Blockchain technology: driving innovation in the supply chain

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To all those who are fighting to protect knowledge and culture
for future generations.

Acknowledgments

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Abstract

This thesis presents a study of blockchain impacts for supply chain (SC) application. By conducting explorative research, the thesis presents a grounded theory analysis based on eighteen interviews with international experts from different fields such as academics, business and institutional representatives.

The study is divided into four phases: the first phase begins with the analysis and identification of the type of innovation for blockchain in SC; the second phase analyzes the effective combination between blockchain technologies and SC management processes; the third phase introduces the major influences affecting SC operations for a blockchain transition in SC; and the fourth one presents a use case.

The research results show that blockchain for SC presents all features to be a sustaining innovation rather than disruptive. However, results confirmed that SCs appear to be one of the most prominent fields of application for blockchain, and a blockchain-based SC fits in supplier relationship management processes and financial business units. Lastly, to mitigate risks, the analysis also identified elements that may support digital transition procedures in SCs.

The thesis concludes by merging all results found and provides suggestions for future research perspectives.

Resum

Aquesta tesi presenta un estudi de l'impacte de blockchain en las eva aplicació a les cadenes de subministrament (supply-chain o SC). Mitjançant la realització d'una recerca exploratòria la tesi presenta una anàlisi fonamentada en divuit entrevistes amb experts internacionals de diferents camps, com ara representants acadèmics, empresarials i institucionals.

La recerca es divideix en quatre fases: la primera fase comença amb l'anàlisi i la identificació del tipus d'innovació per a la blockchain a SC; la segona fase analitza la combinació efectiva entre les tecnologies de blockchain i els processos de gestió de SC; la tercera fase introdueix les principals influències que afecten les operacions de SC per a una transició blockchain a SC; i el quart presenta un cas d'ús concret.

Els resultats de la investigació mostren que blockchain per a SC presenta totes les característiques d'una innovació evolutiva més

que disruptiva. No obstant això, els resultats van confirmar que les SC són un dels camps d'aplicació amb més projecció per a blockchain i que una SC basada en blockchain s'adapta millor als processos de gestió de relacions amb proveïdors i a les unitats de negoci financeres. Finalment, per mitigar els riscos, l'anàlisi també va identificar elements que poden donar suport als procediments de transició digital en les SC.

La tesi conclou presentant els resultats trobats i proporciona suggeriments per a futures perspectives de recerca.

Preface

This doctoral thesis presents the outcomes that resulted from the study of blockchain technology for supply chain applications.
The research study started in 2017, a significant year in which new trends and innovations were distinguishing the perceptions of blockchain as an emerging technology.
Despite the fast changes happening throughout these years, the research aimed to shed some light on blockchain technology by analyzing and identifying the main features characterizing the technology and detecting the pillars that might play a significant role for future deployments.
Data were collected by designing expert interviews with a pool of eighteen international practitioners, who were key to obtaining valuable knowledge and insights.
As a result of the analysis performed, four journal publications described some of the main criticisms identified in the blockchain technology for supply chain applications, and outlined opportunities for further improvements and developments. The four publications are listed below and represent the progressive steps of this thesis work:

- Paper 1

Results of Phase 1 identify the type of innovation for blockchain in supply chains and present the enablers that may foster its deployments.

  - Della Valle, F.; Oliver, M. Blockchain Enablers for Supply Chains: How to Boost Implementation in Industry. *IEEE Access 2020, 8, 209699–209716,* doi:10.1109/ACCESS.2020.3038463.
  - Published in the Special Issue: *Blockchain Technology: Principles and Applications*. (IF 3.367; Q1).

- Paper 2

Results of Phase 2 identify the supply chain management processes that drive blockchain technology.

- Della Valle, F.; Oliver, M. Blockchain-Based Information Management for Supply Chain Data-Platforms. *Appl. Sci. 2021*, *11*, *8161*. https://doi.org/10.3390/app11178161.
- Published in the Special Issue: *New Trends on Blockchain Technology*. (IF 2.679; Q2).

- Paper 3

Results of Phase 3 may support the design phases of digital transition in blockchain-based supply chains.

- Della Valle, F.; Oliver, M. A Guidance for Blockchain-Based Digital Transition in Supply Chains. *Appl. Sci. 2021*, *11*, *6523*, doi:10.3390/APP11146523.
- Published in the Special Issue: *Advances in Blockchain Technology and Applications II*. (IF 2.679; Q2).

- Paper 4

Results of this specific study highlight potential actions for the development of blockchain in the COVID-19 response, keeping a medical perspective as core review.

- Della Valle, F.; Platt, S.; Oliver, M. “Review of Blockchain for Pandemic Surveillance and COVID-19 Response”. *Electronics 2021, (submitted August 30*th, *minor revisions).*
- Submitted at the Special Issue: *Multidisciplinary Views on Mobile Communications*. (IF 2.397; Q2).

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Chapter 1

INTRODUCTION

Sections:

1.1 Contextualization of the thesis

During the first years of implementation, the Enterprise Resource Planning (ERP) systems faced several failure cases and company bankruptcy [1]–[3]. These insolvencies were created from a bad management of the technology implementation, underestimations of related risks, and inappropriate digital transition plans [1]–[5]. In fact, this new way to operate with new forms of managing businesses needs to have solid transition plans and risks mitigations. The same risks companies faced almost twenty years ago with ERP, are now under threats for Blockchain Technology (BT) implementation. In fact, the high expectations of the potential integration of blockchain in industry are pushing the market tests and piloting new deployments in unexplored fields. For such reasons, it is relevant to consider the lessons learned from the failures of ERPs in order to carefully evaluate the future steps of BT development.

Therefore, this research work presents an analysis of blockchain for industrial applications, sharpening the focus on blockchain-based supply chain. The research contribution is articulated in three main papers and an additional one with a presentation of a use case.

The results of the study have the objectives of proposing guidelines, plans and strategies to mitigate implementation risks and encourage good technology management.

The first paper ("*Blockchain Enablers for Supply Chains: How to Boost Implementation in Industry*") analyzes the disruptiveness of blockchain features for supply chains, identifying the type of innovation it represents. This was conducted as the first step in order to recognize specific aspects of the technology and the mechanisms to assess future implementation in supply chain (SC). Acquiring this information was crucial to get to a deeper level of the analysis and address the emerging needs.

The second paper ("*Blockchain-Based Information Management for Supply Chain Data-Platforms*") analyzes the supply chain processes where blockchain may bring significant benefits and which risks may incur. It is relevant to highlight that the supply chain is characterized by high complexity and harmonization of several technology systems that, frequently, are working under time pressure and urgent tasks. Indeed, a blockchain implementation may cause delays in some activities and have negative impacts all along the chain. Therefore, after the identification of key assets where the technology brings value, the third paper ("*A Guidance for Blockchain-Based Digital Transition in Supply Chains*") aimed at sharpening the focus and critical elements for digital transitions of SC.

As a network function, blockchain needs to be carefully designed and deployed in current systems inasmuch it requires large efforts in technologies, resources, and economic burden. In fact, the financial commitment for an implementation in industrial sectors needs to be carefully measured and requires constant leadership from managers and technicians. Hence, the third paper provides a guidance for blockchain assessment in SC operations, suggesting keeping the focus on the value creation and capture, the transformative role of blockchain, and the digital business strategies to perform.

Therefore, the analysis conducted in these three papers started from a broader examination of innovation management and moved deeper in technical aspects related with the area of study, and then with the detection of critical aspects for future transition.

As an additional result, a fourth paper ("*Review of Blockchain for Pandemic Surveillance and COVID-19 Response*") presents instead a use case of blockchain in the COVID-19 response. The 2020 pandemic led to the necessity to assess the potential of blockchain for medical applications and social purposes. This use case was developed together with the UPF NeTS research group and had the intention of providing a contribution for tackling the ongoing health crisis.

1.2 Background

In the last few years the emerging technologies such as Distributed Ledgers Technologies (DLTs) – or Blockchain Technology (BT) – have shown a very rapid growth trend, both for applications and market tests, grasping the interest of the scientific community [6], [7]. The terms DLT and BT can often be considered interchangeable, and it is relevant to note that blockchain has become a more colloquial name for all types of DLTs. However, blockchain is actually one type of DLT. The best-known example of a DLT is Bitcoin [8] which creates decentralized confidence in a currency through a transparent registry called blockchain.

The blockchain community is trying and testing new fields of application, with high expectations and ambitions to disrupt standards and common ways to operate. However, such technology presents some risks and threats related to its early stage of development and novelty [9]. In fact, these aspects can generate unpredictable risks in industrial sectors where communities need proper technology assessments to forecast and set-up the technology in business processes and operations [9].

Blockchain technology (BT) is a novel technology enabling new forms of distributed software architectures [10] and is positioned in the early stage of development [11]. Since 2008, blockchains are rewriting conventional notions of social and business transactions, enhancing transparency, trust, and value transfer; and creating fresh opportunities for value creation and capture.

According to [12]–[15], blockchains may enable innovation and disruption across multiple sectors of industry. They are beginning to bring changes in some financial services by facilitating alternative means to exchange value. Indeed, BT has its origins in the financial sector [16] with a whitepaper describing a new form of electronic cash or digital currency [8]. Here, the first differentiation between previous digital currencies and the new cryptographic currency occurred [17]. Then, with the emergence of several new blockchains, there was a changing point, from ‘*the*’ blockchain to ‘*a*’ blockchain [17].

Moreover, due to its characteristics of decentralization, trustworthiness, and collective maintenance, blockchain provides a trustworthy platform to achieve a reliable peer-to-peer delivery of value without depending on a single centralized organization [18]. Blockchain platform deployment is strengthened by cryptography and consensus protocols and acts as a detractor for cyber-attacks and hacks. These aspects add a particular relevance if BT is applied in digital environments where there are security issues and threats. In fact, contextualizing the blockchain in the Industry 4.0, it indicates promising avenues for enhancing the security levels of digital environments, where devices may represent critical gatekeepers to violate business communication and data.

However, the BT, as a public ledger, provides improving features for transparency, traceability, and tracking for any transaction made and approved in the network. In this case, the meaning of '*transaction*' has no monetary implication only. In fact, as a transaction we can consider any type of value-exchange taking place in a system.

In this instance, many different use cases and applications have been considered for BT such as property ownership, notary deed, intellectual property rights, education and degrees, pharmaceutical products, construction and land management, insurances, e-government, food tracking/tracing, and so on and so forth.

Blockchain has also been identified as a promising technology for supply chain [9], [19], [20], increasing cyber security [19], data management [21], [22], driving digital transformations [19] and enhancing data recordkeeping and provenance [23]. Additionally, it impacts new business models [23], redesigning conventional approaches to behave in digital surroundings.

Therefore, the target of this research is to explore the BT for SC. However, it is hard to predict which directions this technology will take, and which product or service will become in future industrial systems. Hence, studying the emerging phenomena related to BT acquisition in industry is still a challenging topic where promising fields exist, but are still immature for a short-term acquisition.

Considering the supply chain (SC) sector, it represents a quite horizontal area that daily impacts many businesses activities and procedures. Supply chains are complex environments characterized by intricate processes in which many stakeholders are involved, requiring a solid integration management.

Deploying novel technology in these systems imply a large effort in resources, long-term planning, and economic burden. However, supply chain denotes extraordinary abilities and flexibilities for innovations and digitalization. Considering the huge progresses made in the last few years, supply chain techniques have proven a crucial interest in evolving in practices and operations, leading the digital era of delivery. Designing radical harmonization for systems integration and data analysis, international and local SC systems are optimizing the worldwide distribution from raw materials to final products.

Best-practices and good management of SCs have impacts on the product price and quality, with consequences on society. In fact, consumers are even more interested in product provenance and its sustainability, showing their conscious involvement when assessing the final goods. Customers are more demanding and are informed about potential bad practices and unlawful actions that may happen along a supply chain, including about frauds and false information. Thus, these demands oblige the SC managers to provide complete information about their suppliers and nodes.

Permissionless blockchain systems, as public ledgers, allow to have fully transparent information available for the network of partners and stakeholders involved by offering an advanced tool for transparency and traceability, increasing the level of trust in the system. However, it may also present several risks and a loss of competitive advantages on the market due to the sharing strategic business information with competitors. This may require a change of paradox, passing from competition to coopetition. Such an attitude would require technological enablers that may foster these changings.

BT may be one of these enablers that design a new level of trust in the network and may set technological confidence as an automated system that connects nodes, intermediaries, processes, and identities. Addressing ownership and responsibilities along the SC, BT mitigates the dispute resolution between stakeholders.

In this instance, the level of adoption requires an additional understanding and insight about how to design the future implementations, and which would be the most suitable aspects for the developments. Whereas, SCs are characterized by advanced technologies and cutting-edge infrastructures able to respond to the market demand, a blockchain deployment may reduce flexibility of related systems. Thus, it is crucial to lay the foundation to understand how blockchain may be adapted to the current technological dimension of SCs.

This area may be considered as one of the highest readiness levels for a BT adoption; also, it may have greatest impacts for society and benefits for the communities involved.

However, the vision for an adoption of blockchain in SC does not seem to be prompt, and as a first instance, it would be fundamental to identify which form of blockchain to implement (if permissionless or permissioned system) and clarify ‘*how*’ and ‘*where*’ the blockchain may be applied.
Thus, by providing solid guidelines, it is envisaged to engage more stakeholders, with higher awareness and understanding about which benefits they could get from the technology.
Finally, another aspect to mitigate risks in this sector may be scaling down the high expectations that communities have on BT and provide some recommendations to support future evaluations and digital transitions.

1.3 Research questions

Blockchain (BT), as an emerging technology, has been rapidly expanding across many areas other than cryptocurrency, providing a technological tool to enhance trust. The way blockchain has been moving along the Gartner curve and the different early adoption in some areas intrigued us about its disruptiveness. Supply chain (SC) is one of the areas that is running several blockchain pilots and may have an impact on the current business models if it is finally adopted. So, the understanding through the analysis done, is that it is becoming an issue today to learn at which level the BT may disrupt current models (following a solid definition of disruption), may have effective combinations between technology ecosystems, and may have influence on digital business models.
Therefore, this research field was considered as an exploratory analysis, keeping an investigatory character and applying qualitative research approaches to lay the foundation in this research area. In fact, this field of research shows a great potential for further technological developments but, at the same time, it is also characterized by high risks and threats related with its early-stage and novelty, and with the large expectations about blockchain.
One of the *core* features of the BT is the decentralization and the network in which it is generated. This aspect has been considered, from the beginning, as a disruptive feature and a new paradigm for transactions. Radical implementation of decentralized networks in SC may change many areas having relevant impacts on operations. But it is not sure which shape this technology will take in SC and how it will impact the traditional way to operate in business. Hence, this work answers to the following research question (RQ):

- *How blockchain may affect a performance improvement in SC operations?*

To answer at this main RQ, the study was divided into three sub-RQs. Each one was conceived to go deeper into the analysis in order to acquire the necessary evidences and to provide a sharper focus of the research area.
Starting from a broader analysis, the C.M. Christensen's theory of disruptive innovation was adopted (see next section 1.4).
Following the C.M. Christensen's theory of disruptive innovation, distinguishing innovations is extremely important for future

development. This classification explains that the new firms (start-ups) are drivers for innovation, whilst big-established firms have capital to set and invest in innovation processes. This framework defines two types of innovation: disruptive and sustaining innovations. The latter is predictable and can be planned, while the former cannot.
To the best of our knowledge, nobody has studied what disruptive means for blockchain and, there are no studies in which there has been a structured analysis which finds evidence that proves blockchain innovation can be considered disruptive or not for the supply chain.
Therefore, the first sub-RQ was generated in the study, as follows:

RQ.1 What are the enablers for blockchain disruption in supply chains?

After classifying the blockchain-based SC as a sustaining innovation that may bring additional performance improvements in the sector, and with the understanding that the technology is not mature enough to be applied in complex industrial systems, the study proceeded exploring in which specific aspects and processes blockchain may provide further enhancements in SC.
As a result, the second sub-RQ was designed as follows:

RQ.2 How can the information flow structure affect and pilot a suitable blockchain adoption in SC management?

Results confirmed that SCs appear to be one of the most prominent fields of application for blockchain.
For an effective combination between BT and SC processes, the information management is one of the drivers for the implementation and with a specific focus on accounting and administration.
Blockchain-based SCs fit in supplier relationship management processes and financial business units for international trade; however, the blockchain-based SC is not yet a mature technology and the return on investment (ROI) for its deployment is unclear.
Therefore, after the acquired understanding about the type of innovation, and after identifying the possible processes where start the design of blockchain-SC improvements, the study proceeded

analyzing those elements to support a suitable adoption of blockchain in operations.
Thus, the third sub-RQ is presented as follows:

RQ.3 Which are the elements for designing blockchain-based digital strategies that might foster a reliable re-engineering in SC operations?

In this study we analyzed the major influences affecting SC operations, addressing those elements that may support digital transition procedures to blockchain-based SCs such as value of trust, transformative role, and digital business strategy.
As a result, it was identified that the adoption pathway needs to be carefully assessed, and an intense commitment is required to design proper functionalities and exploit blockchain advantages. Thus, exploiting critical performances of traditional processes, BT in SC operations need to show clear and measurable benefits, otherwise risks may occur. Therefore, it is fundamental to identify the value creation and capture blockchain may bring upon existing operations.
In this instance, the identified elements may facilitate risk mitigation and then guide practitioners and innovators to design added-value solutions for a sustainable development of this emerging technology.

Therefore, starting from a broader angle, the research sharpened its focus on specific aspects, consolidating the findings and assessing the technical issues that were emerging from these research lines.

1.4 Setting-up the research experiment

The following sections summarize the methodology adopted and explained in sections 2.2.3, 3.2.3, and 4.2.3, and provide evidence for the replicability of the study.

1.4.1. General overview

This thesis work performs explorative research, conducting a qualitative analysis by ethnographic methods [24]. Eighteen interviews were conducted with worldwide experts to collect a large amount of data. Then, applying the grounded theory approach [25], data were processed to reduce its complexity and to identify the concepts and categories inherited. Following previous research works in the blockchain field [26]–[29], the grounded theory approach was identified as the most appropriate methodology to design this qualitative analysis, given that it has the purpose of constructing theories grounded in data. These are the first steps in exploratory research for a rather novel topic such as the application of blockchain technologies in the supply chain.

1.4.2. Summary of the methodology

This qualitative research applies ethnographic methods based on expert interview [24], [30]–[34]. As presented in sections 2.2.3, 3.2.3, and 4.2.3, eighteen interviews were conducted to collect data and analyzed following the grounded theory approach [25], [35]–[43].

The grounded theory allows us to construct theories grounded in data by the explanations of research findings, limitations, and originality. The research findings are explained by criteria, concepts and their relationships, and then by the conceptual density of categories. The limitations are regarding the macroscope and the microscope of the study, in fact grounded theory allows to identify limitations at the end of the procedure. The originality is about the process identification and significance of findings.

According to K. Charmaz [39], [41], [42], the grounded theory analysis performed was following two relevant features of this approach. In fact, it is fundamental to be compliant during the analysis, the grounded theory is not static, and it is necessary to design possible changes into the method, continually changing in response to prevailing conditions. Additionally, this approach has a determinism issue that may be mitigated by keeping the responsibility, and determinate how actors respond to those conditions; and which are those uncovered conditions.

According to [39], empirical data must be fragmented through coding to identify theoretical concepts. The coding phase is comparing, in an iterative manner, the data obtained with codes with the aim to generate concepts. After this, the analysis incurs in several iterations comparing concepts with codes to generate categories, and then comparing categories with codes to validate results. This coding phase is described for each paper in section 2.2.3, 3.2.3, and 4.2.3.

Table 1.1 summarizes the coding steps during the analysis. According to [35], [40] the procedure followed to perform the study is presented in Table 1.2.

Table 1.1. Coding the data gathered.

Step	
01 – Open coding	Interpretative process in which data are broken-down analytically: - compare for similarities and differences - create conceptual labels
02 – Axial coding	Relationship with sub-categories
03 – Selective coding	Process in which all categories are unified around a central ‘*core*’ category, to be used in the later phase of the study.

Table 1.2. Grounded Theory Procedure.

No.	**Canons and criteria**	**Considerations**
1	Data collection and analysis are an interrelated process	The analysis starts with the first data collected
2	Labelling phenomena: concepts are the basic unit of analysis	Conceptualization of data and concepts labelling
3	Categorized phenomena: categories must be developed and related	Similar phenomenon needs to be grouped to form categories, but not all concepts become categories
4	Sampling in grounded theory proceeds on theoretical grounds	Sampling proceeds in term of concepts
5	Analysis makes use of constant comparisons	For each category, theoretical explanation of specific phenomenon and put them in a correlation
6	Patterns and variations must be accounted for	The regularity of phenomenon

7	Process must be built into the theory	Breaking-down phenomena into stages, phases, steps
8	Writing theoretical memos is an integral part of doing grounded theory	System that checks the outcomes in progress
9	Hypothesis about relationship among categories and developed and verified as much as possible during the research process	Hypothesis must be verified and are in constant revision
10	Broader structural conditions must be brought into the analysis, however microscopic in focus is the research	The research needs to consider minors events, not only the focus

1.4.3. Questionnaire design

The questionnaire represents a critical part of the study. It needs to be properly set and revised several times to reach the final version. In fact, the first three interviews helped to understand some of the limitations of the questionnaire done, and therefore offered the opportunity to improve the structure and to enhance a few of the formulated questions.

For the design, as an initial step, previous studies that designed expert interviews on blockchain-based SC were explored [19], [26], [28], [29], [44]–[48]. Hence, the design of the questionnaire was inspired by and linked to the previous literature. To this regard, some questions were adopted from Y. Wang *et al.*[44] (see Appendix 1).

The fifteen questions designed were constructed from the identification of three macro areas: general, market, and future.

In fact, following the C.M. Christensen theory of disruptiveness [49]–[51], this allowed to have some guidelines to assess the relevance of the questions formulated. Indeed, the C.M. Christensen theory allowed to breakdown technological elements (general), identify technological trajectories (market), and recognize the maturity level (future).

Furthermore, *S-curve* positioning has been considered as a significant tool to be applied to the study [52]. Following C. Pérez's paradigms [53], it supported to set the consideration of blockchain as an "*interrelated, interconnected and interdependent system*".

Therefore, this framework of analysis comes from the harmonization of C.M. Christensen [49], Y. Wang *et al.* [44], and C. Pérez [53].

The questions proposed in the interview format fulfilled narrowed fields of analysis. This aspect allowed to conduct the conversation using questions as a '*funnel*' to extrapolate relevant and significant data for this research. Conforming to the literature presented, expert interviews were set keeping a collaborative, flexible, and informal character. This means, with interviewees, we followed the questions to have a structure of analysis, but we also had an informal chat. During this informal chat, each expert provided further strategic information. Keeping this approach offered the chance to grasp the rationale of some specific areas of knowledge where each expert revealed her/his strength. Based on that, the experts' visions were included as part of the analysis without judging whether it was relevant.

1.4.4. Originality and contribution

A set of related studies are discussed in section 2.2.2, 3.2.2, and 4.2.2, with special references to Y. Wang *et al.* [44], N. Hackius *et al.* [26], and S. Saberi *et al.* [27] works as the ones that address the same research gap from a slightly different perspective. Along the chapters 2.2, 3.2, and 4.2 are presented previous studies that were aimed to interview experts from the supply chain field to prospect the use and impact of blockchain technologies.

Therefore, this research contributes to the body of knowledge by expanding this analysis, not only to supply chain experts, but adding a pool of blockchain experts from both academia and business. In addition, to have a comprehensive understanding, this research involved also institutional representatives from the public administration. As such, the applied framework helps to keep a broader vision about how to manage the blockchain innovation for industry.

The grounded theory analysis, also used in previous related works, has been conducted by following its own principles. As suggested in the literature, the data gathering process needs to be adaptable to the planned experiment. The results have been analyzed in-depth, and to reduce complexity, results are presented in section 2.2.4, 3.2.4, and 4.2.4. Furthermore, given that a quite high amount of data were collected from experts, the research activities have been focused on transforming, lexically speaking, the data obtained in concepts, and then in categories. Thanks to the grounded theory,

this approach extrapolated the rationale from the sentences experts said.
Since the pool of experts was heterogeneous (different backgrounds and disciplines), the data collected needed several iterations to be cleaned. For example, interviewees were from several higher technology ecosystems such as multinational ICT companies, academic professors in advanced university centers, CEOs of global leading blockchain start-ups, port authorities and so forth (see 2.2.3, 3.2.3, and 4.2.3 for insight). In fact, the jargon used from each expert was a bit slightly different, however after several iterations of grounded theory coding, the jargon was cleaned and unified in labels to the higher significance.
The categories discussed in 2.2.4, 3.2.4, and 4.2.4, are the results of an intense work and several coding iterations that show relevant performances of the work done. During the design of the experiment, the framework of analysis was addressed on three main assets: technological elements, technological trajectories, and maturity level. These three assets supported the analysis during the whole process, from design of interview questions to the data analysis, through to the results presentation of the whole effort.
In fact, as a lesson learned from the grounded theory, coding and grouping data in concepts is a process that needs several iterations; and as an outcome from this process, the analysis generates different categories based on the initial settings and scope.

1.5 Networking and international perspectives

To achieve the research results, it was crucial to keep an international perspective during the whole process.
First, to create the network of experts for the interviews, I started exploring industrial ecosystems worldwide where blockchain solutions were emerging for supply chain applications.
Thus, I adopted a scouting procedure to identify experts that might be involved in the interviews, exploring academic publications and seminars[1], conferences[2], business congresses and fairs[3], workshops[4], and then, I looked for start-ups deploying innovative blockchain-based solutions (see section 2.2.3 for insight).
Moreover, thanks to the YERUN Research Mobility Award, I established new research connections by spending a visiting research stay at the University of Antwerp, Belgium.
During my stay, I was hosted by the IDLab, where I expanded my research network, and got contacts with other researchers working on blockchain and supply chain.
The IDLab Director, Professor Steven Latré, introduced to me the IDLab team, explaining the business-oriented research lines they were following. At IDLab, I discovered the level of innovation running into the Antwerp ecosystem, being involved in several meetings about Antwerp's technology development for supply chain and port innovations.
During my time these, I had the chance to test my Interview Questionnaire with other researchers and with several practitioners working in big companies and start-ups, hence improving the focus of the study.
Additionally, thanks to this experience, I discovered some further research opportunities in Belgium at the KU Leuven (Catholic University in Leuven). I then contacted Professor Bart Preneel, Head of the COSIC research group asking for a visiting research stay of three months at KU Leuven. The Computer Security and Industrial Cryptography (COSIC) group is focused on providing a broad expertise in digital security and innovative security solutions,

[1] RMIT University - Expert seminar: The blockchain economy.
[2] European Patent Office: Patenting Blockchain.
[3] IoT Solutions World Congress Barcelona and Blockchain Forum; *Càtedra de Telefónica* Network – annual event.
[4] EU Blockchain Observatory and Forum: Convergence of Blockchain, AI and IoT; CARNET – UPC Technology Centre: blockchain use cases development and assessment.

and I thought it was a good place to increase my research network, enhance my PhD outcomes as well as gain a deeper technical knowledge.
Although I was accepted for this research stay, unfortunately the pandemic situation limited the possibility to spend time in another country. Thus, the visiting stay was not performed.
Beside these activities, I cultivated growing interests for the European Institute of Innovation and Technology (EIT) with specific aspects of the Knowledge and Innovation Communities (KIC). Throughout these years, I consolidated my network in three EIT-KICs acquiring new awareness about business and research ecosystems at European level, and their impacts on society.
Under the EIT Urban Mobility KIC, I was invited as a blockchain expert to attend some events on innovation design and selection pathways, with the scope to define some specific fields where blockchain and distributed ledger technologies may be applied in European ecosystems.
Thanks to the EIT Urban Mobility KIC, I increased the understanding between business and research gaps that are occurring in the blockchain puzzle, and realized the missing knowledge that companies have in this area. Thus, to close these knowledge gaps, I took part in three project proposals to bid for grants together with other renowned European organizations such as the Automotive Research Center Lower Saxony (NFF - TU Braunschweig), the CARNET Technology Center (Technical University of Catalonia), the Technion (Israel Institute of Technology), the University College London, and the Fraunhofer Society for the Advancement of Applied Research.
The submissions were successful, and the projects were granted (see Appendix 2 for the projects' abstracts).

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Chapter 2

DISRUPTIVENESS ANALYSIS

Sections:

2.1 Contextualization of the study

This study is focused on the innovation analysis of blockchain features. After its first appearance in 2008, blockchain technology found higher deployment in the financial sectors and cryptocurrencies. Since 2014, blockchain technology trends started to move towards industrial applications via the developments of several pilots and market tests. However, the technology is still in its early stages and is not mature enough to be applied in complex industrial systems.

As blockchain was defined as a disruptive innovation with relevant impacts on society and business, the correlation between these two impacts was intriguing us to find answers on how the supply chain sector reacts to this technology.

After a preliminary analysis of the literature, it was not clear which structures some practitioners were using to define blockchain as a disruptive application for supply chain. Therefore, in this research we explore the potential features and trends that distinguish a blockchain-based supply chain, with the aim to identify the enablers that may reduce risks and foster further deployments.

2.2 Blockchain Enablers for Supply Chains: How to Boost Implementation in Industry

Results of this study identify the type of innovation for blockchain in supply chains and present the enablers that may foster its deployments.

Abstract

Supply chain management is considered one of the main sectors of development for blockchain technology. This study provides solid contributions to understanding blockchain innovation and presents some main features and guidelines for how to boost blockchain implementation in industry. As explorative research, this chapter presents a grounded theory analysis based on 18 expert interviews. The pool of interviewees is composed of academics and business and institutional representatives with relevant technological knowledge on blockchain and innovation management. Renowned worldwide experts provided us with powerful input to run this analysis and with a general overview of the current situation. Blockchain development of course impacts supply chains, but currently, the analysis shows that it does not seem to be a disruptive technology. In accordance with C.M. Christensen, blockchain presents all the features to be a sustaining innovation rather than disruptive. For this reason, as outcomes, we present five enablers that can foster prompt adoption in industry.

Keywords:

Blockchain, distributed ledger technology, innovation management, knowledge management, supply chain management, technology management.

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2.2.1. Introduction

Blockchain technology is showing a rapid growth rate, both for applications and market tests [1], [2]. Additionally, interest from the scientific community has grown rapidly [3]. However, currently, such technology presents some risks and threats related to its early stage of development and novelty [4], [5]. In addition, the industry has high expectations about blockchain applications as a new enabler to shorten middleware costs and provide additional value such as trust and security. These high-expectations shown by communities on this topic represent a risk for its coming applications and how blockchain is impacting society [6], [7]. To mitigate the risks related to this blockchain surge, this study first introduces the current state of technology implementation and its position into the innovation pathway, identifying new avenues for improvements at a technological level and providing enablers for industry acquisition for supply chains.

According to the best of our knowledge, there are just preliminary studies comparing the degree of disruptiveness and radicalness of blockchain technology. This research intends to fill this gap, by utilizing the C.M. Christensen theory of disruptive innovation [8]. Taking this path allows the authors to achieve the result of delineating the features which make a blockchain system innovative.

This chapter presents explorative research on blockchain expectations among experts and their current and potential applications in industry. In fact, these expectations create risks and uncertainty as to the investment plans for blockchain developments, applications and innovations [5], [9], [10]. Hence, this research conducts a critical analysis of blockchain technology disruptiveness, with special attention paid to supply chains, by interviewing a set of worldwide experts from business, academic and institutional areas.

In fact, the analysis of the interviewees allows us to explore the gaps between the current technology offered and market needs and to identify the areas in which blockchain innovations are well positioned.

A few years ago, blockchain had been tested in several sectors to find effective solutions for real-world problems [11]–[13]. Many companies, consortiums and foundations were convinced of the great impact of blockchain to be exploited in future developments. The key sectors agreed upon by worldwide organizations in which blockchain may have more impact are as follows: financial services, government services and supply chain management [14].

Thus, this research will be focused on supply chains and looking for specific answers to several questions concerning the relevance and impact of blockchain in industry, and we collected those on the following broader question: *what are the enablers for blockchain disruption in supply chains*?

Consequently, we split the previous research question into three subquestions to address specific themes, and then, we collected information on them in a comprehensive analysis:

RQ.1. *What are the present and future perspectives for blockchain in industry?*

RQ.2. *How can blockchain in industry be effectively connected to other interdependent systems?*

RQ.3. *How can blockchain in supply chains effectively foster digital enhancements?*

The research follows a similar approach to those of previous studies on blockchain-based supply chains from Y. Wang *et al.* [15], and N. Hackius *et al.* [16] but addresses the presented research gap from a different angle. To achieve this goal, we conducted qualitative analysis using ethnographic methods [17] and running expert interviews [18]–[21]. In fact, after the exploration and assessment of worldwide experts, a pool of 18 experts was interviewed in this study.

This chapter is structured as follows: it starts with an overview of the literature on innovation, blockchain and supply chains. In the third part, the methodology used to collect and analyze data is presented. The fourth section presents the main findings, which are later discussed in the fifth section. Finally, the limitations and conclusions are presented.

2.2.2. Literature review

In this section, we present a literature review. To the best of our knowledge, these previous publications represent a solid foundation on which we focus our efforts to achieve the goal of the research work. The main pillars that orchestrate the review are innovation, blockchain technology and blockchain for supply chains that we develop in the subsequent sections.

Innovation

Following J.A. Schumpeter [22], [23], distinguishing between innovations is extremely relevant for future development. This classification explains that new firms (startups) are drivers of innovation, while well-established firms have the capital needed to operate and invest in innovation processes. This framework defines two types of innovation: disruptive (for new firms) and structured (for established firms) innovations. The latter is predictable and can be planned, while the former is not.

C.M. Christensen's theory regarding "the innovator's dilemma" [24] presents a theoretical framework regarding how to individuate and manage innovations and shows that different types of innovations require different strategic approaches. According to Christensen's theory, there are specific features for identifying innovations and market trends, dividing the scenario into two possibilities: sustaining innovations vs. disruptive innovations. This framework matters for value creation because the aim of this theory is to support firms in innovating successfully [25]. In fact, adding a secondary evolution of this theory, Christensen highlights a third type of innovation: efficiency innovation [26]. These three types of innovation are able to create a closed loop that can identify innovations and their development stages.

S-curves can be adopted to assess technologies [27]–[29], as such incremental improvements will move along a given S-curve, but radically new technologies will jump from one S-curve to another [27]. S-curves identify the maturity of the technology and when and if the '*jump*' will happen. Embracing Christensen's theory can also support the development of specific metrics and criteria to track and assess potential enablers.

Disruptive technologies offer a revolutionary change in the conduct of processes or operations and provide a basis for a new competitive paradigm [30]. Disruptive technologies act completely independently from mainstream business [8]. Additionally, it is relevant that the effort of the formulation of blue-ocean spaces and the decision as to where to fit the disruptive technology, generates the major pillars for disruption [31], and the blue ocean [32] role is mainly to innovate the business model [31]. Following a three-step method, as suggested by [33], this can facilitate the prediction of disruptive innovation, defined as follows: "*an innovation with radical functionality, discontinuous technical standards, and/or new* *forms of ownership that redefine marketplace expectations*" [33]. For this reason, managers need to pay careful attention to potentially disruptive technologies [8].

Blockchain technology

Blockchain technology (BT) is a novel technology enabling new forms of distributed [34] software architectures [35] and is positioned in the early stage of development [15], [16], [36]. A blockchain is defined by [36] as "*a ledger of transactions of digital assets: of who owns what, who transacts what, of what is transacted and when.*"

The BT research stream can be considered a new field of study [4]; in fact, it started twelve years ago with a whitepaper describing a new form of electronic cash or digital currency [37]. Here, the first differentiation between previous digital currencies and the new cryptographic currency occurred [38]. Thus, Bitcoin was the first decentralized public ledger, and as a distributed application, the blockchain was the innovative technology characterizing the system [7], [39], [40]. This represents an innovative combination, merging peer-to-peer networking, distributed timestamping, cryptography hash functions and pointers, digital signatures and Merkle trees, among others [14], which have existed for decades [7], [39]. Then, many new blockchains emerged, changing the point of view from "*the*" blockchain to "*a*" blockchain [38]. To date, many definitions have been published. For instance, blockchain has been defined as a public history of transactions [41] and as a secure public-distributed ledger platform that is, in practice, a distributed network of computers enabling transparency and verifiability of transactions, due to cryptographic protocols. This design is characterized by asymmetric cryptographic functions that are very difficult to solve but extremely easy to verify, which allows for real-time updating for all network nodes.

The terms distributed ledger technologies (DLTs) and blockchain technologies (BTs) can often be considered interchangeable. It is relevant to note that blockchain has become a more colloquial name for all types of DLTs. However, blockchain is actually one type of DLT [3], [42]. The areas of application for DLTs are currencies (cryptocurrencies), contracts (smart contracts), intellectual property rights, digital identity, voting systems, banking/finance, supply/global commodity chains, property ownership, and so forth [3], [7], [10], [11], [40], [43], [44].

Blockchain for supply chains

Blockchain has been identified as a promising technology for supply chains [5], [10], [16], [45]–[51], ecosystem building [47], increasing cyber security [46], data management [45], [47], [52], [53], driving digital transformations [3], [46] and enhancing data recordkeeping and provenance [54], [55]. Additionally, it impacts new business models and operations in supply chains [4], [54], [56].
Supply chain management is the integration of all key business processes across the whole chain of processes and stakeholders [57]. In accordance with D.M. Lambert [58], supply chain management concerns relationship management and requires the involvement of all business functions [58]. Thus, having good partners is fundamental in the supply chain, and developing the right type of relationship is critical [59]. Some of the largest players in supply chains developed permissioned [60] blockchain platforms for ecosystem building and to manage partners in the chain [55].
Some of the main gains of these developments are '*building trust*'. Trust is the predominant factor driving adoption [55], and it has the power to revolutionize the concept of trust in supply chains [61].
In fact, decentralized systems allow participants, who do not trust each other, to trust in the systems themselves, in their algorithms and in their network of nodes [35]. Here, there might be a conceptual switch of trust because the technology "*removes the capacity to third parties to set what the truth is*" [62], so decentralized mechanisms will assure what trust is. In this mindset, companies need not '*trust*' their partners to the same degree since trust is prebuilt into blockchain systems [3], [39], [55].
Blockchain databases are decentralized ledgers, so provenance can be evaluated even when no one party can claim ownership over all supply chain data [63].
However, blockchains are still at the early stage of development [42], [55], and it remains unclear in which direction they will go [36]. Blockchains are enablers of innovation and disruption across multiple sectors of industry [4], [10], [12], [40], [43], most of all in supply chains [15], [16], [42]. However, not all believe that blockchain is disruptive [7], [9], [39]. A higher digital transformation of international trade, due to DLTs, might create

vast efficiency gains for each actor in the supply chain [4], [51], [54], [64]. Decentralization is valuable for reducing the *cost of trust*; this is considered disruption [53], [62] but also improves performance, reduces the time required [55] and resolves the problem of mistrust.

Furthermore, integrative use with other technologies, such as robotics, artificial intelligence (AI) and the Internet of Things (IoT) [7], [65], is a potential way forward in blockchain deployment [15]. Thus, as defined by [41], "*the combination of blockchains and IoT can be pretty powerful for industrial applications into supply chain management*". The IoT for supply chains represents some kind of access point for cyberthreats [66]. Blockchain can mitigate these cybersecurity risks, but to enhance the security level of supply chain networks, IoT systems need to ensure higher security standards, which need to be designed from the beginning [66].

Other fundamental assets of blockchain in industry are tokens [67] and smart contracts [3], [9], [68]. These functionalities might lead to a fundamental change in the way in which humans exchange value [36].

On the one hand, these assets help by removing the involvement of third parties in any transaction [48], [53] and, on the other hand, create deterministic scenarios and related benefits into a network [69]. These can generate new digital business models, according to the definition in [68]: "*Smart contracts allow us to express business logic in code. A smart contract is deterministic; the same input will always produce the same output.*"

Blockchain perspectives

According to C.M. Christensen theory for disruptive innovations [8], we consider it fundamental to understand those aspects related to the technological nature of blockchain. This can show how the technology is performing with existing systems.

As mentioned in the previous section, blockchain has been defined as a disruptive innovation—or technology—in many studies [3], [4], [12], [15], [43]. To the best of our knowledge, the identification of the degree of disruptiveness has not been based on the qualitative measures presented by Christensen theory of disruptiveness, nor have they been based on other standardized quantitative measures. Existing studies present the growth trend of blockchain [1]–[3], but without a formalized context, such as Christensen—these results may be misinterpreted by practitioners looking to use blockchain technology. This lack of standardized measure is further complicated in cases where business implementation of blockchain provides poor results. In these cases, results of different applications cannot easily be directly compared.

These aspects can generate unpredictable risks in industrial sectors where communities need proper technology assessments to forecast and set-up the technology in business processes and operations [4], [5], [29]. Thus, the research gap we want to enclose within this study is the discordance between the degree of disruptiveness and the results of real industrial implementations thus far. In fact, contributing to the current body of knowledge, this study defines evaluation criteria in order to increase the understanding of blockchain assets.

Additionally, as explorative research, the research will analyze the degree of disruptiveness correlated with the defined enablers—and their related clusters—which could foster an industry acquisition. In this context, this research provides support to those communities working in blockchain fields and gives practical guides for industrial application. Through expert interviews, we identify those enablers which will allow a rooted development in the industrial sector. As a result, this study provides a tool to assess correlated risks for industrial implementations.

2.2.3. Methodology

This study presents explorative research based on a qualitative analysis. Applying ethnographic methods as expert interviews, we collected several data, visions and opinions about blockchain technology in industry. We proceeded by analyzing the data collected with the grounded theory approach.

Uniqueness and previous research

To the best of our knowledge, this research is considered unique, given the pool of experts composed of academics and business and institutional representatives with relevant technological knowledge on blockchain and innovation management. Thus, following previous studies on blockchain-enabled supply chains [15], [16], [42], [46], [70]–[74], our research goes beyond those references,

more specifically reinforcing and complementing the results obtained by Y. Wang *et al.* and N. Hackius *et al*.
Some of the previous studies have chosen experts from the supply chain area, gathering their perspectives on blockchain. Their methodologies were also based on expert interviews, conducted during a very early testing phase of blockchain in industry, when there was a first change in the vision of applications, going from just finance to broader industry applications creating high expectations in terms of cost reduction and threats to existing products. Additionally, during those years, companies were too cautious to adopt such technology, but at the same time, they showed great interest because new market opportunities were arising. Thus, we designed the research work to include complementary aspects according to the evolution of the technology. In our research, we have included experts in all three key areas—management, innovation, and technology—all working in different sectors. In accordance with [19] and [75], we set up flexible guidelines to run this ethnographic research, and we found experts with a high degree of interpretive power and extensive knowledge in the field in which each expert is working.

Designing expert interviews

In accordance with [17]–[21], we designed semistructured expert interviews, considering the interviews as a '*specialty*' approach to collecting information and keeping a collaborative, flexible, and informal character.
To the best of our knowledge, there are no previous interview formats which match blockchain technology with disruptiveness analysis. Thus, relying on C.M. Christensen theory [8], this study designed an expert interview framework taking into consideration the contrast between the level of development of this emerging technology with the high degree of complexity for the supply chain market.
Additionally, some questions were adopted from Y. Wang *et al.*[15]. Thus, we set 15 questions on 3 macro-assets: general, market, and future (see Appendix.1 for the interview format). The 15 questions have been generated in line with the three research questions (RQs) to fulfill the scope of this explorative research.
In the following part of the paragraph, an insight about the construction of expert interview format. Based on different

frameworks, this study starts analyzing and understanding blockchain disruptiveness. C.M. Christensen's theory [8], [24] allowed first for a destructuring of technological elements [general], identifying technological trajectories [market], and the maturity level [future]. According to Christensen's theory, there are specific features for identifying innovations and market trends, dividing the scenario into two possibilities: sustaining innovation vs. disruptive innovation [8]. In addition, in line with [27]–[29], S-curve positioning has been considered a significant tool to be applied. Following C. Pérez's paradigms, we focus on dominant design [76]–[78], technology systems and trajectories [28], [79]. In fact, following C. Pérez's framework, it helped us to set a similar mindset for blockchain technology as an "*interrelated, interconnected and interdependent system*". However, as blockchain technology presents some characteristics still related to its infancy [15], [16], [36], we consider it worthwhile to use the S-curve for the positioning of blockchain in industry, identifying system trajectories and possible directions for future blockchain developments.
To reach these goals, we conducted 18 expert interviews and analyzed data collected following grounded theory.

Grounded theory

In accordance with J. Corbin and A. Strauss [80], we designed a dynamic approach for this qualitative research; this dynamic approach allows us to evolve in design as the study progresses [17]. Thus, as a form of qualitative research, grounded theory (GT) has the purpose of constructing theory grounded in data [80]–[85]. This aspect allows for the identification of general concepts and the development of theoretical explanations and offers new insights for the studied phenomena.
GT is a general method of comparative analysis in which data are systematically obtained [81], [83]–[86]. The use of GT provides modes of conceptualization to describe and to explain the current situation of blockchain in industry. In fact, considering the previous studies on blockchain-based supply chains that also used both GT and expert interviews [16], [70], [71], GT showed better results. GT is an iterative, comparative, and abductive method [85], [87], [88]. Developing a comparative analysis of the data collected, the interactive process helps reach an abstractive level of analysis [85].

Data collection

A list of 52 experts was first identified and classified into three different clusters, where each interviewee presented more experience: academic, business and institutional. A second assessment of the experts allowed us to reduce the number from 52 to 29, taking into account the level of activity in terms of blockchain, innovation and close topics in the last 3 years.

The pool of 29 experts has been ranked *ex-ante* with a priority list. With the support of tables and organizational tools, the priority list allowed to fulfill specific fields of interests required for the study. It was predefined at the beginning of the interview process.

Thus, the final set of 29 experts was contacted by email to concert a first interview. The email structure followed a formal format of presentations, interest in the study and why we consider the involvement of this expert suitable.

Setting a priority list of interviewees, we collected the data between March 2019 and January 2020. Developing grounded theory, we reached saturation after 18 interviews. Finally, a pool of 18 experts was interviewed during this study, with dense interviewing activities between October and December 2019.

On average, this pool of experts provided availability for a 45-minute timeslot each to analyze and discuss the questionnaire presented. However, the average time for each expert interview was 55 minutes. Following [17]–[21], during the interview, we followed a double framework: first an informal and open discussion, followed by a semistructured interview regarding the proposed questions (see Appendix.1).

Additionally, according to [89], 18 interviews are a valid sample for this study.

As shown in Table 2.1, the experts involved were from 3 continents and 9 different countries. Some interviews were conducted in person, following a formal face-two-face meeting [8 experts], and others in virtual meetings [10 experts] using video-conference software. Nine of the experts are academics, representing 50% of the pool; 7 out of 18 are business experts, representing 39% of the pool; and 2 out of 18, are institutional experts, representing 11%. However, following a gender-based classification, 72% are male experts [13 out of 18] and 28% are female experts [5 out of 18]. This 28% female rate is disappointing for us and not as good as we hoped.

Expert backgrounds

The pool of experts is heterogeneous, interdisciplinary, and worldwide, with recognized knowledge on innovation management and blockchain technologies. They have different backgrounds in academia, business, and institutions. On average, interviewees involved were studying and/or working in blockchain technology from 2012-2016 and are equally distributed. They are also equally distributed in terms of permissioned and permissionless blockchain systems. All experts have a '*senior*' profile, and almost all of them were running activities during the "*.com*" era inside the related digital evolutions. Some of them have been involved in the ISO/TC-307 for blockchain interoperability, and most of them have deep market orientations within critical perspectives on blockchain.
Their backgrounds vary and are correlated with intellectual property rights, engineering, telecommunication and Internet of Things, mathematics and cryptology, innovation, economics and business management, supply chain management, identity and privacy, consensus protocols, cryptographic products and financial systems.

Data processing

Collecting all the responses provided by experts during the interviews, we extracted the rationale from each provided answer to reduce complexity during the analysis. In accordance with the grounded theory approach, we collected memos as a source of data. Similarly, we collected a secondary source of data, attending conferences and workshops, analyzing companies' whitepapers and academic reports[5]. In addition, we analyzed some reports from the EU Blockchain Observatory and Forum[6] and governments' guidelines[7]. These double sources of data helped us acquire a broader overview and critical thinking about the data collected.

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5 L. Hoyal, "Talking about a new revolution: blockchain.," *European Patent Office, 2019.;* N. Vadgama *et al*., "Distributed Ledger Technology in the Supply Chain," *UCL Centre for Blockchain Technologies, 2019.*; D. Allessie *et al*., "Blockchain for digital government," *European Commission, Joint Research Centre, Digital Economy Unit, 2019.*; D. Galen *et al.*, "Blockchain for Social Impact," *Stanford GSB Center for Social Innovation, 2018 and 2019.*
6 T. Lyons *et al.*, "Blockchain innovation in Europe," 2018; "Building better supply chains with blockchain," 2019; "Convergence of Blockchain, AI and IoT." 2020; *European Union Blockchain Observatory & Forum*. Online at: www.eublockchainforum.eu/reports
7 "The National Blockchain Roadmap," *Australian Government. Department of Industry, Science, Energy and Resources,* 2020.

Table 2.1. Pool of experts interviewed.

#	Respondent provenance	Respondent position	Gender	Location
01	Blockchain company for Logistics	Chief technology officer; Chief product officer (co-founders)	M	Belgium
02	University – Engineering School	Associate Professor in industrial automation	M	Italy
03	University – Engineering School	Associate Professor in distributed cryptographic techniques	F	Spain
04	University – School of Economics, Marketing and Finance	Research fellow in economics and political economy of blockchain	M	Australia
05	University – School of Information Technology	Lecturer on computer science and blockchain	M	Switzerlan d
06	University – Business School	Research fellow in the digital economy	F	United Kingdom
07	University – Business School	Lecturer in logistics and operations management	F	United Kingdom
08	University – Engineering School	Full Professor on wireless communications and blockchain	M	Spain
09	Consulting company for innovative information technology products	Global growth advisory	M	New York
10	Management consulting company for innovation and research exploitation	Director of technologies and digital areas	M	Spain
11	University – Institute for Innovation	Honorary Professor	F	United Kingdom
12	Blockchain and frontier tech-consulting group	Managing Director (founder)	M	New York
13	European Institution	Deputy Head of the Social Security	M	Belgium
14	ICT – Multinational telecommunications company	Cohead of Blockchain Competence Center	M	Spain
15	European Institution	Director of International Co-operation; Patent examiner	M	Germany
16	ICT – Multinational technology company	Blockchain Principal Investigator/Technical Leader	M	Ireland
17	ICT – Technology provider company on blockchain-based supply chain	Chief executive officer (founder)	F	United Kingdom
18	University – Engineering School	Full Professor on cryptology	M	Belgium

Data analysis

For the analysis, we started collecting memos and audio[8] from each expert interview. This information was analyzed and transcribed for each interview. With these transcripts, we re-assessed all the obtained information during the process, and we validated the next steps. In the end, when we reached saturation, these texts were compared and joined in a single dense text, following the questionnaire's structure. Then, starting from this full version of the compiled text, we proceeded with the data analysis and coding. With the support of tables, we compared data to generate categories, but before doing so, we ran a second iteration of code assessment, reducing the number from 448 lines of codes to 218 lines of '*cleaned*' codes. In fact, in accordance with [85], we fragmented the empirical data through coding in mode to individuate abstract categories that provide a conceptual analysis of the data collected. To identify the theoretical concepts, we iteratively compared the data collected. In fact, to test ideas and concepts, [85] suggests embracing an imaginative and creative interpretation, followed by a rigorous examination. Therefore, comparing data and codes with categories and considering the major categories as concepts, we proceeded by comparing the concepts among them to validate the results [84].

In Figure 2.1, we present the major outcome categories from the analysis.

However, we consider it relevant to present an insight about the analysis to develop the concepts and categories. Thus, in Table 2.2 is presented a brief explanation of the intermediate process that was used to reach final categories. According to the construction of this experiment, three main areas were identified as qualitative measures—as explained in section III.B: A) technological elements to obtain a general viewpoint about the technology usability and technology accessibility; B) technological trajectories to obtain a market value within trends for interrelated and interdependent systems; and C) maturity level to understand how to shape upcoming evolutions that might design future disruptions.

8 We recorded the interviews only for those experts who gave us permission.

Table 2.2. Intermediate process of categories validation.

Areas	A) *	B) *	C) *
Concepts	-technology features -innovation paths -maturity levels	-other technologies relations -supply chains -internet of things -Bitcoin and Ethereum -ISO standardization	-performances -needs -benefits -risks

* see section *Data analysis*

2.2.4. Findings

In this section, a summary of the main findings emerged from experts. The results were assessed and analyzed to create valuable outcomes that focused on making efforts to answer our research questions. Following the structure of the analysis presented above, a clear definition of major categories is as follows: features, innovation paths, digital transformation, maturity level, and industry existing-systems integration (Figure 2.1). In addition, in some parts, where experts presented relevant divergent opinions, we divided the paragraph into issues that generate a common consensus and other issues about which there was some controversy among experts. A brief and concise description of the main findings is provided below, while Table 2.3 presents a summary of the intermediate data from experts, following the abovementioned structure.

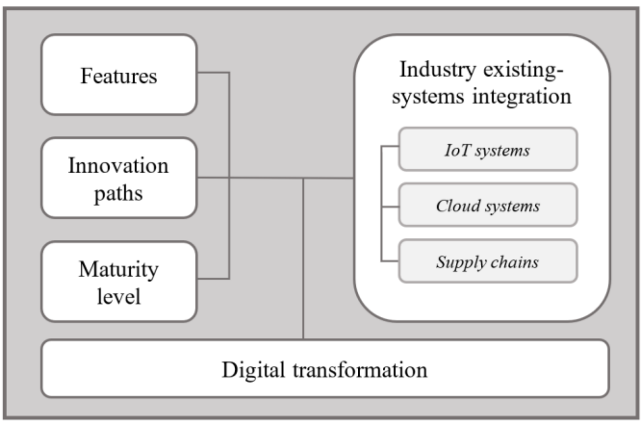

Figure 2.1. Major categories that emerged from the analysis.

Table 2.3. Summary of intermediate data from experts and quotes.

Categories	Responses from experts		
	Commonalities	**Controversies**	
		Academics and researchers	**Business and institutional representatives**
Features	-As a software-based technology, BT is just a new technology layer -BT is a secondary system alongside the primary running systems	-High risk	-High costs
		-Lack of efficiency	-Inertia due to change
		*“a fantastic way for organized information and data”	*“what BT does is shift some of the trust in people and institutions to trust in technology”
Innovation paths	-BT is not disruptive, as it is a sustaining innovation that only increase performance -Permissioned blockchains are incremental by nature -BT is a technology-driven innovation -Larger industry tests are centralized	-Power to change behaviors for administrative tasks	-Power to change business models and business processes
		-As institutional innovation, BT is a government toolkit for public administrations	-BT may represent the loss of a democratic society, and thus, it is not for digital democracy
		*“blockchain represents a sustainable innovation”	*“blockchain is a bottom-up innovation”
Maturity level	-There are no working use cases in industry -This is a learning moment for R&D, and there is no dominant design -BT will not be a product but rather a service (BaaS) -Broad communications, websites and daily news that are not informative and generate perplexity and mystification -Exit strategy from BT is an issue	-The market is not ready, and there are no parties ready to join	-Tokens have been broadly tested
		-The maturity level is low, and neither the market nor the technology is ready for adoption in industry	-The technology side is mature and ready for market implementation
Digital transformati on	-BT is a structural chance, due to the other technologies harmonized with it -Bitcoin and Ethereum are only applications -The ERC-20 standard for tokens allows people and companies to launch ICOs worldwide	-For identity, digital signatures, IoT and data, AI	-For blockchain-led mobility, blockchain-led logistics, tokenization
		-BT is a ‘catalyst’ for digital business implementation and industry transformation	-Reducing costs before creating transformative business models
		*“simple standards can support new business models”	*“ERC-20 allows for the sharing of value in a standardized way”

Industry existing-systems integration	IoT systems		
	-IoT systems are crucial for BT in industry -IoT is a key component adding distributed consensus -IoT and BT can solve some inefficiencies	-The BT's changing point will be its integration with IoT systems	-IoT and smart contracts will enable new blockchain-based business models
		*"IoT systems are the catalyst that can enable the machine-to-machine payments by smart contracts".	*"IoT systems are the bridges to using DLTs in a real world. However, the match is worthy and risky at the same time because nobody controls IoT systems"
	Cloud systems		
	-Fair analogy between blockchain and cloud systems -BT is a database technology: decentralized databases with the addition of consensus protocols -Facilities and computational power worldwide -Accesses from local units to remote units	-New generations of databases would emerge	-Blockchain systems are shaped platforms that have methods (tokens) and logics (smart contracts)
	Supply chains		
	-The supply chain is a key area for BT applications -Blockchain-based supply chains are nondisruptive applications -Most famous projects are centralized blockchain-based platforms -Blockchain, as a service, generates frictionless operations and new negotiation procedures -BT creates and supports the redistribution of value in the value chain -BT is a solid application for ecosystem building -Higher level of transparency -Food is one of the environments that will obtain greater benefits	-No working uses cases in supply chains apply the whole BT's potential	-Blockchain-based supply chain is simple and easy to develop
		-The challenge is how to share data to create intelligence	-Difficulty in resolving the 'coopetition' paradox
		-Lost intermediary and being paperless	-BT does not have to be a 'disintermediator' to generate value
		-BT creates closest venues for/to consumers	-BT for supply chains is a small financial system
		*"the future implementations of BT into supply chains will empower customers changing their behaviors in the market"	*"BT has the ability to boost confidence in the relations between players in a network."

* quotes are provided as insight to illustrate some of the bullet points

Features

The evolution of certain technologies during the last 40 years has allowed for and supported blockchain creation. Thus, blockchain is a technology aggregation of several individual technologies and is defined as a new technology layer for industrial applications. It uses five assets: cryptography, protocols, software, computers and the network (see Table 2.4).

Blockchain shifts some of the trust in people and institutions to trust in technology. People need to trust cryptography, protocols, software, computers, and networks. People need to trust them absolutely because they are often the single points of failure.

The technology side does not need to be increased; in fact, this technology provides new access and decentralization, without the need for a central authority. Additionally, blockchain is defined as a fantastic way in which to organize information and data, and blockchain has a fundamental role in digital assets. However, it does not mean disruption; in fact, blockchain might be defined as a database technology. It is a decentralized database with the addition of consensus protocols. The consensus mechanisms are the '*plus*' that blockchain technology brings to markets, and it will be a secondary system after the primary running systems.

Permissioned blockchain systems are shared databases with shared ledgers. Thus, in these '*shaped*' platforms, customer decision making might be modeled as a vending machine (VM) that has methods (tokens) and different logics (smart contracts). Hence, blockchain is not a consumer technology but rather a software-based technology, and even if there are some limitations (lack of efficiency, high costs, and inertia due to change), all technical problems will be solved, aligning them to the other platforms/systems in use.

Table 2.4. Example of technological aggregation that defines the blockchain invention.

Technologies	Features*	Activities*
The Cryptography	Hashing and asymmetric cryptology	Digital signatures/keys Simplify connections
The Protocol	Network language based on consensus	Monitoring and control
The Software	Collaborative approach for computer programs	Time stamps Transactions
The Computers	Decentralized databases with consensus protocol	Record keepers Computational power
The Network	Public computers with Internet (with open or restricted access)	Validation/deny Stream data

* not an exhaustive list

Innovation paths

Since DLTs bring into the market public computers, experts highlight that these public computers are the new paradigm. Public computers are the '*novelty*' for blockchain innovations. Thus, blockchain is not disruptive; it is a sustaining innovation that only increases performance.

Moreover, blockchain is a bottom-up innovation and, as an incremental innovation (see its definition at [79]), it brings about progressive changes and performance improvement for already existing systems. Permissioned blockchains are incremental by nature and, in several companies, innovation managers overestimate them.

Experts do not see blockchain technology as a new technology revolution but rather a technology system. The sector is highly fragmented concerning this technology-driven innovation, and the blockchain's evolutions are pushed by technology and shaped by the market. In this context, blockchain follows a bottom-up development

process, where communities play a key role. Additionally, blockchain impacts business procedures, changing operational strategies. Therefore, processes will be replaced in industry.

Consequently, and according to our experts' findings, blockchain is defined as a toolkit to use, not a need; in fact, there are no needs from the market, and citizens have no need for blockchain. However, what blockchain does is change possibilities and provoke people to change their customer attitudes and behaviors.

Currently, large companies are leading blockchain development (incumbents), and these larger industry tests are centralized.
In the next few years, the blockchain market will become more competitive, and these large companies will become leaders in different blockchain applications.

Digital transformation

Considering digitalization strategies, this technology might represent a '*catalyst*' for digital business implementation and transformation. In the short term, it will predominantly reduce costs before creating transformative business models. In fact, blockchain facilitates structural changes, and due to the other technologies harmonized with it, people may have the chance to change possibilities, channels and access to technologies and markets. Moreover, initial coin offerings (ICOs) showed good results in exchanging digital assets and changing customers' attitudes and behaviors, but the disruption here concerns business processes and accessibility.
Experts have highlighted that Bitcoin and Ethereum are just applications. The Bitcoin blockchain is the first successful use case for Fintech, but currently, Bitcoin is acting as a detractor for practitioners and industries. In fact, Bitcoin is not the leader at all, as blockchain has been polluted by Bitcoin's reputation. Instead, the Ethereum blockchain is the first successful use case in industry for ecosystem building, as an open system, for its collaborative approach, and for the standardization '*The ERC-20 token*'. Thus, there are currently no pioneers or leaders in terms of industrial blockchains.
Consequently, ISO standards have impacted business and society because they allow for the sharing of value in a standardized way, but ISO acquisition takes time, and the standards need to be as simple as possible to support new business models. ISO/TC-307 standards might provide better accessibility, representing a tool to disseminate innovation and to harmonize different protocols, mitigating interoperability issues. For instance, *the ERC-20* standard for tokens allows people and companies to launch ICOs worldwide. Hence, ISO/TC-307 might also represent a good tool to open new markets and increase the chances for improvements in the blockchain world.

Standards are not going to impact blockchain technological innovations. If the ISO/TC-307 is pushed, then it might have dangerous effects, converting its power into a tool to combat against technology progress for blockchain. Therefore, it is crucial to mitigate these risks, keeping in mind the decentralized nature of such technology.

Some controversial opinions have emerged about the future evolution of the technology in sectors where it would be more impactful. Academic experts have addressed its potential in terms of accountability, public administration and education, whereas experts from businesses and institutions have addressed its potential in terms of finance, banks and related services.

In fact, some of the interviewees defined blockchain as an institutional innovation and as a powerful governmental toolkit for public administrations. Controversially, other experts added that blockchain can achieve a better design if pushed by governments, but at the same time, some of them believe that blockchain may represent the valuable loss of a democratic society (with high social concerns), so they explain that blockchain is not useful for improving the digital democracy.

Maturity level

According to the maturity levels established by [27], [28], [78], the development of blockchain in industry is positioned into the proof of concept (PoC) phase, where there is no dominant design; thus, the dominant design has not yet been reached. In fact, PoCs are not ready for massive industry implementation, and neither the market nor technology are ready for the general adoption of PoCs. Thus, the market is not ready for this technology, and there are no parties ready to join. Therefore, the interviewees point out that the real challenge is to find a working use case where blockchain is applied in industry because there are not yet working use cases in industry that allow for prompt adoption in the industrial sector. Hence, in this PoC phase, even if the maturity level is low and there is deep market confusion, the *core* technology side is considered mature and ready for market tests. However, experts do not see blockchain as a product but rather a service. In some environments, blockchain has been tested following the blockchain as a service (BaaS) model.

Currently, a learning moment for R&D exists, and more education is needed regarding blockchain. Additionally, higher confidence (*trust*) in technologies is needed, but inside the community, more clarifications as to the implications and exact meaning of *trust* are needed. Additionally, trusting open systems (OS) might help solve scaling-up issues. As a 'network language', a classification of this language must be applied in industry. Because there are high expectations for blockchain, it is not completely understood and faces the risk of being overestimated.

The interviewees also agree that blockchain in terms of social aspects is not scalable, and if pushed, unexpected risks may emerge. In fact, achieving full decentralization, data face the risk of privacy. This privacy issue is one of the main criticisms, critical for data integration and for data analytics, and for this reason, permissionless blockchains might represent risk.

Another problem is asymmetry in information and communications. Mass communication is not informative and generates perplexity and mystification within the community. Quite often, the daily news is untruthful and misleads communities, hampering industry acquisitions. For example, cryptocurrencies have scared practitioners in terms of financial consequences and speculations.

Additionally, the lack of an exit strategy for blockchain is an issue.

Industry existing-systems integration

These findings have been split into three main areas: Internet of Things systems, cloud systems, and supply chains.

a) **Internet of Things systems**

The Internet of Things (IoT) is a key component in which adding distributed consensus methods opens up new opportunities. Hence, leveraging IoT infrastructures with blockchain will generate new working use cases, and IoT systems are identified as a crucial asset for blockchain in industry. In fact, the lack of technology enablers might be filled (partially) by the Internet of Things as a '*means*' through which smart contracts are run. However, the IoT is able to run smart contracts and tokens at the same level of application, enabling new blockchain-based business models for industrial implementation.

In the long term, experts see that smart contracts represent future power and could disrupt operations (*with new logics*), but in the short term, tokens (*new methods*) will be the nearest future with a good market space. In fact, tokens are much more mature in the market because they have been frequently tested and implemented in the banking and finance sectors with ICOs. Additionally, the '*changing point*' is identified when integration with IoT systems will happen because IoT systems might be the catalyst by which *machine-to-machine* payments can be enabled by token (*methods*) and smart contracts (*logics*).

The implementation of the IoT in blockchain-based supply chains can enable ownership of things and identification and match with the real world. These relationships with the identity of objects, ownership and sensors need to be strategically designed; otherwise, they do not make any sense. This strategic implementation is related to value capture and value proposition for application in business operations. In fact, running IoT-based data capture for DLTs might allow IoT systems to act as the '*bridge*' to use DLTs in the real world.

Here, a third party is needed because if the IoT is the '*controller*', then the third party controls the controller. Therefore, the match between blockchain and Internet of Things is worthy and risky at the same time. This implementation is critical and needs a step in between to be more secure and to mitigate this lack of control of IoT systems.

Moreover, the IoT and blockchain can solve some inefficiency. They can increase the traceability of transactions and increase security, but a differentiation between products (e.g., diamonds) and processes (e.g., oil or chemicals) is needed. For instance, in specific environments where security and safety are essential (such as chemical tanks), sensors become an extremely relevant feature to be considered for blockchain applications.

b) **Cloud systems**

Experts also highlight the fair and clear analogy between blockchain and cloud systems. They provide a comparison between these two technology systems. In fact, as cited above, blockchain might also be defined as a database technology, that is, a decentralized database with the addition of consensus protocols.

The comparison between blockchain and cloud systems highlights the main aspects that are correlated with these two systems and analyzes the main aspects and characteristics distinguishing these two technology systems.

Therefore, experts have provided some additional food for thought about which progresses will be generated and what evolutions and

impacts will characterize *blockchain as a service* in future applications in industry.
They infer a set of common aspects: both are designed *as a service*; both are software-based technology; deployment models are public or private; security follows cryptographic protocols; the access evolves from local units to remote units; applications are on private and public networks; and ISO standards are both in progress.
Different aspects are presented as follows: the network is centralized/decentralized for clouds (*A*), whereas the network may be decentralized/distributed for blockchain (*B*); the assets for *A* are archives and back-up keepers, whereas the assets for *B* are recordkeepers and decentralized ledgers; and the assets for *A* are centralized databases, while those for *B* are decentralized databases with consensus protocols. Thus far, the enabler technologies for *A* have been the evolution from hard disk drives [HDD] to solid-state drives [SSD], whereas for *B*, the evolution (so far) concerns the mining processing that started using the central processing units [CPUs], graphics processing unit [GPU], and then application-specific integrated circuits [ASICs]. The growing third-party capabilities were storage space worldwide for *A* and computational power worldwide for *B*; the impacts have been on remote storage for *A* and on remote computing for *B* (cloud mining).
Given this explanation, we would like to provide experts' overviews and focus on how these evolutions, such as remote access, can enable new technological '*shapes*' for database technologies in industry, open up new levels of performance and change paradigms, and run operations. One of the '*impacts'* might be the opening of new business models and digital services enabling IoT devices to become increasingly powerful, externalizing (running remotely) all the '*heavy*' processing procedures.

c) **Supply chains**

Experts have agreed that blockchain-based supply chains are nondisruptive applications that add a new technology layer to software-based technological systems, and experts define supply chains as a key area in which blockchains are implemented in industry. Thus, the blockchain-based supply chain will be an added '*service'*, and a *blockchain as a service* (BaaS) might generate frictionless operations and new negotiation procedures. To allow for this, three key points need to be taken into consideration: the decentralization level, scalability potential, and security clearance.

Currently, most renowned projects are centralized blockchain-based platforms that are showing solid applications for ecosystem building in the chains. This technology will be the trust keeper, impacting all recordkeeping processes and at a higher level of transparency for all stakeholders, due to updated real-time information and verifiable processes.

However, *trust* requires an '*e-ID representative*' for provenance verifiability. Experts have defined identity as a potential enabler for blockchain-based supply chains, empowering customers with product transparency and traceability that can level value chains out and boosting supply chain democracy and ethical consumption. A blockchain-based supply chain creates and supports the redistribution of value in the value chain. Thus, blockchain is suitable for the optimization and trust of food supply chain operations, making the food industry one of the first environments to obtain greater benefits from this technology implementation.

Additionally, before the end of this year, many patents will come out, bringing to the market more restrictions and leaders, such as IBM, which is the leader in patenting blockchain. However, experts have addressed the future evolution of supply chains in smart contracts. In fact, designing blockchain-based IoT systems linked with supply chains, logistics can humanize the boxes of a chain, moving closer to the mobility paradigm.

In addition, some controversial opinions have emerged among interviewees on supply chain applications as follows.

The current state of a blockchain-based supply chain is described according to two different views. Academics suppose that there are no working use cases in supply chains that apply the whole technology's potential because incumbents play in a centralized way, designing centralized data platforms. Rather, academics assume that blockchain for supply chains is a tool that can create closest venues for/to consumers. Business and institutional experts have described blockchain-based supply chains as simple and easy to develop, explaining how they represent a '*small financial system*' in which there are fewer and narrower problems to solve.

Additionally, the major impacts of this technology have created controversies, where academics suppose that it will impact customer behaviors, rather than others, in terms of ports and port authorities. This is because the main challenges will be how to share data to create intelligence and how difficult it would be to resolve the '*coopetition*' paradox in supply chains.

Instead, to create value, academics think about the loss of intermediaries and being paperless; other experts explain that blockchain does not have to be a '*disintermediator*' to generate value, but it can represent a changing tool for the stakeholders involved and enhance data management in the network.

2.2.5. Discussion

In this section, we discuss the main findings of the study, providing answers to the proposed research questions, and present our considerations and the contributions of this research.

Answers to research questions

After this analysis, we aim to answer the main research question: *what are the enablers for blockchain disruption in supply chains*?
Thus, following the proposed framework, we proceed, answering in line with the three subquestions to address specific themes and then collecting them in a comprehensive analysis in the next paragraph.

a) **RQ.1 What are the present and future perspectives for blockchain in industry?**

The industrial applications for the present situation are clearly assigned to the proof of concept phase. In fact, according to [28], until the dominant design is reached, the technology system needs to be considered inside the exploration phase. Many trajectories of development could emerge from this individual technology before it reaches a clear direction on the 'S-curve'.
Thus far, for blockchain in industry, there are no working use cases that exploit the full potential of this distributed technology. Moreover, this technology is considered a bottom-up innovation where communities play a key role in the development of blockchain as a service. However, so far, they are centralized applications.
Additionally, several companies, projects and organizations are using blockchains as a marketing asset, not for applications but only to enhance their cutting-edge profiles. This aspect creates confusion and perplexity in communities approaching blockchain, creating misunderstandings about its real features and usability.

Otherwise, regarding future perspectives, the blockchain's potential is clearly seen by experts. However, blockchain is not seen as a disruptive innovation because there is a lack of enablers for industrial acquisition. Hence, with a lack of key enablers, this process will take time before being fully operative in the market. Furthermore, the solving of some of the several issues affecting blockchain is needed, and it can help with the faster acquisition of blockchain in industry.

b) **RQ.2 How can blockchain in industry be effectively connected to other interdependent systems?**

Following [8], blockchain is not disruptive; instead, it is a sustaining technology that increases the performance of existing processes. Thus, blockchain systems need to be connected to other technological enablers that may support new business models and a possible disruption in industry.

Moreover, as has emerged, identity is not a blockchain problem, and the related issues need to be solved with other technologies. In fact, identity is considered off all the technical configurations; however, digital identity is considered one of the main sectors to explore because it represents one of the potential enablers that can facilitate acquisition in the network and provide better accessibility.

Furthermore, blending digital identity and IoT systems in blockchain structures would foster the generation of new digital business models as a key asset for the next development steps. Thus, this development needs to be designed as an open system, where communities can act and play a fundamental role in it. The Internet of Things (IoT) is also considered one of such enablers.

From experts' visions, the IoT makes sense in the future development of industrial blockchains. In addition, it will be the added technology layer that can enhance negotiation procedures and industrial trust. Otherwise, a third added layer is needed in between to be implemented into industrial systems and to assure trust and trustable data.

c) **RQ.3 How can blockchain in supply chains effectively foster digital enhancements?**

Since the current industrial tests are centralized, a challenge will be to improve the decentralization level in blockchain-based supply chains. Running applications are a good tool for ecosystem building and achieving higher levels of trust in business networks. Thus, this can fairly support the resolution of the '*coopetition*' paradox in supply chains and in the designing of new processes that are mutually beneficial for the stakeholders involved. In fact, there is a growing necessity of engaging stakeholders to understand their needs, in order to deal with the '*coopetition*' paradox [90]. Hence, breaking down trustable operations can help to create value for the whole supply chain, fostering technology scalability and overall decentralization.

As a first identified solution, considering the technological gap between research and industry, it might be required to define a fair tradeoff between distinguishing features—decentralization level, scalability potential and security clearance—as this tradeoff may also play a relevant role in contributing to both industry and understanding.

However, blockchain will be a *service* for supply chain stakeholders. These new services can support the restructuring of value chains, with new information flows and new responsibility duties. In addition, food supply chains are considered the field in which it makes more sense to apply (step-by-step) these technology improvements. In addition, trust (or *chain-of-trust*) could be set as a new service for customers that can bring about more ethical consumption in the market and then strengthen the community of informed customers.

Therefore, merging existing systems, such as digital identity and IoT systems, with smart contracts and tokens can generate '*killer*' applications for supply chains. Enabling business networks to move toward a higher level of digitalization and automatization of administrative duties.

This can be designed as a deterministic virtual machine for industrial operations, following an accurate definition of processes, procedures, responsibilities, and duties. Additionally, extraordinary or emergency situations can be defined, but this digital enhancement directly address autonomous payments, autonomous maintenance, and machine-to-machine transactions for frictionless business negotiations.

Hence, concerning digitalization strategies, a key asset for industrial automation is addressed as to how the cryptographic identity of IoT devices can replicate the asymmetric cryptography used on blockchains to generate randomness in devices' identities, enhancing security and control.

Finally, some kind of artificial intelligence ought to be blended with these solutions to spread the potential for new business model generation and new industrial viable solutions.

Contributions of the study

Due to the interview sessions, several data points were collected, assessed and analyzed to reach the aim of the study. With these obtained results, we identified key enablers where communities need to focus more efforts to foster blockchain adoption in industry.

Identifying enablers will guide practitioners during the risk assessment related with blockchain deployment. Given that implementation risks are still high for blockchain, isolating specific features would be relevant to define the required steps for development.

Therefore, considering this as exploratory research, we present possibilities to identify specific acquisition steps that can allow for frictionless blockchain developments in industry. This means the identification of those enablers that bring about new technology improvements in the technology system.

In this section, we present our consideration for future possibilities. We have identified four main areas: 1) positioning, 2) timing, 3) change management and 4) enablers.

From these following four paragraphs, we lay the foundation for improving management of blockchain innovations. Approaching new levels of developments, it is critical to take into consideration relevant risks, intended function, and the ability to design and assess the benefits—where they exist—of technology acquisition.

a) Positioning on the "S-curve"

Blockchain per se is not disruptive; experts see it as a sustaining innovation/technology that brings about new performance in a new technological layer. As an aggregation of several technologies, the innovative step lies in the combination of activities and in how individual technologies are aggregated and blended. Therefore, we can say that the *novelty* aspect of blockchain has no technical features (see Table 2.4), whereas such *novelty* is present in public computer networks and the access thereof.

Blockchain is a technology system; as such, blockchain innovations are opening new trajectories of development in several industrial sectors, impacting them in different manners. Given that there are no working use cases in industry but only proof of concepts (PoCs), we can assign blockchain models into the explorative phase of the ‘S-curve’ graph [28]. In fact, there is no dominant design; according to C. Pérez, the design is still open to new industrial ‘*shapes*.’ These new shapes will play a part in new digital business models and in new ways in which to manage processes. However, this process takes time and is not predictable right now. According to this, we provide an example in Table 2.5 to assign this unpredictable process to some events that occurred during the development path.

Table 2.5. Example of an innovation pathway.

To provide an example regarding the positioning into the ‘S-curve’ graph and trying to represent the “*dilemma zone”* for blockchain in industry, the following can be true: “considering Hyperledger as the leader in designing *Blockchain as a Service* and providing several tools for companies in narrowed market niches, considering Bitcoin as a use case for banks and financial procedures to solve double-spending problems, and considering Ethereum as a use case that allows for the transfer of ownership, we can follow the evolutionary progresses on these three large networks and imagine this flow as three common steps of development: STEP_1) in 2008, Bitcoin launched blockchain for fintech and banks applying new ‘*methods*’ to manage and exchange money – cryptocoins; STEP_2) in 2014, Ethereum created a new language (solidity) and new ‘*logics*’ to manage the ownership of money – smart contracts; STEP_3) in 2016, Hyperledger created a network where these ‘*methods*’ and these ‘*logics*’ might be applied in industry. These new models, patterns and structures have been implemented ‘*as a service*’, capitalizing the ownership of money for interested companies (still in proof of concepts). However, it created new blockchain-based services (or *BaaS*) that are following the ‘*methods*’ and ‘*logics*’ used before.

b) **Timing for adoption**

Since a dominant design is missing, after the analysis of collected information, we can expect a minimum period of three years before blockchain enters industry, contributing to value creation and value exchange. However, there are still many issues to take into account and resolve before this acquisition; in fact, the interviewees consider this prediction optimistic.

In addition, as experts remarked, several regulations are still missing, and this progress will take time to be operative and acquired in the business world. Governments and institutions, who are imagining blockchain development for public procedures and for public administration, still have a long path to run. We can optimistically presume a period of five years.

However, we can suppose that in the next five years, blockchain will achieve robust development and interoperability with other systems and will assure feasibility at scale. This will be possible due to the growing focus institutions and business communities are placing on the technology, and the growing investments they are exploiting.

c) **Change management for technology Trust**

For centuries, the common meaning of '*trust*' was allocated to people, institutions or third parties. In recent decades, technological development has added a further level of '*trust*', switching some elements of trust to technology trust. Blockchain technology is part of these changes, and managers need to consider it in advance because these changes will impact common ways in which to operate and processes. Hence, new different paradigms of management will emerge to set up new lean procedures to assign technology trust.

For example, considering a blockchain-based food supply chain, the word '*trust'* for companies means transparency, traceability, tracking and tracing. These four aspects together impact the whole system, allowing for real-time information systems, digital identities of approved parties, ethical attitudes/behaviors for stakeholders involved, and a closest avenue to/for customers. However, these '*4Ts*' of trust require an effort by the management team in companies to solve related problems coming from new business models, new/higher technical applications, and higher expectations from customers on controlling the net. Therefore, trusting technology will be a business advantage, but it needs to follow a rigid management procedure; otherwise, it will be considered a risk for the companies involved, causing them to lose their market position.

In addition, to properly manage a blockchain core business, the management team needs to mitigate the missing technical-knowledgeable people inside companies. This is an aspect that cannot be excluded or underestimated for blockchain businesses, or otherwise, it may generate unpredictable risks. In fact, technical people cannot be a third-party or an externalized service; they need to be inside and completely part of the team. If the technical aspects are the *core*, then the core technology cannot be externalized to mitigate, monitor and control all security management procedures.

Therefore, risk mitigation and risk management need to be structured and defined before starting a blockchain project.

d) **Enablers**

As mentioned above, blockchain is not disruptive for industrial applications. It is a sustaining innovation that increases the performance of processes and operations. However, following the examples provided by [25], neither Uber nor Netflix use fully disruptive technologies, but they are considered disruptive due to the enablers applied in a specific market sector (see Table 2.6). Thus, we would like to discuss our findings in terms of blockchain's potential enablers.

As has emerged, we present a proposal of the potential enablers of blockchain in industry. In accordance with this study's research findings, based on expert interviews. To the best of our knowledge, these enablers have the potential to turn future blockchains into disruptive applications.

As mentioned, disruption is not predictable, but within this study we lay the foundation for the identification of enablers, following the Christensen theory. This identification might guide practitioners during the assessment of risks related with blockchain developments. In such cases, this guide would help isolating specific blockchain functions/activities. Isolating specific functions, practitioners can test if blockchain makes sense for the analyzed operations, and if the solution is exploiting the whole technology potential.

Furthermore, as explained above, these enablers not only increase performance but also can foster new ways in which to operate, new processes and the generation of new digital business models (see Table 2.6). In fact, due to these enablers, new *blue ocean opportunities* [31] might succeed in industrial sectors, so that they would be likely exploited to achieve disruptive innovations.

Hence, as listed and explained below, we conclude by highlighting our main contribution of answering the broader research question we pointed out in the section I: *what are the enablers for blockchain disruption in supply chains*? Thus, the identified enablers are gathered in five categories (Figure 2.2): 1) access enabler: identity and digital signatures; 2) value-creation enabler: artificial intelligence and data; 3) interoperability enabler: tokenization; 4) remote enabler: Internet of Things; and 5) social enabler: blockchain-based mobility and blockchain-based logistics.

Table 2.6. Example of a disruptive implementation.

As an introduction, the Uber example is explained as follow. Uber is a new taxi service, and the application per se is not disruptive because it only digitalizes the calls for a taxi ride. This digitalization is a performance improvement, so it is assigned as a sustaining innovation. Otherwise, this new digitalization of calls for taxi rides would become disruptive due to the smartphone app. In fact, the app is considered *the enabler*, providing a tool for customers that allows for a peer-to-peer connection with taxi drivers. The match between these two aspects—the digitalization plus the connection—converts Uber into a disruptive innovation [25].

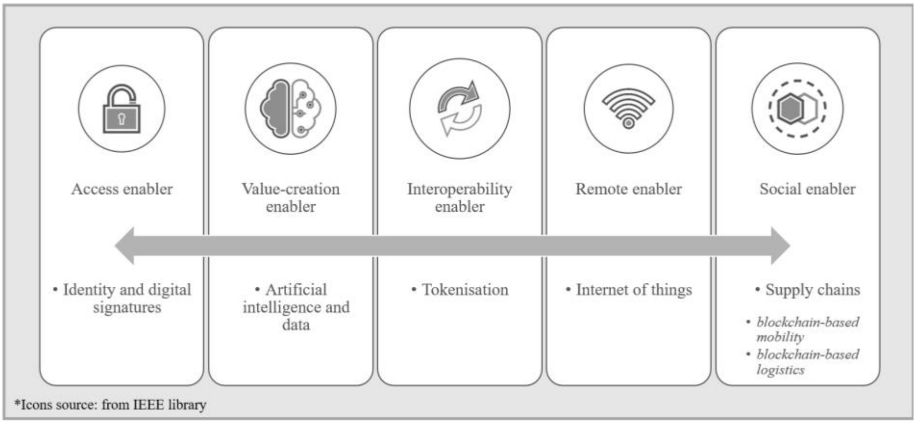

Figure 2.2. Identified enablers in a conceptual framework with a 5-step implementation process.

1. Identity and digital signatures

Identity and digital signatures are not technical problems that may be solved just by blockchain. Identity requires other technologies, and these technologies are already deployed in industry, presenting good levels of performance and security. Otherwise, considering the outcomes of this research, identity is considered the '*access enabler*' for blockchain development. In fact, identity, in the broad spectrum for people, companies, robots, objects, etc., is considered the first key step in gaining access to a blockchain network. This proof of access can lead to new technical opportunities for blockchain in industry.

2. Artificial intelligence and data

The match between blockchain and *artificial intelligence and data*, as has emerged, offers opportunities for better oversight and accountability. The match between them can be the enabler to solve interoperability issues, impacting recordkeeping processes, including the way in which transactions are initiated, processed, authorized, recorded and reported. In fact, this '*value-creation enabler*' creates changes in business models and business processes and may impact back-office activities, such as financial reporting and tax preparation, especially given that blockchain has been defined as "*a fantastic way to organize data*". Hence, while blockchain can help industry track, understand and explain the decisions made by artificial intelligence (AI), inversely, AI can manage blockchains more efficiently. Since the blockchain technology layer must relate to other technology levels, AI needs to be taken into account for industrial development. Moreover, regarding distributed implementations, determining how a distributed ledger will be managed falls to a single third party in charge of key considerations, such as that who has access and can invite new members into the ledger. In this sense, AI may set basic rules about onboarding new users, likely addressing the offboarding process, keeping the "*exit*" issue as one future problem to assign for industry.

3. Tokenization

Tokenization may represent '*a first step*' for systematic interoperability. Considering Ethereum's standardization of tokens (*ERC-20*) as the enabler that allowed for a new kind of crowdfunding and interoperability, this tokenization impacted new forms of practices and accessibilities for fintech. As a result, the ERC-20 created some frictionless procedures on investments and trading, reducing barriers, and empowering users by allowing everybody to take part in the system.

Furthermore, this digital transformation designed a new business model, known as an initial coin offering (ICO), instead of the common initial public offering (IPO). Thus, since 2017, the ICO concept has brought about potential for new dominant designs in cryptobusinesses, bringing new digital access and perceptions to the market. Hence, we could affirm that this '*interoperability enabler*' may represent an enhancement to digitalization procedures, even if many regulations are in progress to define the positive consequences and to mitigate the negative impacts. A delineation of a potential interoperable token may be the potential enabler for widespread acquisition in industry.

4. Internet of things

The *Internet of Things* is considered the '*killer*' application or catalyst for frictionless negotiation procedures where machine-to-machine transactions may emerge [15]. In fact, due to smart contracting and autonomous contracting, this machine-to-machine procedure is a software program deployed following specific requirements depending on the goals to achieve. Therefore, blockchain-based IoT for robotic devices may support chain-of-trust and managing data and act as a new service for data optimization.
In addition, the business intelligence applied to this chain of trust would organize it in a better framework using blockchain. As such, considering the blockchain as a decentralized database technology with a consensus protocol, remote computing can allow IoT systems to propose new business models, foster new access, design new device architectures, and empower a new level of performance.
However, this '*killer*' implementation would need a third party to control it because considering the IoT system only, they will not be able to assure the data gathering in a trustable framework. Thus, this third party may be considered the basic enabler for IoT developments in this implementation; this '*remote enabler*' can be reached with existing technologies.

5. Blockchain-based mobility and blockchain-based logistics

Regarding supply chains, *blockchain-based mobility* and *blockchain-based logistics* are considered two enablement sectors where blockchain may have a higher impact on society. In fact, as has emerged, new types of data management platforms have been implemented and have shown good results so far, but these data platforms are only a first step of development for blockchains that increase industrial performance. Therefore, to exploit the whole potential of blockchain technology, these data platforms need to reach an advanced stage of development, and to reach this progressive evolution, they need enablers.
In this case, for logistics and mobility, enablement factors may be new types of engagement with society, empowering customers with new forms of decision-making toolkits, redistributing value into the economic paradigm, or providing metrics for social responsibility

(e.g., value chains and sharing economy). All these potential enablers will not be related to key performance indicators (KPIs) as one of the standard ways in which to manage decisions inside companies , reducing costs and improving performance, but these enablers will be related to social behaviors, social attitudes and hyperengagements. Thus, we can affirm that these enablers have the power to change people' behaviors, to educate urban and rural communities, and to create a more aware society with higher impacts on environmental issues, healthcare, and climate urgency[9].
Therefore, considering logistics and mobility as two similar models, we would like to consider these '*social enablers*' as good food for thought for the sustainable development of blockchain and to mitigate some of the many issues and concerns that present in the discussion on blockchain. Furthermore, considering the interoperability of different technological layers, these social enablers may be the '*vector*' for new value propositions in industry, mixing and blending all the enablers cited above.

2.2.6. Limitations

The explorative research carried out has some limitations that we state in this section. The selection of experts may miss several of the renowned representatives working in blockchain, who might have brought valuable further data to the study. Additionally, as a qualitative approach, data collection and data analysis might be affected by our personal judgments. However, we applied grounded theory in a meticulous manner to assure the mitigation of possible misleading results and respecting the defined criteria. Additionally, as we collected a flourishing range of results, the presented outcomes are not fully comprehensive but are focused on answering the research questions. Moreover, as the expert interviews were applied to technology-oriented people working on innovation and blockchain in different sectors, some insight for supply chain areas might be missed. In addition, we provided some development steps for acquisition in industry but with a low level of details and keeping a macro-overview for the implementation.

9 R. Born, "DLT for Climate Action Assessment", *EIT Climate-KIC and ETH Zurich, 2018.* Online at: https://www.climate-kic.org/in-detail/dlt-for-climate-action-assessment/

2.2.7. Conclusions and future research

In this chapter, we explored experts' opinions about blockchain disruption in supply chains and industrial applications. Applying an explorative research approach, we designed 18 semistructured interviews that allowed us to run an analysis on the current situation of blockchain (S-curve positioning), on the interconnections and interdependences, and on what industry needs to understand to identify how blockchain may affect supply chains.

Due to the grounded theory approach, we identify five categories that make an effort toward and explore this research line in more detail. As the main result, we individuate that blockchain is not disruptive; instead, it is a sustaining innovation. Thus, it is worth identifying some enablers that can allow for its prompt acquisition in industry. A simple conceptual framework of 5-step implementation has been presented to underline the milestones that the industry needs to develop before starting a blockchain project: a) access enabler, b) value-creation enabler, c) interoperability enabler, d) remote enabler, and e) social enabler.

This study lays the foundation for the identification and assessment of risks related with blockchain developments. This study could help isolating specific blockchain functions and activities. With this isolation, practitioners can test if blockchain makes sense for their operations, and if their solution is exploiting the whole blockchain potential.

In addition, we understand that this process will take time, approximately three years, and we can suppose that in the next five years, blockchain will experience robust development and interoperability with other systems and will assure feasibility at scale.

Regarding change management, blockchain shifts the trust in people and institutions to trust in technology. This change needs to be carefully taken into account by managers before starting a blockchain project, and if the blockchain is a *core* activity, then know-how needs to be inside company, not externalized. Therefore, the '*4Ts*' of trust are not enough, and managers need to add new layers to create and exchange value.

After this analysis, we will focus our future efforts on studying in-depth some of the findings presented in this chapter. These findings have been recognized as enablers for potential improvements of blockchain systems in industry.

Furthermore, as has emerged in the study, more education is needed about blockchain. Hence, in addition to research activities following the lines presented above, we will be committed to designing, preparing and editing blockchain educational materials. With these materials, we believe that we will contribute to fulfilling some lack of knowledge that brings about perplexities and mystifications regarding this topic. Therefore, we would like to contribute to increasing the awareness and understanding of providing educational materials for students, practitioners, and representatives.

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Chapter 3

BLOCKCHAIN AND SUPPLY CHAIN

Sections:

3.1 Contextualization of the study

After the results obtained in chapter 2, the study proceeded with additional questions and interests.

Although it was identified that blockchain development impacts on supply chains, the analysis showed that blockchain does not seem to be a disruptive technology in this sector, but rather a sustaining innovation that may bring additional performance improvements.

However, given the complex nature of supply chains and their intense connections with markets and industry, it has been crucial to sharpen the focus on the potential applications of blockchain in order to proceed with the research analysis.

Therefore, at this stage it was considered relevant to assess and identify in which specific aspects and processes the blockchain technology may provide enhancements in supply chains. As a result, two processes were identified and discussed in the study.

3.2 Blockchain-Based Information Management for Supply Chain Data-Platforms

Results of this study identify the supply chain management processes that drive blockchain technology.

Abstract:

Performance measurement and information management are vital assets for supply chain management. In this study, we analyzed the effective combination between blockchain technologies and supply chain management processes. We conducted eighteen interviews with international experts from different areas and analyzed the collected data following a grounded theory approach. We have identified five main categories in this area including accounting and administration, trust, data platform, interoperability, and disintermediation. The main findings concluded with a set of seven statements as key elements to summarize how blockchain-based supply chains fit in with supplier relationship management processes and financial business units for international trade. The seven statements also recommend future research activities and trajectories.

Keywords:

blockchain; decentralized applications; information management; supply chain management

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3.2.1. Introduction

In the last few decades, due to research efforts and an increasing level of digitization, supply chains have improved in terms of performance and process optimization [1]. Digital technologies allow for information sharing across supply chains [2], providing a set of benefits such as enhancing performances, implementing re-optimization procedures, and load-based optimization for sudden and unexpected events. These benefits also mitigate negative consequences and repercussions for other planned duties. In the transition to Industry 4.0, information sharing through internet of things (IoT) systems has become a strategic factor and a key component for market competitiveness [3].

Industrial IoT (IIoT) is developing new industrial management paradigms, enabling aggregations of large-scale data internally and externally to the company [4]. This progress developed new systems operating in more intelligent and interconnected platforms. Thus, the number of IoT devices is increasing every day within the industrial sectors, although this intensification of IoT devices jeopardizes several companies [5]. Moreover, an increasing number of IoT devices expose these companies to further risks, increasing their vulnerability to cyber-attacks and hacking.

Blockchain technology mitigates some of these risks [6]. Blockchain platform deployment is strengthened by cryptography and consensus protocols and acts as a detractor for cyber-attacks and hacks. Several studies [6]–[8] explore the leading factors of blockchain-based supply chains, assessing industrial applications that may foster digitization in operations. In this instance, the dilemma for decentralization is currently under discussion [7]. Blockchain (BC) shows a broad range of advantages but at the same time represents huge risks for companies. Blockchain platforms generate innovation for ecosystem-building among supply chain partners; however, sharing key business information on permissionless systems might expose companies to the loss of business spaces in favor to their competitors. Other advantages, such as real-time information and trust, were identified for the implementation of this technology. Nevertheless, it is relevant to consider that they can be achieved with existing technologies. Therefore, further research is necessary to explore how blockchain platforms should be tuned for supply chain operations and to identify sufficient benefits, as well as maximize the reward. This will be fundamental in assuring a higher level of efficiency and effectiveness [8], [9].

The current study addresses the aforesaid gaps, providing an identification of those processes for which blockchain platforms may benefit supply chain management (SCM) operations. In developing a cross-analysis between technological and managerial fields, this research study seeks an answer to the following research question (RQ): *how can the information flow structure affect and pilot a suitable blockchain adoption in SCM?*

We conducted interviews and collected data from a pool of eighteen experts. In analyzing data from the experts, we performed an explorative research study that provides a neutral and impartial approach. The research contribution is detailed in the discussion section, in which answers to the RQ are provided.

Following an analysis of all the interviews with international experts and by applying the grounded theory methodology, the analysis of the data allowed us to address the research question as the main contribution of our work.

The research contribution provides the following outcomes: (I) a summary of the key findings of previous research and existing work; (II) a presentation of findings emerged from the experts interviewed; and (III) seven statements as key points to drive blockchain technology in supply chain management processes.

The remainder of this chapter is structured as follows: Section 2 presents the literature review of the most relevant research works for the present study; Section 3 details the grounded theory methodology and analysis of the collected data; Section 4 elaborates on the findings of the analysis; Section 5 offers a discussion and the research contributions; and Section 6 provides the conclusion.

3.2.2. Literature review

As a distributed ledger technology, blockchain has the potential to increase certain levels of performance in terms of time and security in data platforms, but it also has limitations regarding the property of bandwidth or data storage. Blockchain, considered as a sustaining or non-disruptive innovation [10], performs a decentralized database technology recognized as a new implementation layer. This layer will shift to new communication models and support changes concerning the systems' access

required for industrial communication, enabling the availability of public computers within the network.
Blockchain uses asymmetric cryptographic protocols and through a consensus model, it allows data to be acquired by the system in a pre-established logic. Concerning decentralized databases, these logics (smart contracts) use methods (tokens) to process and exchange information in the network [10], [11].
Blockchain technology is an aggregate of previous existing technologies [10]–[12] and improves on established concepts such as smart contracts launched in the 1990s [13] or digital currencies of the 1980s [14].

Technology definitions

Blockchain technology has its origins in the financial sector [15], [16] and is in the nascent stage of development for industry [15], [17]–[19].
However, due to its characteristics of decentralization, trustworthiness, and collective maintenance, blockchain provides a trustworthy platform to achieve a reliable peer-to-peer delivery of value without depending on a single centralized organization [20].
According to Fosso Wamba et al. [21], blockchain is defined as ‘a data-management technology with 13 intrinsic characteristics: secure, shared, immutable, decentralized, distributed, authenticated, encrypted, open-source, incorruptible, integrated, publicly visible, chronological, permanent’, while Esmaeilian et al. [17] defines blockchain as ‘a decentralized, distributed data structure and public digital ledger’.
Although the current business applications have designed blockchain as a platform [22], this technology can be also viewed as a replicated database that is distributed among thousands of nodes which belong to diverse parties [20].
Additionally, Leng et al. [23] describes blockchain as a distributed accounting system implemented by computer technology and set by distributed databases. According to Kouhizadeh et al. [24], blockchain has positive impacts on information sharing and is a data structure [25]; all transactions are easily auditable. Therefore, blockchain is a ‘*trust machine*’, leading to a data-driven economy [26]. Unfortunately, appropriate regulations are absent in this area [10]. Caligiuri [27] provides a complete legal and regulatory framework regarding blockchain and its legal and business

implications, and further provides an exhaustive overview of the correlation between blockchain and GDPR, finance, notarization, traceability, and food supply chains. In this context, Pólvora et al. [18] presents an analysis of blockchain and policy foresight for data management. At several levels, data management distinguishes itself as an essential part of blockchain deployment across sectors [18] as this technology is a secure protocol to store information [28].

Supply chains

SCM is the integration of all key business processes across the whole chain of processes and stakeholders [29]. According to D. M. Lambert [30], SCM pertains to relationship management and requires the involvement of all business functions. Therefore, it is fundamental to have effective partners in the supply chain (SC) and crucial to develop the right types of relationships [31]. However, according to Rao and Weintraub [32], to foster innovation, enterprises often devote greater attention to resources, processes, and measuring successes that are easily quantifiable. Contrastingly, enterprises focus less on values, behaviors, and climate, which are the harder-to-measure and people-oriented determinants of innovative culture.

Performance measurement in the SC is vital [33]. In this context, it is critical to identify bottlenecks, wastage, problems, and improvement opportunities. According to Akyuz and Erkan [34], SC performance measurement needs to be addressed on the: development of partnership, collaboration, agility, flexibility, information productivity, and business excellence metrics. Furthermore, innovative performance measurement systems need to be adopted and centered on value creation, long term orientation, transversal metrics, and the monitoring of improvement [34].

The decision-support methods in SCM domains are required to be both proactive and reactive, as well as proactive and reactive simultaneously [35]. This can be achieved with robustness reserves and the speed and scale of recovery actions. Both SC robustness and resilience should be estimated to mitigate risks [35]. Risk management plays a vital role in the effective operation of SCs in the presence of a variety of uncertainties [36].

Additionally, according to Büyüközkan and Göçer [1], the digital supply chain (DSC) framework is composed of three key components, that is, digitalization, technology implementation, and SCM. There are several risks in the digitalization of SCs [22]. Advanced tracking and tracing technologies can provide real-time event identification and SC visibility; however, they have both benefits and threats that must be carefully assessed. Hence, the development of real-time coordination can mitigate certain SC risks [2].

Blockchain-based supply chains

Blockchain adoption in global SC, transport, and logistics is still in its infancy [7], [19], [37]. Despite the immaturity of blockchain [19], it is set to transform SC activities by increasing transparency and accountability [8]. According to Hastig and Sodhi [38], transparency is a factor in the level of traceability. Alternatively, according to Bai and Sarkis [9], there are three SC transparency types: (i) range of transparency; (ii) product transparency; and (iii) participant transparency. Therefore, to boost the implementation of blockchain-based SCs, the analysis of SC transparency factors is necessary and needs to be correlated with an opportunities and risk-perspective analysis aimed to assess the possible gains or losses [9]. Consequently, blockchain has the potential to help achieve the seven SCM objectives of cost, quality, speed, dependency, risk reduction, sustainability, and flexibility [8].

However, according to Saberi et al. [19], four barriers exist for the development of blockchain-enabled SCs: inter-organizational, intra-organizational, technical (system-related), and external barriers. Despite the prominence of technological and intra-organizational barriers [24], blockchain is a driver for digitization in the SC [39].

According to Kshetri [8], blockchain has the potential to break down data silos, offering one source of data and digitalization with a real-time data control for all (trusted) partners in the network. Trust and security can be improved with blockchain [8]. Additionally, business value exists in building trust through blockchain, improving efficiency, reputation, time-to-market, responsiveness, and material savings [16]. Thus, blockchain positively impacts SC performances [40]; however, for operation management, it provides advantages over the existing systems [6]. According to Cole et al. [15], enterprise resource planning (ERP), radio-frequency identification (RFID), and blockchain are complementary technologies, and it is fundamental to assess their best combination to maximize effects and impacts.

Given that blockchain has an emerging nature in business [41], all nine dimensions of a business model can be translated into key SC design decisions to build a viable blockchain-based SC ecosystem. However, blockchain cannot be used in isolation for SCs [41]. The challenge remains that the return on investment (ROI) for blockchain implementation is unclear [7], which makes it difficult to involve all the parties in the transition and furthermore considering that the related performance improvements are difficult to predict [9].

All the benefits stakeholders can obtain by blockchain deployment are related with immutable information and sharing; however, it is fundamental to avoid centralized platforms [11]. In a blockchain deployment, neither party would be the owner of the blockchain infrastructure [7].

According to Kshetri [8], a key element of blockchain-based models is that all transactions are auditable, which is particularly relevant in gaining the trust of all interested parties. Therefore, all SC stakeholders must accede for the blockchain adoption to succeed.

Finally, to support the development and understanding of blockchain technology in the SC, interdisciplinary investigations are required to build theories and designs for blockchain technology [19]. In this instance, blockchain-based social sustainability and responsibility could enable firms to extend visibility, assuring their due diligence in line with the legislations against modern slavery [15]. Moreover, there is a lack of experience, knowledge, and understanding regarding blockchain [39]. Additionally, the labor skills gap concerning the technology needs to be filled [38]. According to Pournader et al. [37], for blockchain, both technological and business limitations need to be addressed because there is an inflated expectation from blockchain, which might exacerbate the effect of the failed adoption in industry.

An effective combination: BC, IoT, and SCM

In this section we explore the combinations between blockchain (BC), the internet of things (IoT), and SCM. Assuming blockchain can strengthen IoT security, it can ensure SC security through IoT systems [25]. According to Kshetri [8], an IoT system in blockchain-based solutions validates the identities of individuals and assets, thereby enabling the use of blockchain in an SC to determine who is performing what actions. Additionally, these features facilitate a valid and effective measurement of outcomes and performances of key SCM processes.

Furthermore, Ben-Daya et al. [3] explored the role of IoT and its impact on SCM processes and applications. Thus, according to Ben-Daya et al. [3], IoT for SCM will affect procurement, production planning, management of inventory, quality, and maintenance.

IoT systems offer SCM an unprecedented visibility into all aspects of the SC [3]; however, the IoT for SCM is still in its early stage of development. In this instance, there are several risks correlated with the implementation of IoT in SCM [5]. According to Birkel and Hartmann [5], these risks are divided in three clusters: (i) environmental; (ii) network-related; and (iii) organizational. These risks impact Industry 4.0 and either the IoT for Industry 4.0 or the IIoT [3], [4], [42] needs an adequate level of security to mitigate environmental, network, and organizational risks.

Esmaeilian et al. [17] defines IIoT as ‘connecting and monitoring industrial objects and physical devices through the internet’.

Blockchain-based access management systems can address key IoT security challenges such as those associated with internet protocol address spoofing [25]. According to Weingärtner and Camenzind [43], identity is a crucial property of IoT devices. Blockchain and decentralized identifiers (DID) can be used to trace back the origin of the device, which is especially important in security-relevant environments [43]. Consequently, blockchain may be used for the allocation and management of device identities, which will be an essential feature for future blockchain-based applications [43].

A blockchain and IoT combination facilitates the sharing of the services and resources leading the marketplace between devices, paving the way for automation and a more secure way for innovation [20]. The blockchain–IoT combination is powerful and is set to transform many industries [20], [44]; for instance, IoT devices can conduct autonomous transactions through smart contracts [44], establishing machine-to-machine autonomous payments [45] and machine-to-machine autonomous communication and decision-making [3], and alter how IoT systems are used in business worldwide [20].

Therefore, the combination between blockchain, IoT, and SCs might represent a performance improvement in information management for interlocked devices.

3.2.3 Methodology

According to Saberi et al. [19], grounded theory approaches can be used to expand blockchain's features and practical implementation observations. Thus, following Corbin and Strauss [46], a dynamic approach was designed for this qualitative research. This dynamic approach enables evolution in design as the study progresses [47]. As a form of qualitative research, the grounded theory has the purpose of constructing theory grounded in data [46], [48]–[52]. By identifying general concepts, the development of theoretical explanations offers new insights for studied phenomena.

This study maintains an investigatory character and lays the foundation for this research area. In accordance with Bogner et al. [53] and Bolger and Wright [54], we established flexible guidelines to run this ethnographic research study and identified experts with both a high degree of interpretive faculty and extensive knowledge in their respective fields.

The pool of experts (Table 3.1) is composed of academics (AC, eight in total), information and communication technologies professionals working in renowned companies (ICT, eight in total), and institutional representatives (WO, two in total). The international experts are from EU and non-EU countries and possess a proven knowledge of blockchain.

Data collected

On average, the interviews were conducted for a timeframe of 45 min in which, after a first open discussion (of 10 min circa), semi-structured interviews were performed following the designed questionnaire. The questionnaire consisted of 15 open questions distributed into three sections. The first section collected general information and the expert's background; the second section was focused on market aspects of blockchain for supply chains; and the last section was tailored for future trends and perspectives from the expert's perspective.

Data were collected through memos and notes. The interviews were recorded following prior authorization and the data collected followed a screening process to develop a narrowed analysis for the study.

Although the 18 interviews allowed us to collect a large amount of data, other sources of knowledge (The World Economic Forum: Strategic intelligence, Transformation Map for Blockchain, and The

European Blockchain Observatory and Forum: Reports) have been considered in this research study.

Table 3.1. Pool of experts interviewed.

#	Respondent Provenance (anonymized)	Sector of Interest	Gender	Location
1	ICT_1_Logistics	Handling	M	Belgium
2	ICT_2_Consulting	Business models	M	New York
3	ICT_3_Consulting	Business services	M	Spain
4	ICT_4_Consulting	Financial flows	M	New York
5	ICT_5_Telecommunications	Service provider	M	Spain
6	ICT_6_Technology	Service provider	M	Ireland
7	ICT_7_Logistics	Software architecture	F	United Kingdom
8	ICT_8_Manufacturing	Industrial IoT	M	Italy
9	AC_1_Social science	Innovation	F	United Kingdom
10	AC_2_Social science	Economics	M	Australia
11	AC_3_Social science	Information flows	F	United Kingdom
12	AC_4_Engineering	Network technologies	M	Spain
13	AC_5_Engineering	Network security	M	Belgium
14	AC_6_ Engineering	Cryptography	F	Spain
15	AC_7_ Engineering	Computer science	M	Switzerland
16	AC_8_Social science	Digital economy	F	United Kingdom
17	WO_1_Law and regulation	Policies	M	Belgium
18	WO_2_Computer-implemented invention	Technicians	M	Germany

Grounded theory assessment

While conducting the grounded theory, the analysis was passed over three steps of codes iterations. The first screening process passed from more than 600 codes to 270 codes and the second iteration reduced the number of codes to 82.

With the support of tables, data were compared to generate categories. Before doing so, we fragmented the empirical data through coding in mode to individuate abstract categories that provide a conceptual analysis of the data collected. To identify the theoretical concepts, we iteratively compared the data collected. Therefore, comparing data and codes with categories, as well as

considering the major categories as concepts, we proceeded by comparing the concepts among them to validate the results.
The third screening process supported the categories' drafting and identification of the ten main concepts.
Five categories were defined and the ten concepts were segregated into categories, namely two concepts per category.
As presented in Table 3.2, the identified categories are: (1) accounting and administration, (2) trust, (3) data platform, (4) interoperability, and (5) disintermediation.

Table 3.2. Identified categories that emerged from the analysis.

No.	Categories	Main Concepts (intermediate data)	HP	LP	Contr.
1	Accounting and administration	Government accountability, financial reporting, and tax obligation	11	6	# Federated systems obtain collusions with blockchain
		Economic aspects, negotiation procedures, and international issues	8	9	# Many regulations are needed
2	Trust	Real time information and cost reduction	7	10	# Risk of monopolization
		Safer digitalization strategies and security	7	10	# Risk of anonymous behavior
3	Data platform	Data ownership and legacy data systems	8	10	/
		Data sharing is a digital asset and represents a value exchange	10	8	/
4	Interoperability	Blockchain platforms facilitate transactions	6	11	# The blockchain potential can be achieved only with open systems
		Smart contracts and tokens facilitate the exchange of digital assets	7	10	# High costs for energy consumption
5	Disintermediation	IoT and data capture is the link between the real–virtual world and has a relation with society	6	10	# Scalability issues # More research is needed to improve technology performances
		Smart contracts are mechanisms that define the rules set	9	7	# Scale-up factor is not affordable for SMEs # More research is needed to decompose and analyze each blockchain component

Abbreviations: HP—high priority; LP—low priority; and Contr.—controversial. Controversial notions are numbered by tags (#).

a) **Explanations of categories**

In this subsection we provide explanations of the categories.

The accounting and administration (1) emerging from the imperativeness of financial aspects related to blockchain and cryptocurrencies, in which financial statements and economic instruments play relevant roles, are considered.

Trust (2) is designed from the intrinsic features of blockchain and is built in both permissioned and permissionless networks. It is originated from the implementation effects that blockchain brings in ecosystem-building and information management.

With regards to the data platform (3), this category grouped several concepts from digital assets to competitive advantages. However, the implication is to retain the blockchain data infrastructure to describe the data ownership sharing process, thereby creating value.

For interoperability (4), blockchain resources, as smart contracts and tokens, emerge as a fundamental source to link different systems and ecosystems.

Finally, disintermediation (5) is introduced as an expressive form for the IoT–blockchain combination given that the combination of these two technologies may reduce the need of intermediaries and middle-men.

b) **Insights on the assessment**

Before the category identification, in analyzing the 82 codes, the distribution linked with categories was grouped as follows: accounting and administration, 19.5% (16 codes); trust, 17.1% (14 codes); data platform, 19.5% (16 codes); interoperability, 18.3% (15 codes); and disintermediation, 25.6% (21 codes).

Additionally, in analyzing the 82 codes and maintaining the correlation between codes and experts' profiles, the pool of experts were impacted in the following manner: ICT for 53.7% (44 codes); AC for 34.1% (28 codes); and WO for 12.2% (10 codes). Therefore, considering the heterogeneity of the pool, composed by eight ICT (44.5%), eight AC (44.5%), and two WO (11%), it is evident that there is an alignment of data analyzed with the relevant variance of the codes gathered. This balance validates the results of the grounded theory analysis, highlighting a major influence of information and communication technologies professionals working in renowned companies.

Unfortunately, there is no gender parity in the pool of experts given that only five out of eighteen experts were women.

Data analysis

Following data elaboration, Table 3.2 indicates the results of the analysis, with the five identified categories and ten intermediate concepts that emerged during the assessment. For each concept, three dimensions were set: high priority (HP), low priority (LP), and controversial (CONTR). Furthermore, the experts' views were addressed in each dimension to identify dominance. In Table 3.2, the values in columns HP and LP represent the numbers of experts for each dimension who agreed with the concept. Controversial notions are numbered by tags (#) and represent the experts' opinions that strongly disagreed with blockchain development for that concept. There are few experts who disagreed with most concepts, with the exception of category number three (data platform) for which no controversial opinions emerged from interviews.

Consequently, to define the priorities among categories, we applied mixing methods for explorative research [55], [56], thus the qualitative data collected are analyzed by a simple quantitative framework to define priorities. Using the Likert scales [57] for the three dimensions (HP, LP, and CONTR), values were addressed to the results as follows: (1) HP—strongly agreed; (2) LP—moderate detection; and (3) CONTR—strongly disagreed. Thus, to define priorities, weights were assigned to each dimension: three for strongly agreed; minus one for moderate detection; and minus five for strongly disagreed.

Therefore, results of the concepts have been aggregated for each category and the final sum {score} highlights the priorities among categories: (1) accounting and administration {32}; (2) trust {12}; (3) data platform {36}; (4) interoperability {8}; and (5) disintermediation {8}.

At this stage, the five categories are combined in three main groups. Results define priorities and are ranked according to the obtained value {score} as follows: (i) data platform; (ii) accounting and administration; and (iii) trust, disintermediation, and interoperability.

In the following sections, the descriptions of the emerged results from the interviews are presented in the order of priority.

3.2.4. Findings

In this section, the main results of the analysis are presented in a descriptive manner. Each paragraph clearly focuses on empirical findings, retaining the explorative character of the research work; all outcomes are provided following a neutral and impartial approach.

Data platform

Data is a crucial asset for digitalization. From the interviews, it becomes apparent that current applications of blockchain are as data platforms. These platforms support data management for shared and updated ledgers in real-time, which will be an effective key-asset for new business developments.

Interviewees explained how blockchain data-platforms have been well explored for finance and banking sectors. The development of cryptocurrencies and crypto-exchanges indicate several working solutions for currency transactions and its traceability. These aspects assure transparency regarding where the money is being invested. In this regard, data management for accountability corresponds particularly well for blockchain and a clear example is the initial coin offering (ICO) expansion that exhibited impressive results for new business investments.

Furthermore, a blockchain-based infrastructure facilitates business intelligence for analyzing data and its organization, with a pre-set of logic for gathered data. Interviewees remarked that the real business challenge is to share data to create intelligence. With blockchain as a toolkit for data integration and record keeping, it would be affordable to deploy permissioned systems to share databases into a closed business ecosystem.

Interviewees emphasized that sharing a database for a closed business ecosystem corresponds with a digital asset. This represents a value exchange and a competitive advantage for the entire community. Therefore, it offers opportunities to real-time data platforms that can evidently increase value exchange and capture, improving performances in those processes in which the time of decision-making is relevant. Within a peer-to-peer data platform, all parties are aware of the information chain and all the key information. Interviewees relied on sharing data and how it enhances business trust between partners. Furthermore, real-time and up-to-date information are key assets for global business competitions, creating efficient data management for all stakeholders involved.

Similarly, the adoption of blockchain by the enterprise resource planning (ERP) systems is needed for future development.

As a result of data accessibility, interviewees emphasized that tracking and tracing product origins represents receiving a true value for blockchain deployment. In this context, blockchain data-platforms foster the development of value chains, in which tracking, tracing, traceability, transparency, and trust are considered fundamental priorities for deployments. Integration and interoperability are required for data as well as for platforms, otherwise it is impossible to design scalable solutions. Thus, interoperability features and data privacy must be considered during the design phase of blockchain systems, especially in designing permissionless data-platforms to prevent and mitigate the risk of privacy issues.

Additionally, interviewees highlighted the importance of maintaining the ownership of data during the process, respecting compliances and GDPR regulations, and carefully selecting the optimal structure between permissioned and permissionless systems. Therefore, it is beneficial to integrate distributed ledger technologies (DLTs) with legacy data systems, assuring that these systems can communicate with other blockchains and guarantee trustworthiness to customers.

Accounting and administration

Interviewees highlighted how both the shared ledgers' functionality and the peer-to-peer payments will boost the blockchain adoption for accounting and administration. Blockchain indicates advanced stages in payments and platforms for administrative tools, facilitating transactions in a global context. Furthermore, blockchain deployment impacts all recordkeeping processes, which also include the approaches used to initiate transactions as well as processing and authorization, including recording and reporting duties. Therefore, all these changes may impact business models and processes affecting the administrative activities, financial statements, and tax liability. Interviewees remarked that blockchain considerably fosters digitalization and a high degree of transparency for tax preparation and audits.

Therefore, in public administration, revenue and customs divisions may represent a key asset on which to deploy blockchain. In this application, companies and governments need to cooperate in designing a mutually beneficial toolkit platform for taxation monitoring and control. Governments will receive the higher benefit from a blockchain deployment. Additionally, tax collection agencies incur costs of intermediation and bureaucracy, which can be drastically reduced by blockchain by applying new digital tools and duties' automation, albeit initial investments are necessary.

Interviewees explained how a blockchain-based accounting system guarantees no-double spending, dispute resolution, immutability of records, lean management, accuracy, and a clear advantage in both international finance and trade.

The interviewees emphasized that for international trade, blockchain platforms assure innovative cost-effective methods for invoicing, accounting, purchases, and sales. These cost-effective methods will impact the financial business units of companies, changing the way of operation and communication with the systems involved, including public administration.

Finally, artificial intelligence (AI) plays an important role in bookkeeping. Blockchain and AI are cutting-edge technologies on their own, although they can become especially revolutionary if merged. Each of them may improve the capabilities of the other, increasing the potential for better oversight and accountability.

Contrary to what has been discussed so far in this section, a different point of view from interviewee ICT_4 is provided hereunder. Concerns about the nature of blockchain, in terms of openness and collaborative approaches, is in contrast with federated systems of public administration. There may be many risks and federal governments must not collude with lower powers regarding centralized artefacts. However, before designing strategies and action plans for blockchain in public administration, regulatory control is necessary, as governments are required to adhere by the welfare function.

Trust, disintermediation, and interoperability

As explained above, the five categories were divided by priority scale. The first two categories are discussed singularly above, while the other three categories grouped together and presented hereinafter.

Trust enters in the digitalization strategies and goals for business development. Interviewees emphasized that by enhancing digital trust, blockchain will be a transforming tool for many sectors. This aspect will create changes in the processes and operations of the value chains. With digital toolkits, examining, verifying, and authenticating business reports/documents with digital signatures and reporting to other parties in real-time within the network is possible.

Interviewees remarked that blockchain resolves the problem of time and real-time information with the timestamp functionality and provides assurance on the occurrence of time events. This may bring about cost reductions and benefits related to the reduction in the processing and fulfilment time of these administrative activities/tasks, thereby enhancing the performance of administrative duties.

Interviewees emphasized how blockchain enables entire ecosystems and all partners to work collectively in a reliable environment, thereby establishing mutually beneficial environments for stakeholders involved and generating distributed trust in global business ecosystems. A higher level of trust can be ensured to create fair markets and safer internet spaces, thereby improving the security and safety of data, as well as providing trustable products in the marketplace. However, security and access-controls of the blockchain design must be specified, otherwise key business information vulnerability increases. Risks might emerge in this context and business players may lose their competitive edge. Interviewees further explained that onboarding and offboarding procedures should be designed to increase trust.

Additionally, a higher level of technology trust mitigates social concerns and certain responsibility issues. Within blockchain-based trust, technology can be used to mitigate the consumption crisis for commodities, providing additional product transparency for both provenance and processes. Interviewees highlighted how a gap-of-trust appears in this context between companies that accept blockchain and those that deny it.

The interviewees stated that disintermediation is also a key discussion for future applicability. Considering blockchain is a new technology layer, it requires an intensive research effort to decompose and analyze each technology component, understanding and identifying specific links to connect other technologies, and creating value in a global perspective. Ethical considerations must be carefully considered at this stage.

Furthermore, the interviewees emphasized the intrinsic disintermediation feature of blockchain and the way this feature could generate worthy consortiums in future deployments. For instance, as blockchain is a secondary system in global markets, it equips accountability; future blockchain solutions for accountability purposes will create new needs for companies and authorities.

However, in the short-term, the focus for blockchain development will be on reducing cost, strengthening its immutable features, and strengthening its relations with society. Moreover, IoT systems play a fundamental role in future projections. IoT can open several trajectories for blockchain disintermediation in the industry, becoming the device that allows to disintermediate in businesses. In a similar manner, interviewees underlined how the IoT-data capture would be a good starting point to design new logics to organize data and this represents another real value of blockchain data-platforms, in which data are organized by default.

Thus, IoT systems are physical devices that represent a crucial connection with real-work environments and blockchain technologies, providing the link between the real and virtual world. In addition, interviewees remarked that blockchain-enabled IoT systems can foster the development of machine-to-machine payments due to smart contract functionalities.

Blockchain platforms are tailored for digital improvements to solve inefficiencies. Functionalities related with smart contracts provide automatization of administrative duties, allowing for software creativity and linking blockchain with the real world. Thus, smart contracts are identified by interviewees as powerful computer programs for administrative automation.

Alternatively, regarding interoperability, interviewees believed that it is fundamental to consider both public and private blockchains and define how these systems communicate with each other. Given that DLTs are public computers, interviewees explained that identity toolkits are a necessary step in obtaining access to networks and facilities. In future technological developments, several different blockchain platforms will coexist, implying that blockchain platforms will represent several separate products and/or services. Thus, for international interoperability, relevant standards are necessary for a broad implementation.

Interviewees further highlighted that additional research on privacy-preserving technologies and integration between different blockchains is required. The main sources of developments are in alternating consensus methods and energy performances; however, research communities must endeavor to define and understand how some problems can be solved, regarding what is '*in*' or what is '*out*' from blockchain issues.

Furthermore, interviewees remarked that there are several missing spaces in which enabled technologies can play a fundamental role in blockchain systems. For instance, both tokenization and smart contracting enable interoperability in sectors such as creative industries, logistics or automotive industry—that is, music and film, port management, or manufacturing (robotics), respectively—providing a broad range of advantages from the implementation of blockchain solutions parallel to other (existing) technologies.

Contrastingly, the controversial opinions (CONTR) emerged from the trust, disintermediation, and interoperability categories are grouped and presented hereinafter.

The concerns relating trust feature around the centralized aspects that are characterizing the blockchain development for business and institutions currently. Certain solutions provided by the interviewees explain that centralized platforms need to be managed by a central entity. Interviewee AC_8 explained that if this aspect is not mitigated, future development might be under the risk of creating a monopoly of information for specific sectors/applications. Another concern revolves around ensuring a fully transparent source of information and mitigating the risk of anonymous behavior in the network.

As far as disintermediation is concerned, a cost–benefit analysis is essential to relieve scalability issues that blockchain has exhibited in industry deployments. In this context, interviewees ICT_8 and WO_2 underlined that it would be fundamental to compare future blockchain-based solutions with existing technologies and ascertain the optimal technology '*mix*' for each specific application. Some priorities are regarding academic research efforts, as it has been discussed, as more research is needed to decompose and analyze each blockchain feature that creates the puzzle for the entire blockchain scenario. Specific insights would be set on improving the technology performances and on designing new business models.

Regarding the interoperability, there are concerns about permissioned and permissionless blockchain systems. A strong remark focused on the real technology potential. Interviewee AC_5 pointed out that blockchain was created as an open system for distributed applications and this distributed dominance cannot be achieved with permissioned or centralized systems.

3.2.5. Discussion

In this section the main considerations emerging from this study are discussed. This section provides an identification of those key fields in which blockchain platforms may benefit SCM operations and, answering the RQ, the contribution of the study attempts to bridge the gap in the existing body of knowledge.

Firstly, we recognize certain limitations of the study. In the selection process for experts, we may have overlooked several renowned experts who may have brought a valuable perspective into the analysis. In this context, the experts interviewed are from Western Europe, Australia, and the United States. We recognize that in recent years, blockchain has also shown impressive practices in Asian countries such as China, Japan, and South Korea, and this may represent a limitation of this study.

In a similar manner, as a qualitative approach, the data collection and assessment might have been influenced by our personal judgments. However, the grounded theory was applied in a meticulous manner to assure the mitigation of possible misleading outcomes, respecting defined criteria. Furthermore, in the data analysis during priorities' definition, weights were assigned to each dimension: three for strongly agreed; minus one for moderate detection; and minus five for strongly disagreed. This definition was a critical step to score priorities of the five categories and the impacts of this definition may have leveraged some research perspectives.

Additionally, as we collected a large variety of results, the presented results are not fully comprehensive but focus on answering the given RQ.

Contextualized outcomes from the experts

In this subsection, a set of seven elements are presented.

(1) Blockchain-based SC is not yet a mature technology and the return on investment (ROI) for its deployment is unclear. Thus far, this technology has been implemented and tested in several areas, although SCs appear to be one of the most prominent fields of application for blockchain. Several use cases and companies have already tested the technology in this area; however, performances are still low and there are many concerns about privacy and competitive advantages. Sharing data on a public ledger does not seem to be an appealing feature for companies and consequently they would need to design permissioned blockchain solutions to protect data and businesses.

Statement 1: *hybrid solutions are needed between permissioned and permissionless blockchains.*

(2) Blockchain has its origins in the financial sector with the Bitcoin protocol and it made several improvements regarding cryptocurrencies, payments, and new decentralized financial solutions. If we consider SC as a tiny/small financial system, it becomes clearer how the blockchain may benefit current industrial ecosystems, improving traceability and transparency for many parties involved. However, most of this technology deployment is used as a data platform rather than for its whole distributed potential.

This opens new trajectories for data and information management, as blockchain allows for pre-setting the logic on data organization and real-time information, demonstrating a performing feature about sharing data on the blockchain data-platform. These data are validated by the network's nodes and added to the chain, respecting the timestamps of when processes are run.

Statement 2: *information management is one of the drivers for blockchain in SCs.*

(3) Despite the low performances, the many barriers, risks, and security concerns related with its implementation, blockchain data sharing is a digital asset and may represent a value exchange in the stakeholders' network. Several technological gaps are wide open between research and industry, and it may be necessary to define a fair trade-off among them, with distinguishing features such as the decentralization level, scalability potential, and security clearance.

In this context, applications such as accounting, financial statements, and tax obligations are consolidated duties in business management, and they might be automatized by blockchain-based solutions. Thus, by creating links between the blockchain-based information management platforms, all bookkeeping processes can be automatized and shared in a business ecosystem, for which governments can play the crucial role of due diligence compliance assessment.

Statement 3: *blockchain-enabled autonomous audits and lean administrative procedures for financial statements.*

(4) Regarding operation management and optimization, smart contracts can be applied, designing a deterministic virtual machine. Application steps may be set by analyzing industrial operations, defining processes, identifying procedures, and assigning responsibilities about '*who does what*' in the whole SC. These aspects would lead a digital enhancement of SCM, directly addressing all the data in a one-source platform. Thus, the combination between smart contracts, IoT, and SC promise to afford a new level of corporate liability for industrial management.
In a future trajectory, IoT systems will lead the automation of physical devices with data-coordination of real-world environments, whereas smart contracts will lead the automation and accountability of virtual environments. In this context, statement four is presented.

Statement 4: *an appropriate technology mix can enable and leverage future blockchain implementations.*

(5) Blockchain technology finds its foundations in asymmetric cryptographic protocols and consensus algorithms. These foundations allow to structure a reliable and secure digital transition for SCs through which all processes could be potentially digitized. The expert interviews indicate that a development of data platforms would allow for key information sharing within a network of companies and third parties operating in the SC. However, it is relevant to define the recording of such information in the blockchain to not lose competitive advantage in the market. An implementation of blockchain on information management duties can offer administrative improvements regarding the reduction of time, quality of information exchanged, and increased security.

Consequently, blockchain can be part of the digital transition, contributing to a reliable adoption by companies; however, it will be necessary to develop an extremely precise design for the tasks blockchain would have to include [11]. Blockchain can be considered as a service for SC stakeholders, providing enhancements on existing processes [10]. However, considering the recent industrial tests are centralized, the future challenge will be to improve the decentralization degree in blockchain-based SCs. Although existing deployments are tools for ecosystem-building, they have had positive impacts on the stakeholders involved, achieving higher levels of trust in the business networks they operate in.

Statement 5: *blockchain enhances trust in (digital) ecosystem-building for SC stakeholders.*

(6) According to Cooper et al. [29], D. M. Lambert [30], and Kane [31], SCM is composed of eight macro processes: customer relationship management, supplier relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, product development and commercialization, and returns management.

Current blockchain-based solutions such as ecosystem-building and stakeholder engagement are appropriately placed in the process of supplier relationship management. The identification of criteria for segmenting suppliers is essential in this process. Assuming the validity of the main findings of Lambert and Schwieterman [58], in SCM '*it is necessary to have the capability of measuring the performance of the supplier relationship management in terms of their impact on incremental revenues, costs and investment*'. Understanding suppliers' capabilities permits, then, to develop detailed programs aimed at improving SC performance. Additionally, this knowledge allows to negotiate the sharing of benefits and costs such that all the involved players have the incentive to participate [58].

Statement 6: *blockchain fits in the supplier relationship management process.*

(7) Although a process has been identified for blockchain pertinence, other areas of development may be described, for

instance, the finance business units. As shown by the grounded theory analysis (Figure 3.1), accounting and administration is one of the most relevant categories discussed, which becomes especially revolutionary when complemented with Industrial IoT and automation.
In this instance, as an additional outcome of the grounded theory assessment, we identified a further distinction among functional factors, which characterizes categories. What emerged refers to a higher degree of automation for financial duties (i.e., machine-to-machine autonomous payments).
Figure 3.1 presents a conceptual map of the five categories, which are assigned in three sections as functional factors: (i) implementation, (ii) enabler, and (iii) impacts. The former is composed of the accounting and administration category, considered as a vertical implementation for SCM that could be related to almost all the eight processes of SCM mentioned above. The enabler is identified as the new data platform blockchain frames, given that it allows for new improvements for data and information management. This aspect may also be related to the automation and Industrial IoT for future innovative applications. Consequently, trust, disintermediation, and interoperability are the resulting impacts for business ecosystems in which this architecture links all the systems and stakeholders involved into one source of liability.

Statement 7: *blockchain-based SC data-platforms are lean data-driven solutions and become even more revolutionary for future Industrial IoT systems.*

Table 3.3 summarizes the seven statements presented in this section.

Drive the blockchain adoption in SCM

This section is aimed to respond to the presented RQ: how can the information flow structure affect and pilot a suitable blockchain adoption in SCM?
As shown in Figure 3.2, the connection between two major processes identified highlights a segment in which blockchain may fit into SCM. This segment may help to reduce complexities and drive blockchain adoption in future technologies’ deployments.

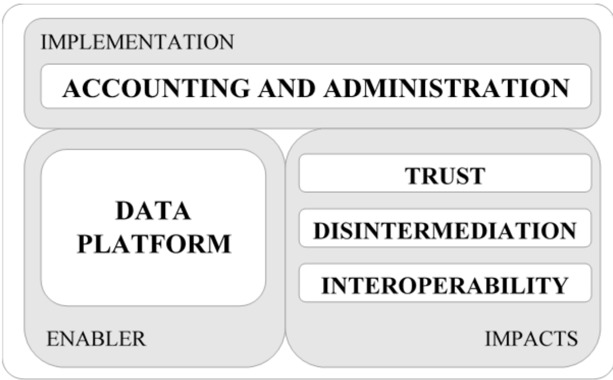

Figure 3.1. Major categories emerged and functional factors.

This macro representation may support the analysis of the internal resources, links, and stakeholders involved that compose the business ecosystem. By downscaling the segment, the appropriate level of details may be found for those digital implementations in which blockchain may mitigate SC risks and enhance the added value in operations.

As an example, following the literature reviewed, for the SC micro risk factors identified by Ho et al. [36], 15 out of 110 risk factors can be mitigated by a blockchain solution (13% circa) in which information management, smart contracts, dispute resolutions, and real-time data-sharing would play a relevant role. Additionally, in detailing the enhancements of SCM in the segment, it would be relevant to assess partners' cooperation, competitive advantages, SC information flow, and partnership governance [38].

At this stage, it is essential to keep focus of the two major processes identified. In fact, those processes are purposed with managing the information flow for supplier relationship management and the financial aspects related to it.

Table 3.3. Precautions for applying blockchain to SCM.

#	Statements
1	Hybrid solutions are needed between permissioned and permissionless blockchains.
2	Information management is one of the drivers for blockchain in SCs.
3	Blockchain-enabled autonomous audits and lean administrative procedures for financial statements.
4	An appropriate technology mix can enable and leverage future blockchain implementations.
5	Blockchain enhances trust in (digital) ecosystem-building for SC stakeholders.
6	Blockchain fits in the supplier relationship management process.
7	Blockchain-based SC data-platforms are lean data-driven solutions and become even more revolutionary for future Industrial IoT systems.

Moreover, considering further digital deployments and industrial improvements that may bring added values in operations, distributed data-platforms will perform innovative roles in SCM. Therefore, data are replicated as many times as the nodes of the network warrant. Thus, it is fundamental to identify those key-data to be shared in the distributed ledger and provide an infrastructure capable of obtaining the best value from a consensus protocol deployment. Once the ecosystem identifies the data to be shared, a blockchain platform can make it available for each stakeholder involved, improving security and reducing time for the information management process. At this layer, the information flow can be set internally to reduce complexities and delays, aligning it to internal software that organizations use to manage day-to-day business activities (ERP, for instance) [15].
To the best of our knowledge and after the presented study, we believe that these results may guide practitioners in identifying an effective information flow structure to deploy blockchain in SCM. However, we recognized some limitations of this research study and further direction is needed to consolidate these results for a broader adoption.

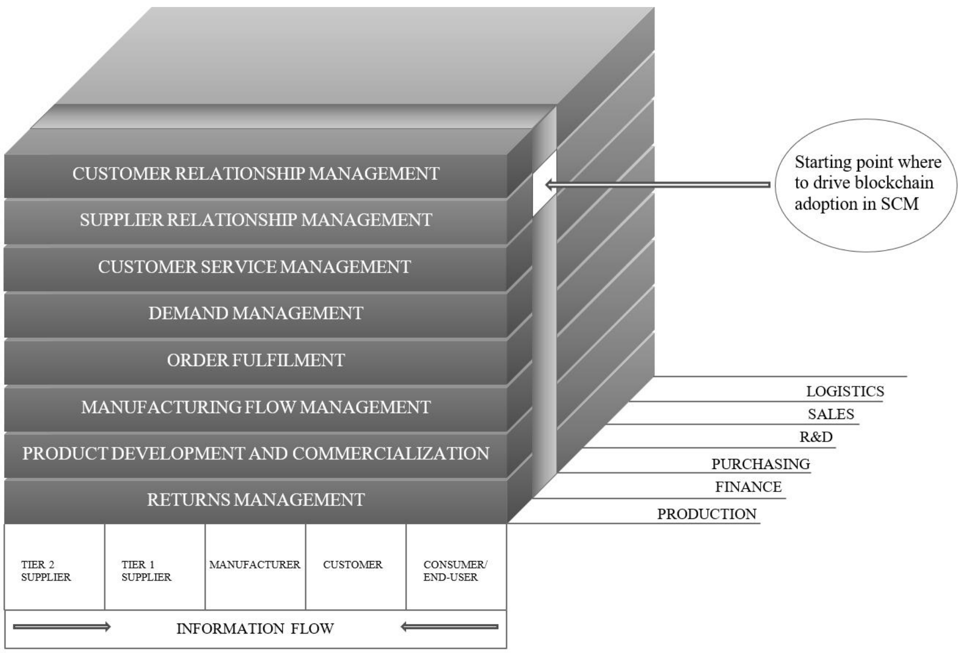

Figure 3.2. The eight macro business processes: integrating and managing business processes across the SC (adapted from [58]).

3.2.6. Conclusions

In this study, experts' opinions on blockchain-based SC are explored. Using an explorative research approach, 18 interviews were conducted with international experts from different countries.

Applying the grounded theory methodology, the data collected were analyzed and five categories were identified. These categories were grouped into three main clusters to present the findings: (i) data platform; (ii) accounting and administration; and (iii) trust, disintermediation, and interoperability.

Each cluster presents the main findings in detailed descriptions and each is a valuable input for research contributions and final statements. As one of the main results, seven statements are provided and explained in the earlier section.

This study lays the foundation for the identification and assessment of blockchain developments for SCM processes. In bridging this gap, the proposed research has an original character and contributes to the body of knowledge, addressing future research needs to the best of our knowledge.

Two major processes are identified for blockchain applications. One focuses on the supplier relationship management process, enhancing performances in terms of their impact on revenues, costs, and investments in complex SCs, suggesting a second process which is more suitable for a lean SCM. Using a data-driven approach, this can lead to leaner financial procedures, the deployment of higher levels of automation and Industrial IoT that are capable of providing a single liability source, and additional feature-related advantages.

However, blockchain for SC is still an emerging technology necessitating further research. It will be prudent to further explore how blockchain-based platforms may transform risk management and corporate liability in future deployments.

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Chapter 4

ADDED-VALUE OF BLOCKCHAIN-BASED SUPPLY CHAIN

4.1 Contextualization of the study

As a final stage of this research activity, this chapter presents the result of a digital transition analysis and its impacts for future deployments.

Considering the achieved outcomes in previous chapters 2 and 3, an additional literature review and taxonomy was developed to highlight the potential assets related to blockchain, digital dimensions and risk mitigation in supply chains.

Thus, after the acquired understanding about the type of innovation that brings performance improvements, and after identifying the potential processes where to design these improvements, this final analysis provides elements to support a suitable adoption of blockchain in supply chain operations. These elements facilitate risk mitigation and guide practitioners and innovators to design added-value solutions for a sustainable development of this emerging technology.

4.2 A Guidance for Blockchain-Based Digital Transition in Supply Chains

Results of this study may support the design phases of digital transition in blockchain-based supply chains.

Abstract:

Blockchains play a crucial role in the digitalization of future supply chains (SCs). In this study, we analyzed the major influences that blockchain-based digital business strategies may play in SC operations. We conducted 18 interviews with international experts from different sectors and analyzed the collected data using the grounded theory approach, identifying four major categories. A set of three matrices is presented to address those elements that may support digital transition procedures in SCs: (1) value of trust and automation, (2) transformative role for operations, and (3) digital business strategy identification. As an additional result, a reference framework was identified for the evaluation and detection of those aspects to be taken into consideration during blockchain adoption in SCs. For use as a guide, this result comprises 22 recommendations and was framed in four progressive steps as follows: (1) identify, (2) assess, (3) design, and (4) assure.

Keywords:

blockchain; decentralized applications; digitalization; strategy; supply chain.

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4.2.1. Introduction

As an emerging technology, blockchain is still in its infancy in business applications [1]–[3]. However, in the last few years, the supply chain (SC) has been considered one of the fields where blockchain technologies have been implemented with higher impact [4], [5]. According to Saberi et al. [6], blockchain is a driver for digitalization in the SC, but the resulting improvements in performance are difficult to predict [7]. The implementation of blockchain-based SCs has been largely explored for the traceability and transparency of products. Traceability and transparency, along with the development of an advanced level of trust, were identified as the main drivers for blockchain adoption [6]–[9].

Nevertheless, there is a lack of experience, knowledge, and understanding regarding blockchain [6]. Moreover, according to Courcelas et al. [10], there is a lack of education programs focusing on blockchain and related skills. Thus, more education and research are needed in this area for a better understanding of the impact of this technology and its acquisition procedures. Additionally, as a software-based technology, blockchain should be addressed in digitalization strategies and goals [11], but thus far, its impacts and digital transitions are unclear [12]. However, information management and trust were identified as factors for the implementation of blockchain-based SCs [13]. Nonetheless, further research is necessary to explore how SC operations may be impacted with sufficient benefits, the reward maximized, and a higher level of efficiency and effectiveness assured [7], [14]. For this purpose, digitalization and digital transition may play an essential role [5], [15]. Thus, this research aims to fill these research gaps, provide an insight into the body of knowledge in this area, and explore which elements might play a relevant role for the identification of those digital strategies that may assure operational efficiency and effectiveness in the SC sector.

Therefore, this study answers the following research question (RQ): Which are the elements for designing blockchain-based digital strategies that might foster a reliable re-engineering in SC operations?

Following an analysis of 18 interviews with international experts, and by applying the grounded theory methodology, we were able to analyze the data obtained to address the above-mentioned RQ and contribute to the body of knowledge in this research area.

As main contributions, this explorative research provides the following outcomes: (I) a summary of key findings of previous research and a taxonomy of existing work; (II) a presentation of findings emerged from the experts interviewed, divided into four major categories; and (III) a set of elements and recommendations presented as matrices and tables for a suitable adoption in SC applications.
The uniqueness of this explorative research is that it merges a qualitative approach based on interviewing experts with an exhaustive and solid literature review to create a scientific contribution that aims to answer the research question. As an interdisciplinary work, it follows previous research in the blockchain field [3], [5], [6], [11], [13], [15].
The remainder of this chapter is structured as follows: Section 2 presents a literature review of the most relevant research works for the study and a taxonomy, Section 3 details the grounded theory methodology and analysis of the collected data, Section 4 elaborates on the findings of the analysis, Section 5 offers a discussion and the research contributions, and Section 6 presents the conclusions.

4.2.2. Literature review and taxonomy

This section reviews the most relevant previous works on blockchain-based SCs and digitalization. Thus, this work is based on a solid literature review that creates the needed state of the art to design this explorative research centered on expert interviews. A taxonomy is presented at the end of this section.

Literature review

In accordance with B. Kitchenham [16], we identified and designed a process for conducting the literature review in three main phases: (I) planning the review, (II) conducting the review, and (III) reporting the review. Moreover, a research question and a procedure were defined for the study. Conducting the review, the databases/platforms used for the exploration were the following: *Scopus*, *Google Scholar*, *IEEE Xplore*, and *Taylor and Francis Online*. During the online search, several key works were applied in those platforms. The review conducted was mainly aimed to explore blockchain-based supply chains and their correlation with

digitalization. Thus, some examples of the keyworks and acronyms that have been used for the exploration are related with blockchain (BT), systematic literature review (SLR), digital and digitization, SC and supply chain management (SCM), and other words connected with the study. Therefore, mixing these words, we collected several research works from the databases used.
At this stage, selecting a timeframe from 2019 to 2021 and applying the first screening by abstracts, we selected the papers for the next stage. Consequently, the literature analysis of these selected research works was performed, and the main findings were collected as memos and notes. Hence, keeping in mind the aims of the study and the research question, we extracted relevant data and presented them in a concise form. Additionally, all bibliographies of these selected papers were analyzed, and a second iteration of literature review performed. This supported the identification of relevant previous works from a wider timeframe and consolidated the body of knowledge for these research lines.
Therefore, Table 4.1 summarizes findings of the most relevant previous studies linked to this explorative research. Findings in Table 4.1 were used to enrich expert interviews' outcomes in an attempt to bridge the gap in the existing body of knowledge and provide a final comprehensive contribution (see Section 5).

Table 4.1. Literature review.

Articles	Focus	Key Findings
Chang et al. [1]	Benefits of blockchain-based supply chain (SC)	(1) streamline and harmonize information and process flow across supply chain networks; (2) improve data quality; (3) support the timely analysis of supply chain risks; (4) develop efficient business processes between governments and global supply chain stakeholders
Saberi et al. [3] and Kouhizadeh et al. [17]	Motivators and barriers for blockchain-based SC	(i) motivators: (1) pressures; (2) drivers (ii) barriers: (1) organizational barriers; (2) supply chain-related barriers; (3) technological barriers; (4) external barriers
Kayikci et al. [4]	Interaction effects of blockchain to strengthen relationships	At a micro level (people, process, technology, and performance), blockchain technology will ensure: (1) non-manipulation of data, (2) transparency, (3) security, and (4) collaboration among the stakeholders
Fosso Wamba et al. [5]	Blockchain diffusion stages	(1) intention, (2) adoption, and (3) routinization
Bai et al. [7]	SC transparency types	(i) range of transparency; (ii) product transparency; (iii) participant transparency
Hastig et al. [8]	Critical success factors for	(1) companies' capabilities; (2) collaboration; (3) technology readiness; (4) supply chain practices; (5)

	blockchain-based SC	leadership; (6) governance of the traceability efforts
Kittipanya-Ngam et al. [9]	Dimensions to underpin the SC digitalization	(1) efficiency, (2) transparency and traceability, (3) environmental and social impacts, (4) legal liability, and (5) e-market/supply accessibility
Seyedghorban et al. [12]	Five paths for digitalization in SC	(1) data science-enabled SC management, (2) SC agility, (3) humanizing manufacturing through digital manufacturing strategy, (4) omni-channel, and (5) resource-based view and beyond
Cole et al. [18]	Characteristics of blockchain-based SC	(1) distributed and synchronized across networks; (2) use of smart contracts; (3) based on peer-to-peer networks; (4) immutability of data
Babich et al. [19]	Strengths and weaknesses of blockchain-based operations	(i) strengths: (1) visibility; (2) aggregation; (3) validation; (4) automation; (5) resiliency (ii) weaknesses: (1) lack of privacy; (2) lack of standardization; (3) garbage in, garbage out; (4) black box effect; (5) inefficiency
Ho et al. [20]	SC risks	(1) macro risk; (2) demand risk; (3) manufacturing risk; (4) supply risk; (5) infrastructural risk
Büyüközkan et al. [21]	SC components for digitalization	(i) digitalization: (1) strategy; (2) organization and culture; (3) operations; (4) products and services; (5) digital customer experience (ii) technology implementation: (6) project management; (7) human and technology relationship; (8) formation of technology infrastructure; (9) technology enablers (iii) supply chain management: (10) integration; (11) automation; (12) reconfiguration; (13) analytics; (14) process
Birkel et al. [22]	Risks for IoT in SC	(i) environmental risk: (1) economic; (2) social; (3) technological; (4) political (ii) network-related risk: (5) relational aspects; (6) identification of trust (iii) organizational risks: (7) internal aspects; (8) high implementation barriers
Bharadwaj et al. [23]	Digital business strategy	Themes (*4S Model*) of digital business strategy: (1) scope (effectiveness), (2) scale (profitability), (3) speed (time), and (4) sources of business value creation and capture (robustness)
Brown et al. [24]	Digital transformation	Theory (*4E Model*) of digitalization: (1) expectations (people, communities, and clients), (2) execution (organization and delivery), (3) ecosystem (platforms and interfaces), and (4) enablers (infrastructure and technology)
Nandi et al. [25]	Capabilities and performances of supply chain (SC)	(i) SC capabilities: (1) information sharing, (2) coordination, (3) integration, (4) collaboration (ii) SC performances: (1) quality, (2) process improvement, (3) flexibility, (4) cost reduction, (5) process time reduction
WEF [26]	Blockchain key issues	(1) blockchain policy, regulation, and law; (2) tokenization and digital assets; (3) blockchain security and interoperability; (4) smart contracts and automation; (5) blockchain and digital identity; (6) decentralized governance and new models; (7) blockchain and leveraging data

Fosso Wamba et al. [27]	Benefits of blockchain in business	(1) operational; (2) managerial; (3) strategic; (4) infrastructure
Wang et al. [28]	Design phases for blockchain-based SC	(1) definition of the best entry point; (2) identification of areas where blockchain adds value to all stakeholders; (3) determination of a minimal number of actors and core members; (4) network orchestration and co-creation; (5) on-chain and off-chain governance; (6) protection of sensitive data; (7) careful consideration for sharing on-chain data; (8) establishment of legal and regulatory documentation

Accordingly, in the next part of this section, the literature review used analyses the several works related to blockchain, SC, and the integration thereof. The selected literature for blockchain-based SCs review is the following [1]–[11], [13]–[15], [17]–[19], [25]–[32]. The SC management were also researched in different scenarios where digitalization and digital business strategies were considered as crucial factors. Thus, the selected literature for digital strategies and SC digitalization is the following [12], [20]–[24], [33]–[37].

a) **Blockchain-based SC**

Although the blockchain technology has its origins in the finance sector [29], it has found a proper space for application in the SC. Blockchain is in its infancy [18]; however, blockchain is described as a ‘*trust machine*’, leading to a data-driven economy [30]. As a distributed database, the blockchain functions may level the value chain [31].

According to Koh et al. [29], more research is needed in multimodal transport and logistics environments. In these sectors, blockchain may be a tool for enhancing the system efficiency [32] and is defined as a driver for digitalization in the SC [3].

The implementation of blockchain in operations and SC management (SCM) [18] is related to the fields of information and automation [19]. Assuming that blockchain is a tool for information management [2], it mitigates the information asymmetry; reduces the bullwhip effect; supports a lean, agile, and total-quality management and just-in-time principles; and collaborates to enhance the internal and external SCM [19], [29].

The challenge for future developments is blockchain interoperability [1]. Thus, for blockchain development, organizations should address it within the existing problems they have in their business [33]. However, a blockchain-based approach is cost-intensive in terms of storage and computational requirements, and as computational costs have become a significant burden [34], new developments in alternative consensus protocols are required.

According to Ho et al. [20], SC risk (SCR) is defined as ‘the likelihood and impact of unexpected macro- and/or micro-level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategic level failures or irregularities’. Ho et al. [20] designed a framework to define risks and easily identify whether they are internal or external risks (demand, manufacturing, supply), macro or micro risks (degree of impacts), or risks related to different types of flow (information, transportation, financial).

According to Büyüközkan et al. [21], the digital SC (DSC) is defined as ‘an intelligent best-fit technological system that is based on the capability of massive data disposal and excellent cooperation and communication for digital hardware, software, and networks to support and synchronize interaction between organizations by making services more valuable, accessible, and affordable with consistent, agile, and effective outcomes’. Consequently, the features of a fully deployed DSC are speed, flexibility, global connectivity, real-time inventory, intelligence, transparency, scalability, innovation, proactivity, and eco-friendliness [21].

In this instance, the decision support methods in SCM domains are required to be proactive and reactive simultaneously [35]. This can be achieved with robustness reserves (proactive: risk mitigation inventory, capacity flexibility, backup facilities and channels) and the speed and scale of recovery actions (reactive: parametric recovery, process recovery, and structural recovery).

Ben-Daya et al. [36] explored the role of the internet of things (IoT) and its impact on SCM processes and applications. The IoT for SCM is still in its early stage of development; in contrast, the IoT for logistics and manufacturing is more advanced [36]. The IoT in blockchain-based solutions validates the identities of individuals and assets. Thus, blockchain can be used in an SC to know who is performing what actions, and these features facilitate a valid and effective measurement of outcomes and performance of key SCM processes [14].

According to Kshetri [37], this combination offers an enhancement of security, given that if the blockchain updates of one IoT device are breached, the system rejects it, and if the network size increases exponentially, a blockchain structure is likely to provide a more secure approach. Here, there are missing spaces for business models beyond traceability-centric values and for the quantification of benefits from IoT in SCM [22].

b) **Digitalization**

In the last few years, the blockchain technology has been considered one of the technologies that can change the way many industrial sectors and processes operate [11]. Furthermore, the new business model paradigms for blockchain may shift the society toward a digital future [29].

According to Bharadwaj et al. [23], digital transformation is defined as a digital business strategy (DBS), which is '*a fusion between IT strategy and business strategy that creates a fundamental driver of business value creation and capture*'. Moreover, Bharadwaj et al. [23] provided the '*4S Model*', which captures the key attributes of the DBS. This four-theme model can support the development of specific intermediate metrics and criteria for tracking and assessing the digital transformation.

Burkhart et al. [38] explored the relationship between the business model concept and other concepts in the management literature, including business process models and strategies. Business models are the '*what*' the firm does to create and capture value, whereas business process models focus on the '*how*', or rather the day-by-day operationalization and realization of the business model. According to Burkhart et al. [38], the distinctiveness of business models and strategies is less clear, but they remain distinct. According to Osterwalder et al. [39], the distinctiveness of the business model is that it provides the '*missing link*' between strategy and tactics. One of the conclusions they draw is that the business model and strategy concepts are related but distinct. Moreover, the business model must be highly focused on the interactions across organizational boundaries, and the notion of value is central to its conceptualization. In terms of value capture, the business model is more concerned with the appropriation mechanisms, whereas in the strategy the attention is directed toward threats to returns posed by current and potential entrants. Additionally, according to Osterwalder et al. [39], there is a strong relationship between the business models and the IT instructors applied by the stakeholders of a network.

For a better understanding of the digital transformation, Brown et al. [24] synthesized a framework—the '*4E Model*'—that can be used for an understanding of the maturity and transformational activities inside companies and governments. This model can also support the development of specific intermediate metrics and criteria for tracking and assessing digital transformation. Therefore, these four layers have different approaches and insights that can support the identification of operational clusters to address digital transformation concerns. In this instance, cultural, capability, and leadership improvements must be addressed.

The 4E Model theory is a simple four-layer structure divided into (I) expectations–including people, communities, and clients; (II) execution—for organization and delivery; (III) ecosystem—containing data, capabilities, and interfaces; and (IV) enablers—involving infrastructures and technology.

The first layer of the 4E Model, the expectation, sets the focus on the end customers and into the requirements needed to satisfy needs and acquire feedback. The second layer (execution) considers the impact of digital transformation on behavioral aspects, organizational structures, and decision-making approaches. Brown et al. [24] highlights that a simple implementation of digital technologies over traditional legacy processes and IT practices will not work. Timing is an important factor for this layer. The third layer (ecosystem) puts the focus on the technology components and business rules, whereas the fourth layer (enablers) is oriented to a classification and assessment of those features that may support the digital transformation.

Taxonomies of existing work

Conducting this literature review, we identified relevant previous studies and methods. These outcomes support this research, providing valuable approaches for identifying those assets for digitalization, and conveying them toward the identification of those elements to design blockchain-based strategies. Thus, recognizing the elements of IT strategies and business strategies, we can see the impact on how the operational clusters are managed during the digital transition.

Therefore, in this paragraph, a taxonomy is presented as the outcome of the literature review performed. Table 4.2 shows a classification in four groups of application. However, we recognize the literature review may have some limitations and that we may have not identified all the most relevant research or studies that were published in renowned journals. However, the literature review methodology was performed in a rigorous manner to assure a high level of research findings, and it may represent non-exhaustive research.

Table 4.2. Taxonomy.

References	Class	Description
[1], [4], [18], [19], [25], [27]	Features	This cluster collect the benefits, characteristics, and aspects about the implementation of blockchain in supply chains
[5], [7], [12], [28]	Phases	Several issues and recommendations are grouped in this class to foster the digital transition in SC, with and without blockchain
[9], [21], [23], [24], [26]	Digital dimensions	Digital transformations models and SC components are gathered in this class
[3], [8], [17], [20], [22]	Risks management	SC risks, barriers, and mitigation aspects are collected

4.2.3. Methodology

In this section, the research methodology is presented. As an explorative study, qualitative methods as expert interviews were applied. With a specific focus on ethnographic and grounded theory approaches, the selected literature is the following [40]–[48].

Design of the study

According to Saberi et al. [3], the grounded theory approach can be used to expand the features of blockchain and its practical implementation. Therefore, following Corbin and Strauss [40], a dynamic approach was designed for this qualitative research. This dynamic approach enables evolution in design as the study progresses [41]. As a form of qualitative research, the grounded theory is used to construct a theory grounded in data [40], [42]–[46]. By identifying general concepts, the development of theoretical explanations offers new insights into the studied phenomena.

This study maintains an investigatory character and lays the foundation for this research area. In accordance with Bogner et al.

[47] and Bolger et al. [48], we established flexible guidelines to run this ethnographic research and identified experts with a high degree of interpretive faculty and extensive knowledge in their respective fields.

Experts description

The pool of experts (Table 4.3) is composed of academics (AC), information and communication technology professionals working in renowned companies (ICT), and institutional representatives (WO). The international experts are from EU and non-EU countries and possess a proven knowledge of blockchain. In this instance, experts have different backgrounds in academia, private companies, and institutions. They were studying and/or working in blockchain technology from 2014, on average.

Table 4.3. Pool of experts interviewed.

#	Respondent Provenance (Anonymized)	Sector of Interest	Gender	Location
1	ICT_1_Logistics	Handling	M	Belgium
2	ICT_2_Consulting	Business models	M	New York
3	ICT_3_Consulting	Business services	M	Spain
4	ICT_4_Consulting	Financial flows	M	New York
5	ICT_5_Telecommunications	Service provider	M	Spain
6	ICT_6_Technology	Service provider	M	Ireland
7	ICT_7_Logistics	Software architecture	F	United Kingdom
8	ICT_8_Manufacturing	Industrial IoT	M	Italy
9	AC_1_Social science	Innovation	F	United Kingdom
10	AC_2_Social science	Economics	M	Australia
11	AC_3_Social science	Information flows	F	United Kingdom
12	AC_4_Engineering	Network technologies	M	Spain
13	AC_5_Engineering	Network security	M	Belgium
14	AC_6_ Engineering	Cryptography	F	Spain
15	AC_7_ Engineering	Computer science	M	Switzerland
16	AC_8_Social science	Digital economy	F	United Kingdom
17	WO_1_Law and regulation	Policies	M	Belgium
18	WO_2_Computer-implemented invention	Technicians	M	Germany

To select these experts, we conducted networking actions and an exploration about the level of activities performed in the last 5 years, in terms of blockchain, supply chain, digital applications, Industry 4.0, and the interests in managing emerging technologies. Thus, we selected over 20 experts to be contacted. Experts were contacted by structured emails, following a formal format of presentations, connections with their activities, and why we considered their involvement suitable for the study.

Only eight interviews were conducted in person, while the other 10 were conducted virtually using video-conference software. Additionally, classified on the basis of gender, 72% of the interviewees were male experts, and the remaining 28% were female (5 out of 18). We tried to assure an equal value in this aspect, but the results were not as good as we hoped.

The balance of their backgrounds varied and were correlated with supply chains and logistics. As presented in Table 4.3, sectors of interest and expertise were from handling to Industry 4.0, from business services to software architecture, from network security to information flow, as well as financial flows, innovation, and digital economy. All these sectors of interest were relevant for this study, and interviews were conducted by keeping the focus on blockchain-based supply chains and their direct impact with supply chain operations.

Data collected

Data were collected through memos and notes. The interviews were recorded with prior authorization, and the data collected followed a screening process to develop a narrowed analysis for the study. Although the 18 interviews allowed us to collect a large amount of data, other sources of knowledge were considered in this study.

Grounded theory assessment

As an explorative research, we recognize the potential limitations of this study. First, the interviewees' selection process may have overlooked several renowned experts who may have brought additional perspectives in the analysis. Likewise, as a qualitative approach, the data collection and assessment might have been influenced by our personal judgments. However, the grounded theory was applied in a meticulous manner to assure the mitigation of possible misleading outcomes with respect to defined criteria. By conducting the expert interviews, we collected a large variety of results, and the presented results were not fully comprehensive but focused on answering the given RQ.

On the basis of a rigorous application of the grounded theory methodology, we identified the main concepts and categories that emerged from the analysis. While conducting the grounded theory, the analysis was passed over three steps of code iterations, reducing the complexity from 600 to 200 codes, and reducing it further to 50 codes in the second iteration. In the third phase, four categories were identified and analyzed. These four categories are presented in the next section.

4.2.4. Findings

In this section, the main results of the analysis are presented in a descriptive manner. Each subsection clearly focuses on empirical findings, retaining the explorative character of the research work; all outcomes are provided following a neutral and impartial approach. Experts' views have been collected, analyzed, and summarized in four major categories: (i) benefits, (ii) concerns, (iii) digital transition, and (iv) digital business models.

Benefits

Interviewees have a common vision of the main blockchain benefits for SC applications. Transparency, verifiable processes, immutability, traceability, and paperless procedures are major benefits. By merging these benefits together, we would find an impact on the platforms for providing event automation and combining the distribution processes within the product lifecycle. Interviewees showed consensus about the crucial effect of these benefits for food SC operations, their optimization, and trust. Furthermore, a blockchain system is suitable for ecosystem building in food SCs, and it can enable autonomous generation of business ecosystems.

Another common vision of interviewees is the impact of blockchain on business procedures. In this instance, blockchain may change many ways to run operations, support digitalization strategies, play a fundamental role in digital assets, and also design some changes in the traditional methods that people and governments are using to perform.

For accounting and public administration, a blockchain system can impact the IT units with deep restructuring, reduction of intermediaries, and paperless operation. It may be an adaptive change; in fact, interviewees emphasized that blockchain would have the power to change behaviors for administrative tasks. With a sharp focus on purchases and sales business units, digitalization is encouraging a cultural change for SC micro-companies. For instance, considering smart-bids, new paradigms and methods are emerging alongside the development of smart contracts for procurements. Interviewees remarked that this implementation can bring to the market a new concept for business trust maintenance and industrial trust, promoting behavioral and managerial changes in the future industry. Accordingly, administrative tasks become lean and transparent for both companies and governments. New ethical standards may emerge in the community as a result of new negotiation procedures and higher levels of trust, and there will be a cultural change in tax obligations and their related economic aspects. In this field of application, blockchain can mitigate a range of problems related to money laundering, tax transparency, illegal labor, black markets, and illegal international trade. In contrast, interviewees noted how ledger (digital) identity is a beneficial technology feature for addressing administrative needs and mitigating the previously cited problems.

Regarding education, interviewees also explained how blockchain can have a positive impact in this sector. Supporting proof of qualifications, proof of training, and degrees at an international level, new applications in the educational sector may play an important role in the future, improving performance in several infrastructures. In this instance, the European blockchain services infrastructure (EBSI) is developing good pilot applications.

In addition, interviewees also pointed out the financial and banking industry. Financial services may lead to a structural chance in traditional operations, enhancing the performance in both digital and security services. For harmonizing other technologies with blockchain, interviewees explained that blockchain, as a secondary system, must be integrated with running systems to exploit the entire efficiency potential, both regarding performance and energy consumption. This may boost blockchain adoption, support new digitalization strategies for business processes, and exchange value between international financial services. However, interviewees remarked how blockchain adoption takes time, and many regulations are still missing.

Concerns

Interviewees also underscored several risks related to blockchain implementation in SCs. The main concern in SC operations is about the current designed systems; in fact, a blockchain-based system in the SC is a centralized system, which reduces the decentralization capacity.

Furthermore, interviewees have a clear consensus on energy issues for the implementation of these emerging systems. In this instance, blockchain technology might powerfully impact industry applications, but it is not a green technology, and environmental issues need to be considered in advance. Accordingly, innovation and research in this field may help reduce energy consumption and increase performance. However, this would be a responsibility issue for the whole research community that is working on energy-intensive technologies such as blockchain.

Furthermore, common concerns highlighted by interviewees are related to the government, consortiums, share costs, legal implications, new technology lawyers, lack of efficiency, expensive resources, and cost of computational power. In addition to these issues, interviewees mentioned the barriers regarding energy questions around the world, the negative impacts of the technology on global warming, the high expectations from potential implementation in the industry, and the concern about possible exit strategies from blockchain data platforms. Other criticisms are more oriented to technical issues and drawbacks such as energy use, low performance (slower than other platforms/systems in use), migration paths, scale-up capability, and other core technology issues.

Interviewees pointed out that, at this stage, blockchain products are data platforms centralized by one or more big companies. This design does not simplify the creation of any value in a chain. Interviewees remarked that blockchain solves only the consortia building process for value chains. In this instance, companies play in a centralized way, deploying platforms as a tool to manage the complexity of stakeholders for international SCs.

Moreover, the common awareness among interviewees is about the infancy and complexity of blockchain. Whereas blockchain does not represent an integrated solution thus far, practitioners are struggling to determine how complex and how big the future blockchain market will be. Even though start-ups would play a fundamental role in blockchain development and innovation, interviewees are skeptical about blockchain applications for small- and medium-sized enterprises (SMEs). This skepticism is related to the adoption of international SCs for multinational companies, where the involved stakeholders would implement the technology to increase a specific operational performance in a wide and complex ecosystem. Thus, in this instance, start-ups would have difficulties finding the right business space. However, interviewees remarked that highly relevant SMEs play in this emerging market. SMEs have agility, dynamism, and openness to boost innovation at a further stage, pushing faster digital transformations and new skills.

Digital transition

After collecting the statements provided by interviewees, a possible framework of analysis for blockchain digital transition—as an emerging technology—may be designed to compare the capacity to transform a single operation with the number of systems involved in that specific procedure. Additionally, to understand future technology/business directions, it is essential to discover the critical performances that can be exploited with a broader blockchain deployment.

Interviewees agreed that blockchain may support digital transition for SCs and that it creates incremental changes and innovations to existing systems. The digitalization and harmonization within other technologies may generate improvements, sustainability, and effective growth for new practices in SCs. Interviewees remarked that blockchain may represent a driver of digital transformation in businesses. In this instance, the growth rate might be explained as a technology-push but shaped by the market. Conversely, regarding marketing strategies, interviewees pointed out that there are also several market-driven approaches for asset digitalization. Thus, blockchain may become a digital strategy in which new business models will emerge to compete in digital spaces. This may represent a value exchange in virtual environments, where exchanging value in a trustable way is a key feature.

In SCs, stakeholders must communicate and share information in real time in an efficient and effective manner. Interviewees highlighted that blockchain systems may enhance communication and information management in SCs; however, other software technologies must be used or connected to it.

Interviewees underscored that blockchain platforms have remarkable functional approaches to frame information and data, given that blockchain allows for the organization of the logic of what data are collected in distributed databases. This enables the blockchain data platform to become an optimization tool for business operations and to support the value chain in managing data. Thus, a blockchain platform provides a new service for data optimization.

As an example, interviewees pointed out SC event management (SCEM) systems as existing solutions for data sharing in SCs. Although an SCEM system solves the same problem as a blockchain, it is quite complex and has some limitations. In contrast, blockchain adds layers to existing technologies and seems easier to deploy with higher flexibility. In this instance, the blockchain adds layers for traceability and transparency by designing incremental features upon existing systems. Therefore, the interviewees remarked that blockchain systems bring incremental changes for SC applications, which result in performance improvements.

Additionally, interviewees identified the identity issue as one of the potential digital enablers that address blockchain in SCs. Digital identity may represent a technological feature where assets, such as people, companies, public entities, machines, means of transport, and objects moving along an SC, can be linked to blockchain systems. Interviewees stated that this aspect could also solve ethical issues running inside international/illegal SCs. Digital identity may be deployed in SCs to prevent fraudulent and illegal SCs, such as those related to trading of wood from illicit deforestation, criminal and slavery mining for minerals, counterfeit food products, and several other contexts of human rights violations and environmental abuses. However, the digital issues—for these above-mentioned contexts—are related to information entry-point gateways and the way in which to set up a safer and secure way to digitalize assets that are entering the chain. In this instance, interviewees remarked that there are several barriers and risks in assuring trust for these kinds of products, and it is extremely difficult to assure product provenance and ethical management for environmental and human rights. However, looking forward to a broad blockchain deployment, some of the current problems may be solved in future/fully transparent blockchain-based SCs.

Digital business models

Interviewees highlighted the relevance of industrial smart contract applications. These industrial applications can lead to new levels of performance in operations, enabling new negotiation procedures and generating new business models. Interviewees mentioned the high impacts of some upcoming blockchain-based business models and how they may improve operational efficiency and effectiveness in future digital procedures.

In contrast, the lack of regulations around this area may hamper the smart contract mechanism to work properly, reducing its applicability to the market. However, interviewees stated how smart contracts are powerful for both SCs and manufacturing operations, but they need permissioned systems; otherwise, unexpected risks may emerge. Thus, the interviewees' consensus is that permissioned systems are more eligible for businesses.

Thus, smart contracts are identified by interviewees as powerful computer programs for administrative automation; however, they have certain limitations and need permissioned systems for implementation in business contexts. Coding smart contracts makes it possible to establish business mechanisms in computer logic and ensure a straightforward level of trust in business procedures. Therefore, distributed systems for ecosystem building employ a new degree of trust, where access control and authorization to invite new members are defined from the beginning.

Regarding the bank and financial industry, interviewees pointed out that tokens have the power to modify several operations and business processes, setting new standards for the exchange of digital assets and value. Although cryptocurrencies and initial coin offerings (ICOs) scared practitioners for their financial consequences and degree of speculation, ICOs have shown good results in the past few years. Interviewees positively evaluated these new mechanisms, and highlighted that tokens have the chance to facilitate transactions and change customers' attitudes and behaviors. Furthermore, tokens may support digital business models, opening new markets, new possibilities, new channels, and providing easier access to technological developments and market strategies.

Additionally, the ISO/TC-307 is seen by interviewees as a standard for financial transactions and human interactions. The ISO has impacts on business and society, and for this reason, interviewees remarked that ISO standards are relevant to allow the sharing of value in a standardized way. Other benefits and impacts include the mitigation of ethical issues, tax obligations, adoption by enterprise resource planning (ERP) systems in SCs, and decentralized identifiers (DIDs) in digital identity. Therefore, the interviewees pointed out that blockchain standardization might help harmonize different protocols and facilitate interoperability issues. However, for distributed technologies, future standards should be as simple as possible to generate new digital business models, produce lean and agile procedures, and push the technology on the market.

4.2.5. Discussion

This section discusses the major considerations emerging from this exploratory study. After a discussion of two main use cases emerged from interviewees, the main reflections and results of this analysis are presented, answering to the RQ in an attempt to bridge the gap in the existing body of knowledge. Therefore, collecting the outcomes of the four categories described in the previous section with the literature review performed, we present the elements for a suitable adoption in SC applications. Additionally, a list of recommendations for blockchain transition in SC operations is provided as a collective result.

Use cases from interviewees: network and ripple effect

In this section, interviewees' overviews about the differences for both network and ripple effects in blockchain developments are summarized. Considering two examples in logistics, two different cases are provided to explain two different effects (network/ripple) and its impactful processes.

The network effect for blockchain can reduce costs and increase security. As the Internet has taught us, when an increasing number of users are using a technology, the network provides a set of additional utilization benefits. Therefore, the more the users in the web, the more the generation of content, information, and power. Accordingly, in the logistics sector, digital representatives for objects—digital twins—are already deployed in certain digital ecosystems, managing events automation and a higher level of transparency for many applications. In this field, blockchain platforms redistribute and combine value in the value chain. Tokenization for objects—a blockchain-based digital representative—corresponds to the lot management concept. If a predefined number of tokens are created in line with lot production, each lot has a clear digital representative and, due to cutting-edge SC platforms, the lot can be tracked and traced during the SC distribution. Thus, if the number of tokens is equal to the number of products, the tokens will be used to combat counterfeiting of products. This application may be deployed for high-value products and assure product identity and originality. Due to the network effect, this kind of application may bring social benefits and behavioral changes correlated with a higher level of trust and higher production transparency.

Ripple effect is easier to identify at the first stage of development for blockchain business communities. When a big market player—such as IBM-Maersk's project (tradelens.com)—decides to deploy a new technology, it forces stakeholders involved in the business ecosystem to apply the same technology too. The ripple effect for blockchain businesses started with big companies and consortiums, deploying the initial blockchain tests, and this development appears discontinuously in groups or swarms. Consequently, it may be compared to information flows along a SC. When a big market player deploys a new technology system to manage information, this impact has a ripple effect along the chain of stakeholders involved (manufacturers, insurance companies, institutions and governing bodies, financial societies, and last-mile logistics companies) and they need to align their communication and information platforms within the big player's standards.

Answers to research question

This section is aimed to respond to the presented RQ: which are the elements for designing blockchain-based digital strategies that might foster a reliable re-engineering in SC operations?

According to the literature reviewed and experts' concepts, blockchain is still in its infancy for prompt adoption in SC operations. However, blockchain presents powerful features for addressing the future evolution and digitalization of SCs.

The adoption pathway needs to be carefully assessed, and an intense commitment is required to design proper functionalities and exploit blockchain benefits.

Therefore, it is fundamental to identify the value creation and capture that blockchain may bring upon existing operations. Blockchain deployment must be supported by digital strategies to identify improvements in trust (for stakeholders) and automation (for operations). In this instance, by addressing the results of expert interviews, traceability, and transparency are key characteristics that should be evaluated for deployment. However, it will be relevant to analyze the processes and data that can be publicly available to stakeholders in the business ecosystem. This increases the level of trust and can support the detection of procedures where tokens and/or smart contracts generate value for critical performance. Moreover, this requires a reengineering of operations with blockchain functionalities, and it must be focused on exploiting the critical performance of traditional processes. To discover business operations where blockchain brings value, research may center digital strategies on single operations, scaling down the complexity and supporting a continuous incremental improvement.

To support the above-mentioned issues, Table 4.4 provides a matrix tool for placing the first steps of the evaluations. Thus, following Cole et al. [18], Ganeriwalla et al. [49], and Brown et al. [24], we adapted an assessment matrix to this study. Addressing the *value of trust* and the *value of automation* from [18], [49], we adopted an additional level from the *4E Model* from Brown et al. described by [24]. Trust aligns the expectations where *people, communities, and clients* are involved, whereas automation is involved in the execution for the *organization and delivery*. As an outcome, the four quadrants were adapted to this scope in Table 4.4 (traditional/existing systems, explore other technologies, niche application, and blockchain makes sense).

In addition, for blockchain deployment, it is fundamental to recognize the technological levels of the ecosystem where blockchain will be developed. In this instance, it is necessary to evaluate the internal technology level and identify technologies that can be interconnected with blockchain. In a complementary manner, the required external technologies must also be identified, understanding if they will be core—and hence, an own investment is needed—or if they will be secondary technological solutions that may be externalized in outsourcing.

Table 4.4. Value of trust and automation matrix for blockchain (adapted from [18], [24], [49]).

Value of automation (execution) / **Value of trust (expectations)**	−	+
+	Explore other technologies	Blockchain makes sense
−	Traditional/existing systems	Niche application

For the integration between blockchain and SC processes, the logic of a distributed data-platform must be defined to avoid excessive computational power consumption. It is relevant to have a sharpening focus on single operations, their interactions, and optimization.

For technology management, risk analysis will be a key asset in understanding the possible negative consequences and harmful impacts for other business units.

At this stage, it is fundamental to consider and carefully assess a performance comparison with other existing technologies or technological solutions. Exploring alternative technological solutions may help organizations mitigate the risks of adoption. Higher risk may result in an excessive effort without receiving real benefits from it. Additionally, blockchain will generate radical changes in other business processes and the way they are accomplished. Thus, a blockchain development plan must be supported by the top management, and an accurate change management plan is required in organizations. Change management should be introduced into digital strategies.

For the abovementioned challenges, it would be relevant to assess the transformative role blockchain may have in operations. Therefore, Table 4.5 was designed in accordance with Pérez [50], Brown et al. [24], and Wang et al. [15]. Addressing the *capacity to transform* with the *number of involved systems* from [50], we adopted an additional level from the *4E Model* described by [24].

The capacity to transform refers to the business ecosystem where *platforms and interfaces* will be deployed, whereas the number of involved systems refers to the internal/external enablers, such as *infrastructures and technologies*, that blockchain needs.

Table 4.5. Transformative role matrix for blockchain-based operations (adapted from [15], [24], [50]).

+ **Capacity to transform (ecosystem)** −	Connecting	Exploration (capitalizing)
	Collaborating	Exploitation (capitalizing)
	− **Involved systems (enablers)** +	

According to Wang et al. [15], transformative roles were addressed in the four quadrants of Table 4.5, as follows: collaborating, connecting, exploitation (capitalizing), and exploration (capitalizing).

Furthermore, according to the interviews and literature review, blockchain is an energy-intensive technology and has high environmental impacts. These negative environmental impacts must be considered during development.

Assessing the environmental consequences of blockchain deployment will support a clear identification of environmental targets and good practices. It is necessary to recognize that blockchain solutions should be implemented only if strictly necessary in operations and only if their benefits are measurable.

With respect to sustainable development, it will be crucial to establish the logics and methods of blockchain platforms that will be able to assure ethical behaviors with respect to human and environmental rights. Corporate liability must also be addressed by this asset.

Moreover, the digital strategy must assure trust and avoid centralized systems. In this respect, for acquiring data from a blockchain-based SC, the information gatekeepers must be carefully designed, certifying the entry points and providing an additional level of trust in the evidence (or events) that create the distributed ledger. For this purpose, identifying the right DBS is a key aspect.

To encourage the DBS identification, we adapted a matrix from Lambert et al. [51] and Bharadwaj et al. [23]. Table 4.6 compares the *supply risk* with the *potential to add value* in SC operations [51], framing the business objectives by segments where a DBS may be applied. Thus, in accordance with [23], the *4S Model* was adopted within this segment to exploit the more suitable digital strategy per business objective. As an outcome, Table 4.6 provides four quadrants to address the blockchain-based DBS that might foster a reliable re-design in the SC, as follows: speed (efficiency), scope (effectiveness), scale (profitability), and source (robustness).

Table 4.6. Digital business strategy identification matrix (adapted from [23], [51]).

+ **Supply risk** −	Scope (effectiveness) Supply quality and continuity	Source (robustness) Profitable long-term growth for parties
	Speed (time) Simplicity and efficiency	Scale (profitability) Cost savings and value maximization
	− **Potential to add value**	+

Recommendations for re-engineering of SC operations

In this section, merging the outcomes from the taxonomy and the results from the expert interviews, we present an additional contribution. Thus, a list of recommendations is provided in an attempt to bridge the gap in the existing body of knowledge.

Summarizing the considerations described in the previous section (RQ), we have framed the results in four steps recognized from the taxonomy: (1) identify, (2) assess, (3) design, and (4) assure. As presented in Table 4.7, this framework is composed of 22 statements that support both evaluations and detections of relevant aspects to be considered during blockchain adoption in SCs. Therefore, all contributions presented in this section are proposed as a guidance for blockchain-based digital transition in SC applications.

4.2.6. Conclusions

In this study, experts' opinions on blockchain-based SCs were explored. Using an explorative research approach, we conducted 18 interviews with international experts from different countries. Applying the grounded theory methodology, we analyzed the collected data and identified four categories.

This study lays the foundation for the development of digital business strategies in blockchain-based SCs and ensures a reliable redesign of those SC operations that can guarantee efficiency and effectiveness for future deployments. As major outcomes, this explorative research provides a set of matrices and a reference framework that can support the recognition of innovative pathways in this area of application.

Additionally, other research insights may be explored and connected with these presented results. To enhance future investigations, future studies may be performed, designing quantitative approaches (i.e., [52]) and merging these two different perspectives, generating comprehensive results.

Table 4.7. Four steps framework for the evaluation and detection of relevant aspects.

	IDENTIFY
1	business operations where blockchain brings value
2	which processes/data can be publicly available
3	which internal technologies can/must be linked with blockchain
4	which external technology can/must be acquired (outsourcing or investments)
5	digital strategies for creation and capture of value
6	operations where tokens and/or smart contracts generate value on critical performances
7	digital strategies for single operations, scaling down complexity for continuous incremental improvement
8	alternative technological solution to mitigate risks
	ASSESS
9	how to exploit critical process performances
10	performance comparisons with other technology solutions
11	(carefully) the change management
12	the internal technology level for a blockchain adoption
13	environmental impacts of a blockchain development
14	the added value and value capture of blockchain-based operations (reengineering)
	DESIGN
15	new procedures and processes for blockchain deployment
16	integrations with internal processes and technologies
17	the data platform logic for the optimization in single operations
18	(carefully) information gatekeepers, otherwise trust is not assured
	ASSURE
19	avoid centralized systems
20	deploy blockchain solutions only if strictly necessary
21	carry out a risk analysis for the implementation
22	establish appropriate blockchain logics and methods that guarantee ethical behaviors with respect to human and environmental rights

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Chapter 5

USE CASE: BLOCKCHAIN AND COVID-19

Sections:

5.1 Contextualization of the study

The thesis was developed between the 2017 and the 2021, and in 2020, the World Health Organization (WHO) declared the COVID-19 outbreak a global pandemic.
When all of us were getting used to this ‘*new normality*’, it was impossible not to dedicate some time to reflect on possible implementation of blockchain in tackling the COVID-19 pandemic.
With the UPF NeTS research group, we started asking ourselves how blockchain may play a role in the contagion mitigation and how medical perspectives could effectively respond to it.
Therefore, we started to review the literature to try enhancing our understanding of medical procedures and how the distributed technology may be linked to those.
Thus, from the end of 2020 until mid-2021, we conducted the literature review and the analysis of previous applications. Within this study, we presented a use case for blockchain in the COVID-19 response, enriching the body of knowledge in the research area.

5.2 Review of Blockchain for Pandemic Surveillance and COVID-19 Response

Results of this specific study highlight potential actions for the development of blockchain in the COVID-19 response, keeping a medical perspective as core review.

Abstract:

As vaccines for the COVID-19 pandemic begin global roll-out, researchers for the first time are able to look retrospectively at the variety of avenues taken to address the rapid pandemic spread and their success in adoption. Among these avenues, blockchain has seen new research applications in digital contact tracing, vaccine supply chain, and the broader electronic medical record ecosystems reaching broad publication in recent months, among others. As a system without a defined owner, blockchain does not inherit a natural fit in crisis applications where there remains a desire for leadership and central authority. This chapter presents an overview of how recent blockchain research has adapted for COVID-19 within the pandemic surveillance categories previously mentioned, and concludes with a suggestion for future research.

Keywords:

blockchain, social impact, COVID-19.

Della Valle, F.; Platt, S.; Oliver, M. "Review of Blockchain for Pandemic Surveillance and COVID-19 Response". *Electronics 2021, (submitted August 30th 2021, minor revisions).*

5.2.1. Introduction

At the time of writing, the novel Coronavirus 2019 or COVID-19 is reported to have infected over 216 million persons while amassing close to 4.5 million fatalities globally, and over 5.2 billion doses of vaccines administered [1]. Traditional paths of addressing the pandemic spread have included social distancing, travel restrictions, administration of antiviral pharmaceuticals, and most recently, delivery of approved vaccines to inoculate the world population. Each of these tasks in isolation has proven to require government scale coordination and increasing cross-border collaboration as the pandemic period has extended, introducing further complications. Viewing COVID-19 in this largest of scales highlights the difficulty of halting a contagion when no single party is in control and no single party has a complete view of the pandemic spread. In this case, the question of who owns, organizes, and is the authority of truth on the shared data is uniquely suitable to the strengths of blockchain database storage. This appeal is further heightened during pandemic events when the variety of organizations reporting data can be quite broad, making data non-uniform as well as in cases when centralized reporting is under-developed or otherwise restricted.

Blockchain as a technology has the unique ability to both decentralize and secure data, while not requiring a direct owner. As a database technology, blockchain in theory, can supplement any application for the purpose of storing data. This data can be internal-use only, decentralized among a consortium, or fully decentralized. Within these data models, varying access models can be applied, such as permissioned or permissionless, and further architecture choices such as how finality and consensus are handled all contribute to its fit for a chosen purpose. Due to the rigid nature of blockchain as an immutable record, care must be given to the initial design and values that are proposed for blockchain storage, with the total deployment deferring to the domain specific context suiting the needs and workflows of the intended end user, whether they be a financial institution, or a medical facility handling records in the COVID-19 related categories previously mentioned.

Therefore, providing a context on how blockchain systems application may be connected with previous models, and looking for a broader relationship between these systems and established medical schemes, a research question emerged for this study: from a medical perspective, which blockchain assets have the highest potential impact on the effectiveness of pandemic surveillance and response?

In developing this work, the author's initial intent was to identify potential gaps within the existing body of blockchain research addressable to COVID-19, and propose a technical solution, a new blockchain-based system that fit a previously unidentified demand. To identify these gaps, authors designed a literature review based on the year 2020-mid 2021 where blockchain-based solutions were designed for COVID-19 response and present a smaller selection of them within the specific context of how they relate to the specific SEIR model deployed in epidemiology. It is the best of the author's knowledge that this epidemiology perspective is commonly omitted when a technology-first perspective is taken.

It is now understood and proposed by the authors however, that blockchain as a database has achieved a level of maturity as an IT system; such that in most cases, where there is a database, there could also exist blockchain. The authors instead for this paper, intend to deliver a timely review of recent research proposing the use of blockchain to present a holistic view for blockchain applications in pandemic surveillance and COVID-19 response. As contribution of this review, authors provide vertical analysis on the identified areas, where blockchain-based solutions for COVID-19 response, might provide a holistic view of deployment.

The remainder of the chapter is organized into three sections. Section 2 includes the methodology applied for the literature review. Next Section 3 details the general medical perspective of pandemic surveillance prior to blockchain and COVID-19 and includes three sub-sections detailing recent blockchain-specific research intended to service IT systems within the ecosystem of pandemic and COVID-19 response. Last, the Section 4 concludes with a discussion, providing a final summary of the study and proposing paths for future research.

5.2.2. Methodology

This work sets up a review for blockchain applications to develop a neutral and distributed tool to design processes linked to the development of future solutions for pandemic response. Thus, the research methodology developed along this work is based on a solid

and recent literature review that creates the needed state of the art to propose new solutions and applications.
According to B. Kitchenham [2], a process for conducting this study was identified and designed in three main phases: I) planning the review, II) conducting the review, and III) reporting the review.
Therefore, the proposed methodology is a literature review based in two steps of iteration. As first step, authors explored the literature linked with blockchain and COVID-19, published during the year 2020-mid2021. After the exploration of several fields of application presented in the identified papers, four main areas were identified as follows: 1) pandemic surveillance prior to blockchain, 2) blockchain for digital contact tracing, 3) blockchain for electronic medical records, 4) blockchain for vaccine supply chain.
As a second step, authors examine the four identified areas. Thus, after an assessment of technological features additional research was explored and linked with this study. In this instance, the global pandemic needs for a global solution to track goods and users in a efficient and anonymous way. The problem can be seen as an ordinary supply-chain exercise, however the validation of the suggested solutions needs to be universally adopted and sensitive to privacy and security when dealing with health data from people.
As an outcome, the literature review first analyses the works related to established medical methods of identifying and tracking pandemic spread events and their control mechanisms. All those studies were performed before the current situation of COVID-19 [3]–[6]. The use of blockchain to trace contacts have been also researched in different scenarios where the use of mobile devices has been crucial [7]–[11]. Further research intends to manage electronic health records linked to medical supply chains related to COVID-19 in more efficient ways [12]–[19]. Additionally, specific applications on the production and distribution of vaccines, in the context of the current pandemic, has also been addressed [20]–[25]. Finally, an additional part about future research is presented [26]–[29].

5.2.3. Blockchain technology for pandemic surveillance

This section presents the main findings emerged from this explorative research. Four major clusters are defined as follows: 1) pandemic surveillance prior to blockchain; 2) blockchain for digital contact tracing; 3) blockchain for electronic medical records; and 4) blockchain for vaccine supply chain.

Pandemic surveillance prior to blockchain

Prior to the 2019 COVID-19 pandemic, over a century of medical experience, dating to before the Spanish Flu pandemic of 1918 up through the SARS coronavirus identified in 2002, medical professionals have established and matured methods of identifying and tracking pandemic spread events [3]. Before highlighting blockchain applications for pandemic surveillance, it is important to raise the medical perspective of such applications. Doing this allows a level of understanding for who are the users of such applications and the corresponding needs. It also gives context to the types of data being stored in such systems and how this data is used. An example of such methods is the SEIR model, an acronym representing Susceptible, Exposed, Infectious, and Recovered [4]. With a limited set of standard data points, such as incidents of infection, researchers are able to probabilistically calculate rates of spread, and the impact of containment measures such as travel bans and quarantine [4]. When combined with health outcomes data, researchers can calculate durations of incubation, active infection, and mortality rates. Further combining these with mechanics such as contact tracing can allow the surfacing of nuanced scenarios, where infection occurs, and a portion of infected individuals are asymptomatic (Figure 5.1) [5].

After the review, the authors conclude that there is a natural fit for blockchain technologies to manage pandemic data. In this instance, there is an extreme incentive for the sharing of data, but to the best of our knowledge a direct coordination may represent higher complexity. Storing this data in a blockchain could also allow more flexibility in who reports data, and the type of data reported. This is significant in scenarios where health systems are not mature, or there are otherwise not sufficient resources to enable strong centralized government reporting.

Making reporting more accessible in this way also has a secondary benefit in making pandemic data more representative. Take for example, the case of imposed travel restrictions during a prolonged pandemic event. In the period between first identification, and the widespread distribution of vaccine resources, a contagious virus can experience seasonality and cross border transmission from regions that are not restricted due to lack of reported data [6]. As a contrast to control on border crossings and domestic mobility, researchers have also investigated and presented the global coordination of vaccine and antiviral distribution as a more effective alternative for containing pandemic spread. Indeed, according to R. Grais *et al.* [6], a global coordination of vaccine management and antiviral distribution chains can be more effective at data-reporting at a wider scale. Such a model is only effective however, to the extent that reported data is representative of actual spread and rates of infection, and a pervasive view of pandemic spread is available.

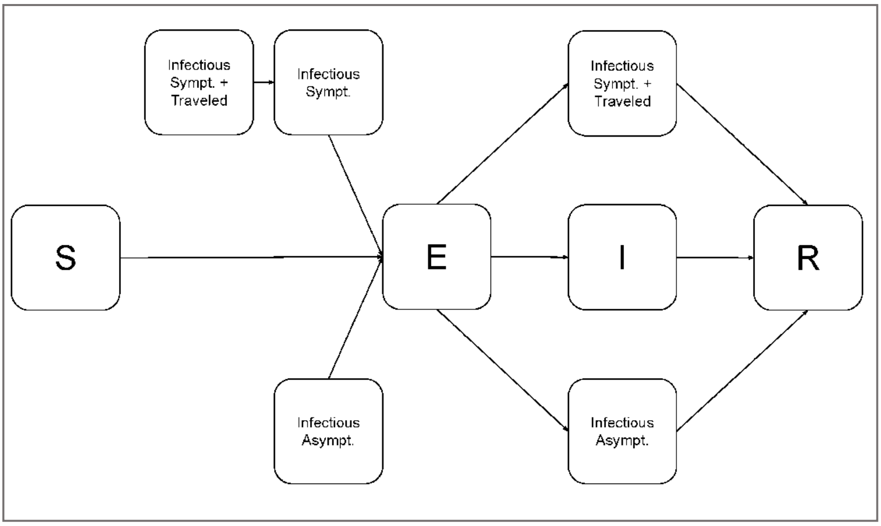

Figure 5.1. An example SEIR model, accounting for asymptomatic spread, and spread originating from travel (adapted from [5]).

Blockchain for digital contact tracing

As a system without blockchain technology, the recently released contact tracing system produced by Apple and Google is an oft-cited research reference. The system developed by Apple and Google runs on a user's smartphone and is designated as opt-in. Once the user opts in, the system relies on Bluetooth beacons to listen for other devices which are nearby [7]. By recording these proximity histories, the system can notify users if they have been nearby a person who has tested positive for COVID-19. The system is able to do this because all histories are stored centrally with Apple and Google, who are then able to perform the matching. To provide a level of privacy to these highly central records, the system relies on the identity provided by the Bluetooth beacon, which is software generated, rotated on a schedule, and not directly related to the individual person's identity at a hardware level. Even in this context, the system has been identified as being vulnerable to trajectory mapping, due to the total histories being visible to Apple and Google who are also the only parties who can identify the real-world device and user corresponding to temporary Bluetooth identities [7].

Organizations who choose to use this format of digital contact tracing make a trade-off between its centralization/privacy and pervasive availability. Outside of the Apple and Google models, a variety of government developed systems provide additional variety of implementation in digital contact tracing. These include Singapore’s TraceTogether [8], which also runs on user smartphones to collect Bluetooth proximity data, but uses real identity stored directly with the central government. There is also China’s Health Code system [9], which requires users to scan barcodes when entering dense areas such as shopping malls, hotels, and restaurants. Data in China’s Health Code system also uses real identity, stored directly with the central government. The system diverges from the Singapore model in that it is less automated and does not rely on Bluetooth or other hardware to remain active in user equipment. The Health Code system can be seen as a lighter weight implementation, but is also more enforceable as the QR code scanning is physically enforced in real world locations and cannot be easily bypassed. At a macro level, each of these systems, while appearing general in design, are modeled for a specific audience, each placing differing emphasis on factors such as privacy, enforceability, and technical complexity.

Extending the models previously mentioned, BeepTrace is a recent research proposal that adds blockchain to the contact tracing infrastructure and places its emphasis on user privacy [10]. Similar to the Apple and Google model, BeepTrace relies on voluntary user participation, but differs in most other technical aspects in that it separates all the functions of the system, to have them operated by independent parties.

While also running an application on the user phone, BeepTrace does not rely solely on Bluetooth beacons for location, it instead proposes tagging location from Wi-Fi, GPS, and cellular towers, in addition to Bluetooth beacons.

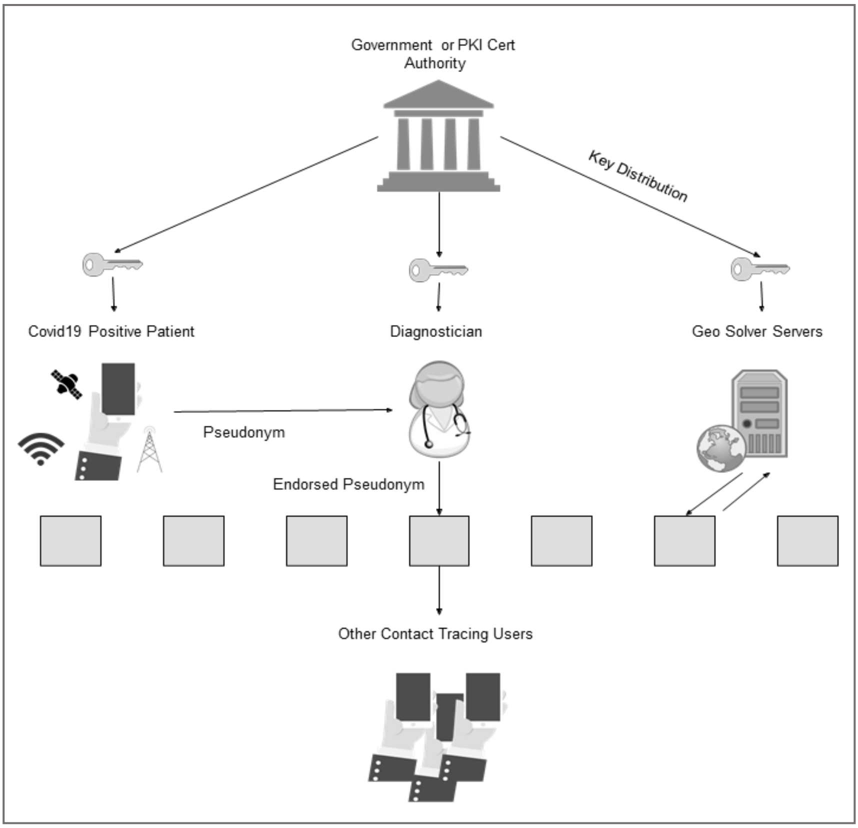

Figure 5.2. The BeepTrace COVID-19 tracking framework (adapted from [10]).

The additional methods of location tagging allows for tracking environment exposure, even under a sparsity of other people; such as a factory location where surfaces, rather than people have been exposed to a person with a positive COVID-19 diagnosis. Figure 5.2 shows the full BeepTrace framework and its component parts.

In fact, this tracking for exposure of a location, rather than an individual has been consistently highlighted as a function not easily served by existing digital contact tracing solutions. Location exposure, rather than people exposure was specifically targeted by Klaine *et al.* [11], who present a model where Wi-Fi and Bluetooth radios are stationary and installed to points of interest to record to a blockchain, occurrences of exposure with persons diagnosed with COVID-19. In these cases, as well as the Apple and Google case, the identities being matched are anonymized and stored for a trailing period, usually 14 days, to allow matching confirmed cases with instances of exposure retroactively.

Blockchain for electronic medical records

Akin to Industry 4.0, Medical 4.0 has been defined by R. Vaishya *et al*. [12] as a set of algorithms which help provide real-time information to all the strategic partners in order to bring traceability to the process of disease control through the effective management of the medical supply chain. To deliver this advancement with sensitive medical data, cryptography played a fundamental role guaranteeing the privacy in medical treatments, protecting all sensitive information involved. Given that a blockchain is characterized by robust cryptographic protocols, it might mislead practitioners in deploying blockchain for medical purposes without additional care given to the specifics of the data being stored. In fact, blockchain for Medical 4.0 needs to be carefully designed to assure privacy, and not to publish sensitive information where not allowed. A good balance between data accessibility and data protection is needed [13]. Additionally, practitioners need to take into consideration that the current cryptographic protocols deployed in current blockchains may become obsolete in the next few years, and if sensitive information goes on the blockchain, these data may become public or otherwise become easier to attack in the future, if not deployed in the suitable context. In this instance, S. Vaudenay [14] compared centralized and decentralized solutions to protect privacy in medical records and tracing. S. Vaudenay highlighted that none of both systems offer a decent level of privacy protection, rather some hybrid directions exist and are promising [14].

According to S. Peng *et al.* [15] a double-level blockchain can be employed to reduce these risks. A double-level means to design a blockchain infrastructure with a higher interoperability, allowing a close interaction between both public (external) and private (internal) blockchains that are maintained separately [15]. This public-private structure allows to mitigate the risks of privacy, keeping sensitive information on the private blockchain, whilst in the public one would be permitted to share a larger amount of encrypted data, without fear of privacy leaks [15].

An effective management of the electronic medical records in the medical ecosystem, can foster real time information sharing to all strategic partners, helping the traceability in the process of disease control [12]. In fact, a blockchain-based disease control system can break down data silos, impacting on public and government agencies for local and regional pandemic management. According to A. Fusco *et al.* [16] and D. Nguyen *et al.* [17], the application of blockchain and artificial intelligence may design new prediction models to mitigate risks of infection spread and new efficient and effective evidence-based decisional procedures.

An additional blockchain feature that has been presented as having a specific fit in sharing electronic medical records is the implementation of data oracles which allow integration of external data into blockchain logic or controls. Deploying data oracles in this context allows an alternate method of gating access to sensitive data, while ensuring trust to these data sources by making their public records auditable and immutable [18], [19].

Blockchain for vaccine supply chain

Supply chain management (SCM) is an established and essential business process in every organization today. A traditional industrial supply chain is composed of the total of systems required to deliver an end-to-end business process, service, or product. Supply chain management in this classic context is the practice of organizing all the data generated by these systems, and is usually aggregated and actioned on, within an enterprise resource planning (ERP) system. As advanced under Industry 4.0, these systems became updated to include higher levels of connectivity, pervasive data, and machine automation. This means that systems producing or consuming resources within a supply chain can self-report, or receive live updates on contingent activities elsewhere in the supply chain. In application, these advances help address information asymmetry which can lead to poor supply chain outcome [20].

Within the broader context of industrial supply chains, are so-called cold chains which apply supply chain management practices to the production of goods which have the additional constraint of requiring a controlled cold storage environment to prevent damage or expiration. This body of knowledge focused on cold chain management has served as a starting point of supply chain delivery of temperature-controller COVID-19 vaccines from Moderna Inc, Pfizer Inc and BioNTech SE. This connection may reduce information asymmetry along the cold chain management, support decision-making practices and reduce management costs. As a result, these management improvements may have impacts on the optimization of the long-term freezing conservation for vaccines. For instance, if the infection ratio is considerably growing in a specific area, a blockchain-based system might promptly provide real-time information for the whole ecosystem and actors involved, acting as an enabler for the empowering connections and the data sharing on the management side of the cold-chain. As a result, this may generate faster dynamics for decision making procedures, saving lives.

A blockchain-based medical supply chain may be implemented to supervise the vaccine supply chain and the emergency-demand forecasting per specific areas. B. Yong *et al.* [21] propose the following specific information to be considered in the design phase of a blockchain-based vaccine supply chain are: a) batch packaging record, b) batch production record, c) inspection record, and d) inoculation record of vaccines. In their research, the authors remarked the importance of sending to regulators and institutions entities all the required information in an automatic manner. To the best of our knowledge, bridging the gap between the batch packing records (point a. of [21]) and the inoculation record of vaccines (point d. of [21]), could be used to foster the supervising of vaccine chains. This may be achieved by implementing some blockchain functionalities to improve data control in emergency situations and demand forecasts. In this instance, the demand forecasting in emergency conditions may be improved with some blockchain features to share data and real-time information in the entire ecosystem. One of the impacts of this implementation, it may help in designing more reactive infrastructures, reducing costs and improving forecasting within ERP systems for vaccine cold chains. This link with ERP and blockchain may allow the identification of the need of vaccine per area, enhancing the distribution efficiency of vaccines and reducing the information asymmetry [13]. This may provide a relevant performance improvement on managing the vaccine storage, given that the current COVID-19 vaccines need to be kept at temperatures as low as a low minus 70 Celsius for proper conservation [22]. In these conditions, small enhancements or improvements may bring greater impacts on the SCM for COVID-19 response – for the best of our knowledge.

Because blockchain technology is a performance improvement for supply chains [23], efficiency and effective management of medical supply chains can be clearly identified. With a focus on the cold chain management of COVID-19 vaccine, enhancing distribution and logistics aspects, it may directly reduce costs for stakeholders involved [24]. According to M. Hulea *et al.* [25], a blockchain-

based cold chain management for vaccine data structure requires the participation of each stakeholder, joining in the cold chain-network with one validator node.
In a global perspective, a proper management of the cold supply chain highly impacts on the quality and integrity control in the distribution process. According to R.H. Bishara *et al.* [24] a monitoring program is essential for cold chain management in pharmaceutical products, increasing trust and safety in the medical supply chains.

5.2.4. Discussion

As blockchain research has matured, there has been an increasingly clear isolation of blockchains' role as simple storage. To the extent that an application makes use of a database to store information, it can be paired with blockchain storage for its intended effect. After an exploration on commonly used medical procedures for pandemic surveillance, technical blockchain-based solutions (and use cases) have been analyzed and discussed, with a sharpening focus on: electronic medical record, digital contact tracing, vaccine supply chain, as they interconnect as part of current COVID-19 pandemic response (Figure 5.3). Specific care is taken to surface both the benefits and risks of each application, keeping the medical perspective designed by the SEIR model and the evolution of pandemic.
In this instance, authors recognized some limitations of the review carried out, and the principal aspects are stated hereafter. As the treated topic is pacing heavily, authors may have not identified all the most relevant research or studies that were published in renowned journals. However, the review methodology authors set was used in a meticulous manner to assure a high level of research findings. Additionally, as the correlation between blockchain technology and COVID-19 represents a research area with a high degree of novelty, authors analyzed the review outcomes in a neutral and objective way, avoiding personal judgements and predictions. Nevertheless, authors identified that several research works are aimed to present tentative proof of concepts or potential ideas for the correlation between blockchain and COVID-19 in its entirety. The authors highlight that this review may represent a not

exhaustive research, but a correlation with medical perspectives rather than a fully comprehensive technical solution.

Therefore, answering the research question formulated, three trends among the current body of research are the main results. The first is a broad risk of overfitting blockchain applications to a narrow and singular use. This most often appears in the form of precise data structures being defined in research experiments. A number of current designs identify a fixed format of block data, a clearly defined user, or a single workflow. Performance measures and comparisons taken against these fixed values make comparison and later reuse more difficult. It applies an amplification of the already rigid structure of blockchain storage in the designs that are being defined. A possible solution for this would be placing an increasing focus on data interoperability as seen in general supply chain and vaccine cold chain applications, where the mix of data, and the users of the data are assumed to be flexible at the start.

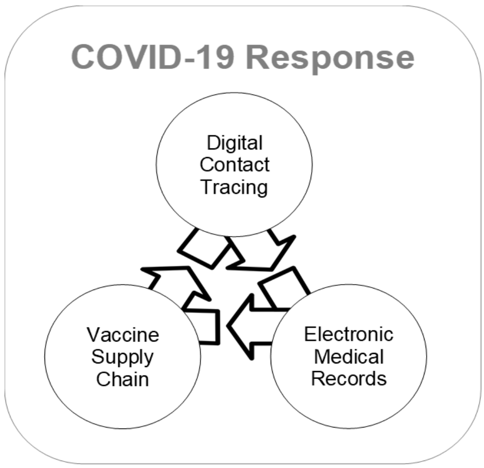

Figure 5.3. Holistic view of blockchain for COVID-19 response.

A second trend of note is the continued tension between ownership and authority. A large incentive for deploying blockchain technology is the ability to operate and update the blockchain system without a central owner. This however is distinct and separate from not having a central authority. Taking the provided example of contact tracing applications, the lack of central owner in these systems can also introduce a bias that places the burden of providing data, or of system operation, on individuals. In the specific case of COVID-19 response, this is undesirable in many cases, because the entity requesting the data, or ultimately actions on the data in many cases is a central authority. A blockchain system which does not allow for this flexibility would be precluded from replacing IT systems such as Singapore's TraceTogether and China's Health Codes. A recommendation in this scenario is the investigation of more modular blockchain designs, which allow various parts to be enabled, disabled, or replaced; where blockchain does not extend beyond its function as storage, and is not allowed impact on the workflows elsewhere in the system. Returning to the very beginning, the SEIR model of pandemic surveillance provides a good example. When abstracted, scientists adhering to the SEIR model in COVID-19 surveillance may only need a dashboard of the SEIR model counts. Underneath these counts may exist any number of blockchain systems, combining all the systems mentioned in this writing. The system described in effect would serve as a meta pandemic response supply chain. To the author's knowledge, at the time of writing, such a blockchain system does not exist and is proposed as a possible path of future research.

Additionally, other research insights may be explored and connected with these presented results. To enhance future investigations, and keep the potential relationship with blockchain initiatives and the SEIR model, other blockchain-based opportunities related with COVID-19 should be explored [26]–[29]. To the best of our knowledge, suggested future researches to be considered are summarized in six areas, as follows:

1. E-government and e-healthcare;
2. Patient information sharing;
3. GDPR and medical data-issues in the public healthcare sector;
4. Sustainable integrations with existing systems and costs reduction;
5. Smart home assistant devices and quarantine healthcare;
6. Passport and immune certificates.

All these areas of investigations may be connected to the holistic view provided in Figure 5.3 to deploy future insights.

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Chapter 6

CONCLUSION AND FUTURE WORK

<u>Sections:</u>

6.1. Merging outcomes

The high expectations on blockchain technology (BT) for industrial application may cause unexpected risks and dangerous consequences for companies involved. Therefore, the contribution of this research work attempts to bridge the gap in the existing body of knowledge, supporting reliable BT deployments in supply chain (SC).

This thesis presents a qualitative analysis performed with ethnographic methods based on expert interviews. Data from eighteen international experts were collected and analyzed using the grounded theory approach. Thanks to this methodology, we identified the main aspects characterizing the blockchain impacts for SC application.

The research was conducted in four steps and provides robust outcomes aimed to: 1) identify the type of innovation for blockchain in SC; 2) recognize the effective combination between blockchain and SC processes; 3) highlight the major influences for a blockchain transition in SC; and 4) describe a use case for blockchain and COVID-19 response.

Hereinafter are presented the three main results identified among the current body of this research.

The first outcome identified highlights that the implementation risks are still high for blockchain in the area of SC, and the current industrial applications are assigned to the proof-of-concept phase, where most of them are centralized applications.

As the main result, we conclude that blockchain for SC presents all features to be a sustaining innovation rather than disruptive, according to Christensen's definition. However, the results confirmed that SCs appear to be one of the most prominent fields of application for blockchain. In fact, as a technology system, blockchain is not seen as a disruptive innovation for SC, rather than a sustaining technology that increases the performance of existing processes.

In future applications, blockchain is considered as a service for SC, enhancing trust in digital ecosystem-building for SC stakeholders involved. This deployment is appropriately placed in the supplier relationship management process.

Even though blockchain is still in its infancy for prompt adoptions in SC operations, it presents powerful features for addressing the future evolution and digitalization of SCs.
Nevertheless, to the best of our knowledge, blockchain-based SC is not yet a mature technology and the return on investment (ROI) for its deployment is still unclear. Thus far, this technology has been implemented and tested in several areas, although SCs appear to be one of the most prominent fields where it may have a higher impact on society – related to social behaviors, social attitudes and hyper-engagements.
As an aggregation of several technologies, the innovative step lies in the combination of activities and in how individual technologies are aggregated and blended. Therefore, we can say that the novelty aspect of blockchain has no technical features, whereas such novelty is present in public computer networks and the access thereof.

The second outcome found is about trust. For centuries, the common meaning of 'trust' was allocated to people, institutions or third parties. In recent decades, technological development has added a further level of 'trust', switching some elements of trust to technology trust. Trusting technology will be a business advantage, and for blockchain, trust (or chain-of-trust), could be set as a new service for customers that can bring about more ethical consumption in the market and then strengthen the community of informed consumers. Therefore, blockchain shifts the trust in people and institutions to trust in technology.
As a consequence, this change of trust may require an effective information flow structure to deploy blockchain in SC.
Sharing data on a public ledger does not seem to be an appealing feature for companies, indeed hybrid solutions are needed between permissioned and permissionless blockchains.
The data sharing is a digital asset and represents a value exchange in the stakeholders' network, but it may denote threats to market competitiveness. Information management is one of the drivers for blockchain in SCs, demonstrating a performing feature for data organization and real-time information sharing. Distributed data-platforms will perform innovative roles in SC. As data are replicated as many times as the nodes of the network warrant, it is fundamental to identify those key-data to be shared in the distributed ledger and provide an infrastructure capable of obtaining

the best value from a consensus protocol deployment. Once the ecosystem identifies the data to be shared, a blockchain platform can make it available for each stakeholder involved, improving security and reducing time for the information management process. In this instance, future developments ought to define fair tradeoffs between distinguishing features such as decentralization level, scalability potential and security clearance. As emerged from the study, blockchain enables business networks to move towards a higher level of digitalization, enhancing digital procedures and vertical implementation for SC. As an example, blockchain-based SC data-platforms are lean data-driven solutions and provide a higher degree of automation for financial and administrative duties.

The third outcome identified in the analysis is about the recognition of value creation and capture that blockchain may bring upon existing operations.
To do so, companies need to evaluate the internal technology level and identify technologies that can be interconnected with blockchain. In a complementary manner, required external technologies ought to be identified too, understanding if they will be core or if they will be secondary technological solutions that may be externalized in outsourcing.
This aspect requires a reengineering of operations with blockchain functionalities, and it can start exploiting the critical performance of traditional processes. In addition, assessing blockchain benefits will be an asset, and they must be measurable. This assessment can be performed keeping a sharpening focus on single operations, their interactions, and optimization inside the whole system. In fact, an appropriate technology mix can enable and leverage future blockchain implementations, supporting the understanding of possible negative consequences and harmful impacts it may have in other business units.
Higher risk may arise if an excessive effort is done without receiving real benefits from a blockchain deployment. Thus, a blockchain development plan must be supported by the top management, and an accurate change management plan is required in organizations.
This transition needs to be carefully considered by managers before starting a blockchain project. To mitigate risks, the know-how needs to be inside the company, and not externalized. Technical-knowledgeable people cannot be a third-party or an externalized

service, instead they need to be inside and completely part of the team. If the technical aspects are core, then the core technology cannot be externalized to mitigate, monitor and control all security management procedures.

Last but not least, the value creation and capture must be designed following all possible efforts to put into practice a sustainable development. To address this target, it will be crucial to establish the logics and methods of blockchain services that will be able to assure ethical behaviors and moral matters. Assessing the environmental consequences of blockchain deployment will support a clear identification of environmental targets and good practices, avoiding excessive computational power consumption.

6.2. Final considerations

The research area for blockchain technology in supply chain can still be considered as a quite novel field of study. However, the scientific interests and efforts are increasing rapidly, both in number and quality. Additionally, a positive incidence of studies involving sustainability and ethical considerations about blockchain are taking higher significance in the scientific literature (see chapter 4.2.2.).

Even though this research study was conducted in a rigorous manner, some difficulties were encountered during the investigation. The main difficulties were mainly addressed during the initial phases, as looking for experts and selecting them have been the crucial activities for setting-up the experiment, which had high impacts on the entire work. As a novel field of research, it has not been easy to find appropriate experts to involve. In fact, a larger sample was considered to solve this issue (see chapter 2.2.3.). Furthermore, finding the most suitable methodology to analyze the data collected has also been a concern to conduct this study. But after exploring similar research works applying ethnographic methods as well as previous studies in blockchain, grounded theory appeared to be as the most suitable approach to follow.

Although this research contribution attempts to bridge the gap in the existing body of knowledge with a thorough analysis, the study presents some missing aspects. In fact, in order to offer a more comprehensive study, a further step could have been to assess the blockchain implementation with higher level of details by providing additional technical specifications as well as information for the economic burden required. Even though it could have brought an added value to the study, we considered such aspects as out of scope of this research.

As additional consideration, we recognized that activities carried out in groups had a strong positive impact on the thesis's outcomes.
Taking part in the European project proposals of the EIT Urban Mobility KIC (see Appendix 2) was a crucial step to understand the needs of the business communities about blockchain, improving knowledge and awareness about current gaps between research and industry. This aspect allowed us to tailor the research outcomes towards the identified needs.

Instead, regarding the use case for blockchain and COVID-19 designed with the UPF NeTS research group, the lesson learned was about the framing of the literature review and taxonomy for specific purposes. This activity had an impact on paper number three (see chapter 4.2. "*A Guidance for Blockchain-Based Digital Transition in Supply Chains*") in which the same approach is applied.

After the above mentioned considerations, the next conclusive section suggests some future research lines in this area of application.

6.3. Future work

In this section some insights for future research are discussed. First, since mostly current industrial tests are centralized, a future challenge will be to improve the decentralization degree in blockchain-based SC. The main difficulties for distributed implementations would be to determine how a distributed ledger will be managed. This because, to define as a distributed ledger will be managed falls to a single third party in charge; such as who has access and can invite new members into the ledger. Thus, this aspect would require a different mind-set and new management paradigms where the continuous tensions between ownership and authority are mitigated. A large incentive for deploying blockchain technology is the ability to operate and update the blockchain system without a central owner. This however is distinct and separate from not having a central authority.
Therefore, placing an increasing focus on data interoperability as seen in general supply chain applications, where the mix of data and the users of the data are assumed to be flexible at the start, may support the design of more modular blockchains. This design can allow various parts to be enabled, disabled, or replaced; where blockchain does not extend beyond its function as storage, and is not allowed impact on the workflows elsewhere in the system.

Another potential future research refers to the mitigation of the broad risk of overfitting blockchain applications to a narrow and singular use. In fact, a number of current designs identify a fixed format of data block, a clearly defined user, or a single workflow. Performance measures and comparisons taken against these fixed values make comparison and later reuse more difficult. In this instance, as explained in the earlier sections, one of the future sectors of study may be focused on the analysis of blockchain for accounting and administration. Here, the match between blockchain and artificial intelligence offers opportunities for better oversight and accountability, and may impact back-office activities, such as financial reporting and tax preparation. In fact, applications such as accounting, financial statements, and tax obligations are consolidated duties in business management, and they might be automatized by blockchain-based solutions. Moreover, the blockchain enablement for autonomous audits, administrative procedures, and financial statements may be explored.

Finally, as emerged in the study, more education is needed about blockchain in industry. Hence, in addition to the research lines presented above, specific efforts should be envisaged to boost the diffusion of multi-purpose educational materials. Fulfilling the lack of knowledge in specific areas could reduce perplexities and mystifications regarding this topic and therefore contributing to raising the awareness and greater understanding about blockchain for a larger audience.

Appendix

Sections:

Appendix 1: Interview Format

Appendix 2: EIT-KIC Urban Mobility projects granted

Appendix 1

Interview format

No.	Questions
	Expert's intro: *background and related digital application interests.* Short introduction, how familiar he/she is with blockchain applications
	General viewpoint: *technology usability and accessibility*.
1	- What is your opinion about the current research and developments in the utilization of blockchain? *****
2	- What are your main concerns about the adaptation of blockchains at a wider scale in your sector/industry or in others? *****
3	- Which criticisms or drawbacks do you think might drive practitioners away from blockchain technology? *****
4	- Are there any current or potential applications (or use cases) of blockchain in your sector that you find disruptive? Why? Which is the most impacting? *****
5	- Which benefits of the technology's implementation do you think would be most attractive to supply chain businesses? *****
	Market value: *trends for interrelated and interdependent systems.*
6	- Radical vs. incremental changes – Which enhancements do blockchain bring to the marketplace?
7	- Which existing technologies could be replaced by blockchain and which blockchain's functionality will boost its market adoption?
8	- Market demand rate vs. technology improvement rate – What do you think is the higher growing rate for blockchain?
9	- Blue ocean opportunities – Which products would be generated by merging blockchain with other technologies?
10	- Critical performance – Which changes or new markets will be generated by blockchain for supply chain sectors?
	Shape evolutions: *future disruption.*
11	- Pioneer vs. leader – Who is the pioneer and who is the leader of blockchain technology in your sector?
12	- Smart contracts vs. tokens – Where is the real disruptive innovation if so?
13	- Satisfying customer needs – Which needs are citizens and companies showing currently that can be satisfied by blockchain?
14	- Which business units will be killed off/deeply restructured by established companies? What will the organizational change be inside companies?
15	- Are international standards for blockchain going to make a difference? Have you heard about the coming standardization ISO/TC-307? Any opinion on that?

*** Source:** Wang, Y., Singgih, M., Wang, J., Rit, M. "Making sense of blockchain technology: How will it transform supply chains?". *Int. J. Prod. Econ., vol. 211, pp. 221–236, 2019.*

Appendix 2

EIT-KIC Urban Mobility projects granted

Three projects granted: two submitted in the 2020 for the year 2021, and one submitted during the 2021 to start in the next 2022.

2021.Project.01.

Blockchain4UM: training and use case definition to leverage blockchain technologies in urban mobility initiatives.

Role
The UPF is project leader.

Abstract of the project
Blockchain4UM will offer complete training on blockchain and other Distributed Ledger Technologies to whole EIT-UM communities and Innovation Hubs. We will provide a complementary, replicable and scalable convenient set of both online and face-to-face educational materials. Moreover, our approach goes one step further of most training programmes by proposing a unique blend of online training – addressed to cities, industry, and R&D organizations – combined with practical, hands-on identification and analysis of specific use cases by engaged stakeholders, addressing their specific challenges, and early drafting potential applications in the context of urban mobility.

2021.Project.02

WalCycData: a data infrastructure for vulnerable road users.

Role
The UPF is task leader for the development of a blockchain-based use case.

Abstract of the project
Increasing the uptake of green transportation modes such as cycling and walking is a priority for many governments and transport

authorities due to the positive impacts on public health, air quality and congestion reduction. In order to increase uptake, it is essential to ensure the safety of vulnerable road users and it is no coincidence that those countries with the highest cycling rates, such as the Netherlands, are also the safest for cycling. The purpose of this activity is to provide a pilot framework for integrating and analyzing data related to cycling and pedestrian transport modes in order to improve safety and user experience for vulnerable road users in cities. The system combines three components:

1. A digital representation of each living lab;
2. A secure data transfer, fusion and analysis framework;
3. A data and analytics dissemination framework for municipalities, businesses and consumers.

2022.Project.01

IoTa: internet of things applications for cities.

Role

The UPF is project leader.

Abstract of the project (2022)

European cities have heavily invested in emerging technologies during the last ten years. In 2019, there were 7.6 billion active IoT devices in the world, which is expected to grow to 24.1billion in 2030 (23% of those devices in the EU).

The IoT has been a promising area where cities have put strong efforts in several areas (smart lighting, or waste collection in Barcelona, tracking of goods in Hamburg, multi-modal transportation in Milan, etc.) linked to Mobility as a Service (MaaS). To leverage all those investments in IoT, a less technical and more business oriented perspective is demanded. However, this fragmented chain creates a lack of holistic vision that emphasizes the business side of the IoT

enterprises is common to most players. In IoTa we propose to create an ecosystem to train how to go deeper in the IoT knowledge, specially from the business (ROI) side, by the definition of a training program and selection of use cases in cities as a showcase of best practices in Europe.