented blockchain technology in their activity. When asked about the processes on which blockchain had been integrated, one firm answered "3D-Print Design".

3D Printing is the process of making three-dimensional solid objects from a digital file, and it can be applied to consumer and industrial products, dental products, prosthetics, architectural models, and reconstruction of artifacts, among others (3DPrinting.com, n.d.). Klockner, et al. (2020) argues that business models built around 3D printing present key issues that stop companies from fully committing to this technology. These issues are unauthorized use of IP (specifically CAD file usage), counterfeiting, and malicious data manipulation. However, the authors argue that "blockchain technology could serve as an underlying safeguarding layer in the 3D printing value chain by protecting data records against manipulation", specifically printing licenses, production process data, simulation data, etc. The authors claim that using blockchain in 3D printing affects the creation and capture of value, by securing the transfer of files, improving cost structures, and monetizing unused production capacity; as well as the value proposition, by offering less expensive products (lowering logistics costs) and more flexible production capacities.

The other firm stated that its use of blockchain was focused on commerce transactions for mass balance verification. According to Agrawal, et al. (2021), mass balance is the application of the mass conservation principle for the analysis of physical systems. In this specific context, mass balancing accounts for the material entering and exiting along with the current mass accumulated in a given system. It is a way to track and allocate quantities of recycled materials in existing systems, allowing manufacturers to know how much of their product is sustainable. A mass balance approach alone acts as a facilitator for the use of recycled or renewable materials. However, blockchain and certification of sustainable material usage ensure the enforcement of mass balance rules and promote visibility and transparency throughout the whole process. One way to aid the mass balance approach would be by adding a "token" to assets, so as to create a digital version of the product. Whatever processes the product goes through will be stored in the token accompanying it, making the product traceable and its data fully transparent across the supply chain.

In another question, both companies stated that the adoption of blockchain did not occur under a publicly financed project, indicating that the implementation was not made in the context of committed public funds, but rather out of the companies' own pocket and effort. They were also asked about their perspective on blockchain now that they have used it. The companies were shown five sentences about blockchain, to which they had to answer with levels of agreement – "Do not agree", "Partially agree", "Completely agree", and "I cannot answer". The sentences and respective results are as follows:

| **Sentences** | **Answers** |
|---|---|
| BCT is easy to understand | Both "Partially agree" |
| BCT is easy to use | Both "Partially agree" |
| BCT contributes to a rise in productivity | Firm A "Cannot answer" and Firm B "Partially agrees" |
| The firm trusts BCT | Firm A "Completely agrees" and Firm B "Partially agrees" |
| The firm plans on using BCT in the future | Firm A "Partially agrees" and Firm B "Completely agrees" |

Table 4 - Agreeability of firms that have used BCT.

Although the number of subjects is limited to arrive at a satisfying conclusion, it can be seen that both companies partially agree that blockchain is easy to use and understand, both trust in blockchain to some extent, and at least one has plans to use blockchain once again in the future.

#### 4.3.4.2. Companies that never considered blockchain adoption

Part 5 of the questionnaire concerns companies that have never considered blockchain adoption. In this part, eleven subjects were asked two straightforward scale-based questions. The questions were the following:

1 – "How important do you think blockchain will be in your firm's and industry's future?"

2 – "On a scale from 1 to 5, how willing is your firm to adopt technologies that contribute to information transparency between business partners? [1-Not willing; 5-Willing to adopt as soon as possible]".

The purpose of the questions in part 5 was to assess whether companies that have not considered the use of blockchain believe that it has any business value to them and if they value the intrinsic characteristics that a blockchain-based solution provides.

In Figure 24, it can be seen that the majority of companies believe that blockchain will be "Very important" to the future of their firm and industry and only one believes it will not be important. Similarly, in Figure 25, no firm has chosen 2 or fewer, meaning that they all value, to some extent, information transparency, a core value of blockchain.

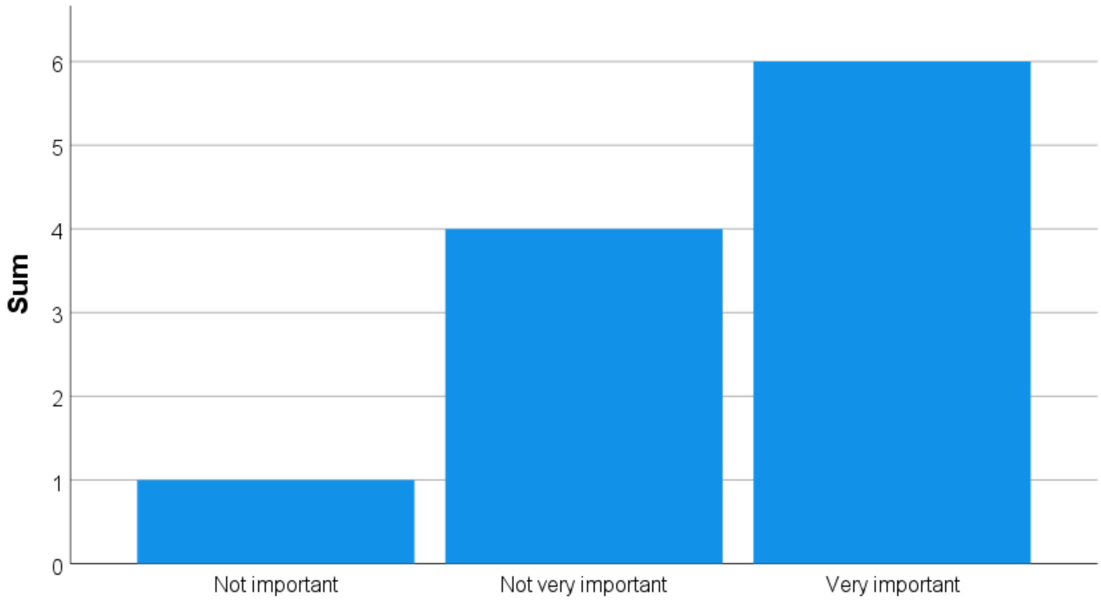


Figure 25 - Perceived importance of BCT to subject's firm and industry

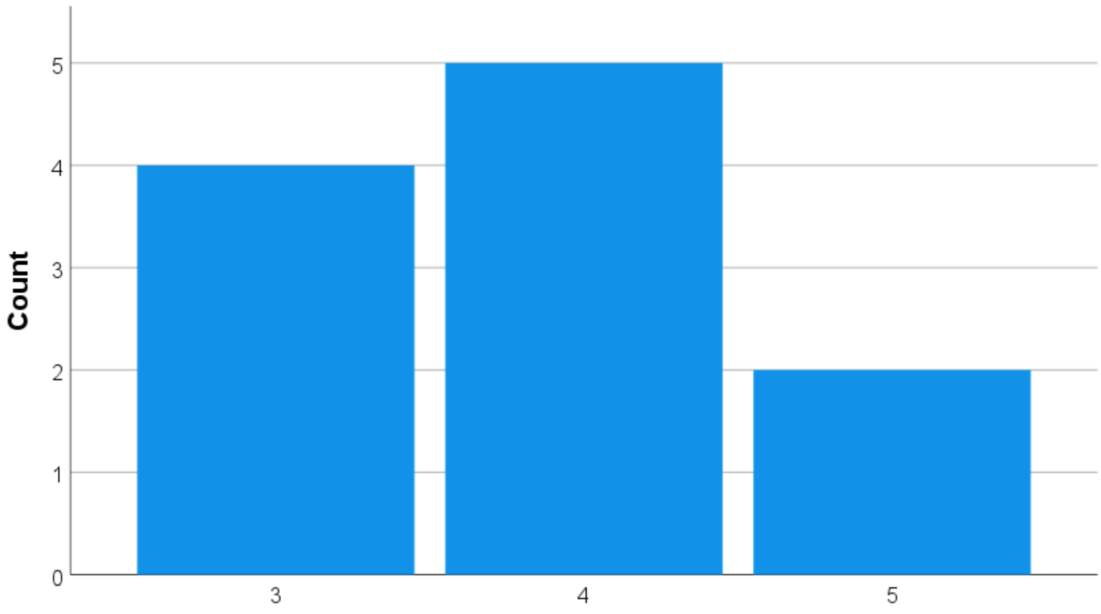


Figure 26 - Willingness to adopt technologies that contribute to information transparency.

#### 4.3.4.3. Brands and tech companies

To address brands, two simple questions were asked. The first one was "Does your company intend to use the term blockchain for marketing purposes?", to which half the companies responded positively and the other half negatively.

Afterward, the companies were asked a scale-based question. The second question was "When applied to the textile industry, blockchain technology could allow consumers to have full knowledge of every place a specific product has been in, as well as its carbon footprint. In your company's perspective, how important is this information to consumers?". To this question, all companies with brands responded with "Very important", which aligns with the fact that product traceability is one of the factors perceived to be very positively impacted by blockchain from the perspective of companies with brands, as figure 27 shows.

Regarding tech companies, 2 scale-based questions were asked. The first question was "On a scale of 1 to 5, how important do you consider that blockchain integration on your products and services is, to your clients?", "1" being labeled as "Not Important" and "5" as "It is essential". In this question, and as Figure 23 shows, companies did not choose options "1" or "5". 60% of companies chose option "2", 20% chose "3" and the remaining 20% chose "4".

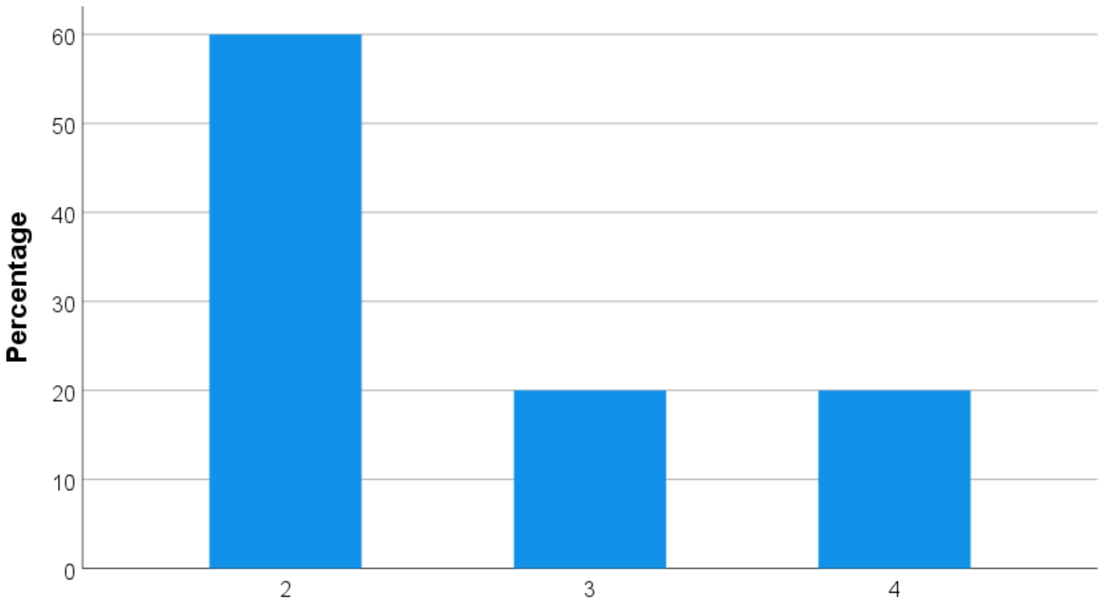


Figure 27 - Perceived importance of BCT integration in products and services to customers

The second question for tech companies was "Do you agree with the following statement: The company considers that it is essential that the future of its business incorporates the adoption of blockchain technology". The answer was scale-based and allowed for three options: "Do not agree", "Partially agree", and "Completely agree".

By analyzing the answers in figure 28, no firm completely agrees with the statement. 80% of the companies partially agree and 20% do not agree with the statement.

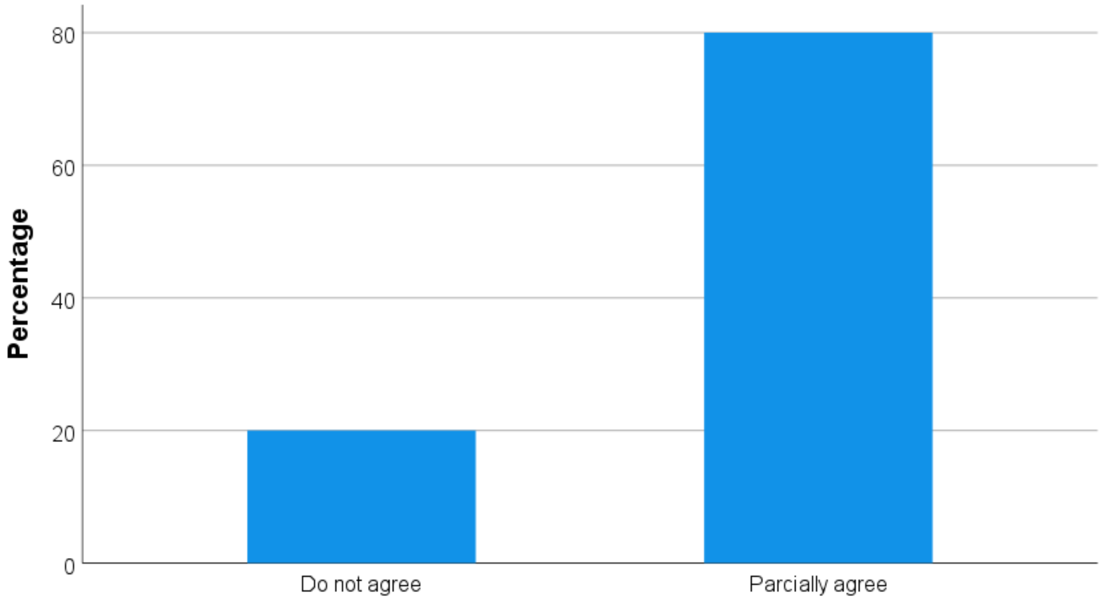


Figure 28 - Do you agree with the following statement: "My company considers that it is essential that the future of its business includes the adoption of blockchain technology"?

## 4.4. Discussion

This chapter aims to answer the proposed questions that served as a guide for the questionnaire. The proposed questions were the following:

> **RQ3:** Are the characteristics of information transparency, data immutability, and product traceability elements of high priority for a selection of companies in the textile sector?
>
> **RQ4:** What is the status of the adoption of blockchain technology in the Portuguese textile and fashion industry?

To answer **RQ3**, Figures 19 to 21 illustrate what companies believe are the most important elements that compose a strong partnership. To assess the degree of priority of information transparency and data immutability, those elements (which will be called the "blockchain elements" for the rest of this chapter) were paired with four other elements that aren't directly impacted by blockchain, but also represent positive contributions to a strong partnership. The other elements are "Quality of products and services", "Compliance with sustainability requirements", "Ability for innovation", and "Personal relationship". It was assessed that the priority of these elements tends to change depending on the type of firm, their choice for blockchain adoption, and their number of employees, indicating size.

Starting with the type of firm (Figure 19), brands appear to be the ones that value the blockchain elements the most, with the highest priority element being "Information transparency" and 3rd highest "Immutability of shared data". For companies in an industrial context, these elements are the 3rd and last priorities, respectively. As for tech companies, "Information transparency" shares 2nd place with "Ability for innovation", and "Immutability of shared data" is 2nd to last on the list of priorities. The fact that companies with brands tend to value information transparency more than the other types of companies could derive from having to deal with the end consumer, who according to the work of Gupta and Kumar (2013), is increasingly demanding with companies when it comes to sustainable and ethical practices, which are shown through data regarding carbon footprint, recycling levels, and location of source of raw materials.

Analyzing this priority of elements through choice for blockchain adoption (Figure 20), it was concluded that blockchain adopters consider blockchain elements to be less important to a strong partnership than non-blockchain elements. However, companies that have considered but never adopted blockchain chose on average "information transparency" as the second highest contributor to strong partnerships. As for companies that never considered blockchain adoption, their answers indicate that "information transparency" is as important of a contributor as "ability for innovation". For all companies in Figure 20, "Immutability of shared data" is the least important contributor to a strong partnership.

When analyzing the priority of elements through firm size (Figure 21), it can be pointed out that only companies with less than 10 employees and companies with 20 or more employees have chosen "Information transparency" as the highest contributor to a strong partnership. However, both these groups of companies have placed "Immutability of shared data" among the lowest important contributors.

To address how companies perceive the **traceability of products**, subjects were asked about what they believe are the most positively impacted elements by blockchain adoption.

Similar to the previous elements, the "Traceability of manufactured products" was one of six elements of the supply chain that companies had to prioritize. Once again, the data was divided and analyzed through types of companies and sizes. To all three types of companies (industrial, technological, and with brands), traceability of products is the second highest element to be positively impacted by blockchain, right after "Transparency of information shared in the supply chain". When analyzing firm size, both these elements are also the choices for the highest perceived positive impact by blockchain, except in the case of micro-enterprises, where the traceability of products has the lowest perceived positive impact.

To answer **RQ4**, out of the 30 companies that participated in the business survey, only 2 stated that they had adopted blockchain. Given that only two companies were able to testify to the advantages of using blockchain technology, this proved to be too few of a number of subjects to be able to extract findings based on companies' type, size, and blockchain adoption choice, thus making it harder to arrive at satisfactory results and conclusions.

Nevertheless, these two subjects indicated that blockchain technology was used for 3D-Print Design, and mass balance verification. Although the companies have not explicitly stated what advantages came from the implementation of blockchain, the literature suggests that blockchain adoption has high benefit potential for value creation and optimization in business models built around 3D Printing; and for data assessment in recycled materials, as it regards mass balance verification.

For this research question, the biggest limitation was found in part 3 of the questionnaire, where only two companies were able to testify to the advantages of using blockchain technology. This proved to be too few of a number of subjects to be able to extract findings based on companies' type, size, and blockchain adoption choice, thus making it harder to arrive at satisfactory results and conclusions.

# 5. Conclusions and future work

This final chapter contains the conclusion of this work, where the objectives of the dissertation are revisited, and an analysis is made of whether or not the objectives were met. Additionally, relevant limitations and obstacles found during the course of this dissertation are mentioned.

The proposed objectives for this dissertation were as follows:

Objective 1 - Analyze the evolution of blockchain-based supply chain solutions in different industries and contexts.

Objective 2 - Assess the implementation of blockchain technology in the Portuguese textile and fashion industry's supply chain, evaluating its impact on efficiency, transparency, and traceability.

The systematic literature review's scope was conditioned by objective 1 of this thesis, which aims to assess the evolution of blockchain-based supply chain solutions across industries. The findings of the systematic literature review indicate that the interest in blockchain as a solution for supply chain issues increased exponentially between 2016 and 2022, and that several major companies are investing in blockchain-driven solutions for supply chain issues. Specifically, the food industry stands out as the strongest investor among industries in this technology, as an increasing number of companies in the food and agricultural sectors view the traceability of products as a defining factor in their near future success, contributing to the increase of consumer knowledge over the foods they purchase, waste mitigation, and efficiency in the supply chain. Additionally, agricultural companies are avid users of IoT technology, which some authors believe to be an effective tool when paired with blockchain technology.

To summarize the results found in the business survey, and to address objective 2 of the thesis, the most important contributor to strong partnerships is "Quality of products and services", and "Information transparency" is among the three most prioritized elements, with specific groups of companies such as brands, micro-enterprises, and large enterprises showing a preference over this blockchain element. As for the second blockchain element, "Immutability of shared data" tends to be one of the least important contributors across all groups of companies. In the case of the traceability of products, although it was not possible to address how companies value this element, it can be concluded that most companies believe that blockchain adoption would positively and highly impact this element.

Additionally, certain specific technologies or practices, such as IoT, ERPs, 3D Printing, and Mass Balance are posed with different benefits when supported by blockchain, with advantages regarding sustainable practices, cuts in the cost structure of business models, and assurance of the transaction of transparent and immutable data. However, companies participating in the STVgoDIGITAL project note that one of the biggest obstacles in PPS 1 is the fact that companies' ERP systems are too different, and in some cases non-existent, which could make it difficult to obtain the necessary data at each step of the production process of textiles.

# References


*About Hyperledger Foundation*. (2022). Retrieved December 12th, 2022, from Hyperledger Foundation: https://www.hyperledger.org/about

Adisorn, T., Tholen, L., & Gotz, T. (2021). Towards a Digital Product Passport Fit for Contributing to a Circular Economy. *Energies, Vol. 14*(8), pp. 1-16.

Agrawal, T. K., Kumar, V., Pal, R., Wang, L., & Chen, Y. (2021). Blockchain-based framework for supply chain traceability: A case example of textile and clothing industry. *Computers & Industrial Engineering, Vol. 154*.

Anwar, H. (2021, April 15th). *Key Differences Between Hyperledger Aries And Hyperledger Fabric*. Retrieved December 12th, 2022, from 101 Blockchains: https://101blockchains.com/hyperledger-fabric-vs-aries/

ATP. (2019, Agosto). *Roadmap para a especialização inteligente e competitividade global da ITV Portuguesa.* Retrieved from ATP: https://atp.pt/wp-content/uploads/2019/06/RoadMap.pdf

Balasubramanian, S., Shukla, V., Singh Sethi, J., Islam, N., & Saloum, R. (2021). A readiness assessment framework for Blockchain adoption: A healthcare case study. *Technological Forecasting and Social Change, Vol. 165*.

Belchior, R., Vasconcelos, A., Guerreiro, S., & Correia, M. (2022). A Survey on Blockchain Interoperability: Past, Present, and Future. *AMC Computing Surveys, Vol. 54*(8), pp. 1-41.

*Byzantine Fault Tolerance Explained.* (2022, December 6th). Retrieved December 21st, 2022, from Binance Academy: https://academy.binance.com/en/articles/byzantine-fault-tolerance-explained

Cao, B., Li, Y., Zhang, L., Zhang, L., Mumtaz, S., Zhou, Z., & Peng, M. (2019). When Internet of Things Meets Blockchain: Challenges in Distributed Consensus. *IEEE Network, Vol. 33*(6), pp. 133-139.

Casino, F., Dasaklis, T. K., & Patsakis, C. (2018). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics, Vol. 36*, pp. 55-81.

Chengyue, Y., Prabhu, M., Goli, M., & Sahu, A. K. (2021). Factors Affecting the Adoption of Blockchain Technology in the Complex Industrial Systems: Data Modeling. *Complexity, Vol. 2021*, pp. 1-10.

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and Smart Contracts for the Internet of Things. *IEEE Access, Vol 4.*, pp. 2292 - 2303.

*CircularChain® Passport*. (n.d.). Retrieved January 4th, 2023, from Suez: https://www.suez.com/en/circularchain

Erol, I., Ilker, A. M., Ihsan Ozdemir, A., Peker, I., Asgary, A., Tolga Medeni, I., & Medeni, T. (2020). Assessing the feasibility of blockchain technology in industries: evidence from Turkey. *Journal of Enterprise Information Management, Vol. 34*(3), pp. 746-769.

*Estatísticas*. (2021). Retrieved February 14th, 2023, from ATP: https://atp.pt/pt-pt/estatisticas/estatisticas-2020/

*European Commission*. (2022, March 30th). Retrieved October 1st, 2022, from European Commission: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013

Faccia, A., & Petratos, P. (2021). Blockchain, Enterprise Resource Planning (ERP) and Accounting Information Systems (AIS): Research on e-Procurement and System Integration. *Applied Sciences, Vol. 11*(15), pp. 1-17.

Farooq, M. S., Riaz, S., Abid, A., Umer, T., & Zikria, Y. B. (2020). Role of IoT Technology in Agriculture: A Systematic Literature Review. *Electronics, Vol. 9*(2), pp. 319.

Feng, H., Wang, X., Duan, Y., & Jian, Z. (2020). Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges. *Journal of Cleaner Production, Vol. 260*.

Frankenfield, J. (2023, February 17th). *What Are Consensus Mechanisms in Blockchain and Cryptocurrency?* Retrieved March 22nd, 2023, from Investopedia: https://www.investopedia.com/terms/c/consensus-mechanism-cryptocurrency.asp

Frankenfield, J. (2023, May 31st). *What Does Proof-of-Stake (PoS) Mean in Crypto?* Retrieved from Investopedia: https://www.investopedia.com/terms/p/proof-stake-pos.asp

Fu, B., Shu, Z., & Xiaogang, L. (2018). Blockchain Enhanced Emission Trading Framework in Fashion Apparel Manufacturing Industry. *Sustainability, Vol. 10*(4).

Gupta, S., & Kumar, V. (2013). Sustainability as corporate culture of a brand for superior performance. *Journal of World Business, Vol. 48*(3), pp. 311-320.

Haber, S., & Stornetta, W. S. (2001). How to Time-Stamp a Digital Document. *Advances in Cryptology - CRYPTO'90* (pp. pp. 437-455). Berlin, Heidelberg: Springer.

Hader, M., Tchoffa, D., Mhamedi, A. E., Ghodous, P., Dolgui, A., & Abouabdellah, A. (2022). Applying integrated Blockchain and Big Data technologies to improve supply chain traceability and information sharing in the textile sector. *Journal of Industrial Information Integration, Vol. 28*, pp. 1-20.

Hemphill, T. A. (2020). Biologics regulation, second-to-market competition, and theuse of blockchain technology: an opportunity for the FDA tosupport responsible biotechnology innovation. *Journal of Responsible Innovation, Vol. 7*(3), pp. 689-696.

Irannezhad, E., & Mahadevan, R. (2020). Is blockchain tourism's new hope? *Journal of Hospitality and Tourism Technology, Vol. 12*(1), pp. 85-96.

Klockner, M., Kurpjuweit, S., Velu, C., & Wagner, S. M. (2020). Does Blockchain for 3D Printing Offer Opportunities for Business Model Innovation? *Research-Technology Management, Vol. 63*(4), pp. 18-27.

Köhler, S., & Pizzol, M. (2020). Technology assessment of blockchain-based technologies in the food supply chain. *Journal of Cleaner Production, Vol. 269*.

Kusi-Sarpong, S., Murabik, M. S., Khan, S. A., Brown, S., & Murabak, M. F. (2022). Intellectual capital, blockchain-driven supply chain and sustainable production: Role of supply chain mapping. *Technological Forecasting & Social Change, Vol. 175*, 121331.

Mahmood, F., Khan, A. Z., & Bokhari, R. H. (2020). ERP issues and challenges: a research synthesis. *Kybernetes, Vol. 49*(3), pp. 629-659.

Manzoor, R., Sahay, B. S., & Singh, S. K. (2022). Blockchain technology in supply chain management: an organizational theoretic overview and research agenda. *Annals of Operations Research*.

Nair, N., Dalal, A. K., Chhabra, A., & Giri, N. (2019). Edu-Coin: A Proof of Stake implementation of a decentralized skill validation application. *2019 International Conference on Nascent Technologies in Engineering (ICNTE)* (pp. pp. 1-4). Mumbai, Índia: IEEE.

Nakamoto, S. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System*.

Nazam, M., Hashim, M., Marcel Nută, F., Yao, L., Azam Zia, M., Yousaf Malik, M., . . . Dimen, L. (2022). Devising a Mechanism for Analyzing the Barriers of Blockchain Adoption in the Textile Supply Chain: A Sustainable Business Perspective. *Sustainability, Vol. 14*(23).

Nguyen, C. T., Hoang, D. T., Nguyen, D. N., Niyato, D., Nguyen, H. T., & Dutkiewicz, E. (2019). Proof-of-Stake Consensus Mechanisms for Future Blockchain Networks: Fundamentals, Applications and Opportunities. *IEEE Access, Vol. 7*, pp. 85727-85745.

Pedreira, V., Barros, D., & Pinto, P. (2021). A Review of Attacks, Vulnerabilities, and Defenses in Industry 4.0 with New Challenges on Data Sovereignty Ahead. *Sensors, Vol. 21*(15), pp. 1-21.

Pérez, J. J., Queiruga-Dios, A., Martínez, V. G., & del Rey, Á. M. (2020). Traceability of Ready-to-Wear Clothing through Blockchain Technology. *Sustainability, Vol. 12*(18).

Shou, M., & Domenech, T. (2022). Integrating LCA and blockchain technology to promote circular fashion – A case study of leather handbags. *Journal of Cleaner Production, Vol. 373*.

Stretton, C. (2022, April 20th). *Digital product passports (DPP): what, how, and why?* Retrieved October 1st, 2022, from Circularise: https://www.circularise.com/blogs/digital-product-passports-dpp-what-how-and-why

*STVgoDigital: Digitalização da cadeia de valor do STV*. (2020). Retrieved September 14th, 2022, from Citeve Tecnologia Têxtil: https://www.citeve.pt/artigo/stvgodigital

Sumnola, F. T., Burgess, P., & Tan, A. (2021). Building Blocks for Blockchain Adoption in Digital Transformation of Sustainable Supply Chains. *30th International Conference on*

*Flexible Automation and Intelligent Manufacturing. Vol. 55*, pp. pp. 513-520. Athens, Greece: Elsevier Ltd.

Turilli, M., & Floridi, L. (2009). The ethics of information transparency. *Ethics and Information Technology, Vol. 11*, pp. 105-112.

*What is 3D Printing?* (2023). Retrieved January 8th, 2023, from 3DPrinting.com: https://3dprinting.com/what-is-3d-printing/

Xu, S., Zhao, X., & Liu, Z. (2020). The impact of blockchain technology on the cost of food traceability supply chain. *2020 International Conference on Green Development and Environmental Science and Technology. Vol. 615*, pp. pp. 1-8. Changsha, China: IOP Conference Series: Earth and Environmental Science.

Yousuf, S., & Svetinovic, D. (2019). Blockchain Technology in Supply Chain Management: Preliminary Study. *2019 Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS)* (pp. pp. 537-538). Granada, Spain: IEEE.

# III. Attachments

| | |
|---|---|
| A. Fúzia & Irmão, Lda | LASA - Armando da Silva Antunes, S.A. |
| A. Sampaio & Filhos, Têxtil S.A. | Latino Confeções, Lda |
| AAC Têxteis, S.A. | Lopes & Carvalho, Lda |
| Coltec – Neves & Companhia, Lda | MIB – Máquinas Industriais para Bordados, Lda |
| Confetil, S.A. | Mundotêxtil – Indústrias Têxteis, S.A. |
| Cordeiro, Campos & Cª Lda | NKA - New Knowledge Advice, Lda |
| Domingos de Sousa & Filhos, S.A. | Pafil – Confeções, Lda |
| Dune Bleue, Lda | Pedrosa & Rodrigues, S.A. |
| Estamparia Adalberto, S.A. | Priority Season Unipessoal, Lda |
| Fluxodata, Lda | Têxtil Manuel Gonçalves, S.A. |
| F3M Information Systems, S.A. | Tintex Textiles, S.A. |
| Impetus Portugal Têxteis, S.A. | TMR Fashion Clothing, Lda |
| Infos, S.A. | Unifardas, S.A. |
| Inforcávado – Informática, Lda | Nº - Zeitreel Sonae |
| Inovafil, S.A. | |

Table 5 - Companies that participated in the survey.