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THE IMPACT OF DIGITAL TECHNOLOGIES ON THE DEVELOPMENT OF SUSTAINABLE SUPPLY CHAINS: THE ROLE OF VISIBILITY

Pedro Miguel Ferreira Guedes

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PhD Ricardo Augusto Zimmermann

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Acknowledgements

As I approach the culmination of this academic journey, I feel an immense sense of pride for the path I have traversed and the personal growth I have experienced.

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Abstract

Recently, organisations have faced several disruptions that have made operations in global supply chains more vulnerable. This uncertainty has had a direct impact on various sectors of the economy and, consequently, on consumers. As a result, companies have sought to implement initiatives that mitigate potential impacts and build more resilient supply chains.

The concept of Industry 4.0 represents a paradigm shift in the way organisations operates, driven by advances in technology that seek to characterise the supply chain with greater efficiency and productivity. The use of flexible production systems, real-time communication and data exchange with suppliers and consumers offers several benefits to organisations. However, there is a need to accept and address some of the underlying barriers to the implementation of digital and connected manufacturing technologies, despite their high practical and theoretical relevance.

Through a case study of two large companies in the Portuguese textile sector, this study explores how the adoption of technology 4.0 enables the development of more sustainable supply chains. Both companies are undergoing a digitalisation process within the STVgoDigital project. Consequently, this study has the potential to contribute to the overall sustainability of the sector by reducing its environmental impact, ensuring fair and ethical working conditions and promoting long-term economic viability.

The results show that acceptance of this journey of continuous development starts with top management, through strategic adaptation and the promotion of an organisational culture that advocates innovation and continuous learning. Furthermore, the concept of supply chain visibility has been shown to play an essential role in this relationship through easy, fast and timely access to information.

Keywords: Industry 4.0; Efficiency; Productivity; Real-time communication; Data; Case study; Sustainability; Top management; Visibility

Resumo

Recentemente, as organizações têm sido confrontadas com inúmeras pertubações, que tornaram mais vulneráveis as operações nas cadeias de abastecimento globais. Esta incerteza teve um impacto direto em vários setores de atividade e, consequentemente, nos consumidores. Por isso, as empresas têm procurado implementar iniciativas que mitiguem eventuais impactos e construam cadeias de abastecimento mais resilientes.

O conceito de Indústria 4.0 representa uma mudança de paradigma na forma como as organizações operam, impulsionada pelos avanços da tecnologia que procuram caracterizar as cadeias de abastecimento de maior eficiência e produtividade. A utilização de sistemas de produção flexíveis, a comunicação em tempo real e a partilha de dados com fornecedores e consumidores oferece várias vantagens às organizações. No entanto, esta elevada relevância prática e teórica das tecnologias de fabrico digital e conectado implica que é necessário aceitar e enfrentar algumas barreiras subjacentes à sua implementação.

Através de um caso de estudo envolvendo duas grandes empresas do setor têxtil português, este estudo investiga como é que a adoção de tecnologias 4.0 permite o desenvolvimento de cadeias de abastecimento mais sustentáveis. Ambas as empresas estão a ser alvo de um processo de digitalização no âmbito do projeto STVgoDigital. Por consequinte, este estudo tem potencial para contribuir para a sustentabilidade global do setor, reduzindo o seu impacto ambiental, assegurando condições de trabalho justas e éticas e promovendo a viabilidade económica a longo prazo.

Os resultados mostram que a aceitação por esta jornada de desenvolvimento contínuo começa com a gestão de topo, através de uma adaptação estratégica e a promoção de uma cultura organizacional que defenda a inovação e a aprendizagem contínua. Para além disso, o conceito de visibilidade na cadeia de abastecimento mostrou ter um papel essencial nesta relação, através de um acesso à informação fácil, rápido e oportuno.

Palavras-chave: Indústria 4.0; Eficiência; Produtividade; Comunicação em tempo real; Dados; Caso de estudo; Sustentabilidade; Gestão de topo; Visibilidade

1. Introduction

The covid-19 epidemic posed a threat to modern society (Queiroz et al., 2020). Numerous disruptions, including travel restrictions, the shutdown of factories and local shops, and the forced lockdown of people, had an impact on organisations. These restrictions led to shortages of labour, raw materials supply, goods, and products (Xu et al., 2020). Consequently, common challenges like uncertainty, risk, vulnerability, and complexity were considerably challenging (Núñez-Merino et al., 2022). Even global supply chains, which had previously been relatively resilient to disruptions, experienced extreme pressure on their operations, revealing their vulnerabilities (Qader et al., 2022).

Every stage of the supply chain, including production, logistics, and shipping was compromised in the majority of organisations (Xu et al., 2020). Suppliers faced difficulties in fulfilling their deliveries, which presented additional challenges for them (Ivanov & Dolgui, 2020). As a result, deliveries were more often delayed, which affected service level and customer satisfaction (Spieske & Birkel, 2021). Many organisations' responses turned out to be inefficient and lacking agility, raising growing concerns about the reliability and resilience of supply chains (Qader et al., 2022).

Supply chain resilience has emerged as a key concept and discussion point. A resilient supply chain can effectively foresee, respond to, and recover from unplanned events or disruptions (Núñez-Merino et al., 2022). Readiness, response, and recovery are the three main determinants of resilience (Queiroz et al., 2020). Ideally, the information available can be crucial for a more efficient recovery, giving the organisation a competitive edge over its competitors. (Ivanov & Dolgui, 2020; Spieske & Birkel, 2021). However, to have a resilient supply chain, organisations must have visibility across their supply chain. Visibility can be defined as the ability of a supply chain to monitor the flow of goods and access data from suppliers or even customers (Zhong et al., 2016) to share information and support decision-making (Cao et al., 2020). Only supply chains that are highly integrated and flexible may achieve these two characteristics (Xu et al., 2020).

The adoption of digital technologies has the potential to provide real-time information, decentralised decision-making, and an integrated environment (Piccarozzi et al., 2018). The technologies associated with Industry 4.0 have the potential to promote increased supply chain visibility and collaboration (Qader et al., 2022). Therefore, I4.0 is characterised by the

digitalisation and automation of processes, enabling real-time communication and information exchange among supply chain partners (Núñez-Merino et al., 2022). This ability to share and exchange information should increase transparency and visibility, helping organisations to be better prepared to respond to disruptions (Cao et al., 2020; Ivanov et al., 2018). Thus, organisations must strive to be more resilient and proactively anticipate and prepare action plans (Qader et al., 2022).

According to Majumdar and Sinha (2019), the textile and apparel supply chain is one of the most complex. Short life cycles, high unpredictability of demand, and growing competition have pressured the textile sector to reduce costs and lead times (Braglia et al., 2020). Rapidly changing fashion trends have encouraged consumers to buy more frequently, leading to a reduction in the lifetime of clothing (Cai & Choi, 2020). This shift significantly impacts the environment because it increases the consumption of many natural resources such as energy, water, cotton, linen, wool, and others, and produces harmful waste (Cai & Choi, 2020; Majumdar & Sinha, 2019). Additionally, the lack of transparency and insufficient data sharing among supply chain players perpetuates these challenges (Ghoreishi et al., 2020).

Therefore, agile supply chains emerge as a need to address the present challenges, including those arising from globalisation (Braglia et al., 2020; Nayak et al., 2019). The T&A sector is typically represented by global supply chains, as many brands are produced in emerging markets (Warasthe et al., 2022). Building trust between supply chain partners, especially those distributed around the world, requires considerable effort (Müller et al., 2018). Traceability has emerged as a necessary condition for global supply chains to deal with misleading information and low visibility (Agrawal et al., 2021). It not only meets consumer demands for authenticity assurance and transparency but also provides visibility throughout the supply chain (Brun et al., 2020). This can be accomplished by implementing technologies and devices that promote better supply chain collaboration, digitalisation, and integration between all players (Braglia et al., 2020).

Thus, research on the contributions of digital technologies in the development of sustainable supply chains could advance the field of knowledge. This study seeks to answer the main research question: 1) How do digital technologies contribute to the development of sustainable and resilient supply chains in the textile sector? Additionally, some sub-questions can be addressed: 2) How do digital technologies contribute to the increase of supply chain

visibility? 3) What is the relationship between supply chain visibility and sustainability?

These research questions will be addressed through a qualitative methodology. To gather information for the empirical analysis, two in-depth case studies of two large companies operating in the textile sector in Portugal are analysed.

The present dissertation is structured as follows. This dissertation commences with a comprehensive literature review, which is divided into three main theoretical sections. The first section focuses on the new paradigm of Supply Chain 4.0, including the associated technologies and the challenges that hinder its implementation. The second section explores the relationship between supply chain visibility and sustainability. Thirdly, the specific context of the textile sector is characterised. Subsequently, the methodological approach of the case study is detailed, outlining the process of data collection and analysis. Section 4 presents the findings of the case study, encouraging an insightful discussion and shedding light on the digital transformation initiatives of two representative companies in the Portuguese textile industry. The findings are analysed concerning existing theories and the perspectives of the interviewees are presented. Finally, the dissertation concludes with a synthesis of the main findings, highlighting the principal contributions and limitations of the study and suggesting potential directions for future research.

2. Literature Review

2.1. Supply Chain 4.0

In recent years, supply chains have faced constant challenges, arising from factors such as global competition, the demand for customisation is high, and shorter product life cycles (Hofmann & Rüsch, 2017). Industry 4.0 provides supply chains with the tools they need to be more resilient to disruption and to respond and react more efficiently and effectively (Qader et al., 2022).

The emergence of I4.0 is perceived as a chance to innovate and boost firm competitiveness (Piccarozzi et al., 2018). A wide range of innovations is about to be introduced by I4.0, describing a broad spectrum of process changes across multiple domains and the adoption of new technologies (Koh et al., 2019; Rad et al., 2022). This integration of cutting-edge processes and technologies might collaborate to produce customised products or provide services more quickly while consuming the least amount of resources (Kamble et al., 2018a; Koh et al., 2019). Moreover, the ability to respond to market demands is strengthened as a consequence of shorter lead times, optimised use of resources, and the flexibility to diversify product lines (Ivanov et al., 2018).

The implementation of these technologies can revolutionise processes, ease the design of new products, and optimise supply chain management (Tjahjono et al., 2017). Nevertheless, a strategic shift is required to achieve a successful transformation (Oztemel & Gursev, 2020). By supporting decentralised and autonomous behaviour, the integration of new digitalised processes facilitates the development of highly customised manufacturing systems (Koh et al., 2019). Consequently, supply chains are reconfigured to efficiently address customer demand, while products are tailored to satisfy individual customer needs (Rad et al., 2022).

2.1.1. Enabling technologies for supply chain management 4.0

I4.0 introduces a smart factory paradigm, where machines, products, and technologies can collaborate with minimum human intervention (Manocha et al., 2020; Oztemel & Gursev, 2020).

Smart manufacturing evolves synchronisation and real-time access to information across the entire supply chain (Núñez-Merino et al., 2022). These smart factories are characterised by organisational structures and operational procedures that continuously gather and exchange data from interconnected machinery and production systems (Chen et al., 2018). In this context, cyber-physical systems (CPSs) play a major role in smart factories (Ivanov et al., 2018; Wang et al., 2016).

CPSs integrate the physical and virtual worlds, providing essential support for traceability, monitoring, collaboration, and efficiency (Ghobakhloo, 2018; Hofmann & Rüsch, 2017). Through these CPSs, the smart factory can act, communicate, and trigger responses (Berger et al., 2016; Kamble et al., 2018a). By analysing and understanding production needs and requirements, decentralised control systems can optimise production (Tjahjono et al., 2017; Xu et al., 2018). Furthermore, I4.0 makes integration possible by allowing data management, tracking, communication, and access throughout the supply chain (Rad et al., 2022). It also enables real-time monitoring of products (Núñez-Merino et al., 2022).

As they evolve, supply chain 4.0 become global platforms integrating multiple human and process insights (Manocha et al., 2020). This facilitates collaboration and increases trust among supply chain actors (Tjahjono et al., 2017). Improving communication also encourages flexibility, which helps to eliminate obstacles (de Paula Ferreira et al., 2020). Automation and data management are driving I4.0, promoting decentralised and more informed decision-making (Núñez-Merino et al., 2022). Consequently, supply chains become endowed with characteristics that enhance their flexibility (Piccarozzi et al., 2018). Thus, supply chain 4.0 demonstrate increased agility (Braglia et al., 2020).

Table 1 summarises the key technologies and the benefits that they may bring to supply chains.

Technology	Description	Benefits to SCs	References
Augmented Reality	A set of technologies that integrates the digital and physical worlds, ensuring precise matching between digital dimension and what the user is tracking. The objective is to provide users with advanced information about their reality, whether it is a physical store or an item. An enhanced version of reality through data.	Collaboration | Efficiency | Customer service | Integration	(Berryman, 2012; Braglia et al., 2020; de Paula Ferreira et al., 2020; Ghobakhloo, 2018; Kamarul Bahrin et al., 2016; Kamble et al., 2018a; Oztemel & Gursev, 2020; Rad et al., 2022)
Additive Manufacturing (3D printing)	By combining the materials layer by layer, additive manufacturing is a combination of technologies that can be used to produce 3D objects.	Customisation | Improved environmental performance | Reduced inventory costs | Integration	(Ghobakhloo, 2018; Kamarul Bahrin et al., 2016; Kamble et al., 2018a; Koh et al., 2019; Rad et al., 2022; Spieske & Birkel, 2021)

Technology	Description	Benefits to SCs	References
Big Data Analytics	Big data technologies can be used to analyse and manage vast amounts of data across the supply chain. These technologies support real-time data collection from a variety of sources while generating added value.	Transparency | Informed decision-making | Cost reduction | Reliability	(Braglia et al., 2020; Ghobakhloo, 2018; Kamble et al., 2018a; Koh et al., 2019; Oztemel & Gursev, 2020; Rad et al., 2022; Spieske & Birkel, 2021)
Blockchain	Blockchain technology uses shared data infrastructure that is updated in real-time, resulting in a traceable record of every stage in a product's journey through the SC. Every transaction is completely auditable, ensuring data security and immutability.	Integration | Traceability | Transparency | Data security | Increased visibility	(Agrawal et al., 2021; Ghobakhloo, 2018; Qader et al., 2022; Queiroz & Fosso Wamba, 2019; Rad et al., 2022; Spieske & Birkel, 2021; Wang et al., 2020; Wang et al., 2019

Technology	Description	Benefits to SCs	References
Cloud Computing	This technology provides reliable solutions for managing large volumes of data. It supports the storage of shared data through web-based applications.	Scalability | Flexibility | Improved flow of information	(Braglia et al., 2020; Lee et al., 2015; Ghobakhloo, 2018; Kamble et al., 2018a; Koh et al., 2019; Oztemel & Gursev, 2020; Rad et al., 2022; Spieske & Birkel, 2021; Xu et al., 2018)
Cyber-physical systems	CPSs connect the virtual world and real-time physical processes. A network of interconnected systems that can communicate and store data.	Integration | Coordination | Flexibility | Real-time information	(Berger et al., 2016; Ghobakhloo, 2018; Lu, 2017; Oztemel & Gursev, 2020; Spieske & Birkel, 2021; Xu et al., 2018)

Technology	Description	Benefits to SCs	References
Internet of Things	This refers to a network of physical devices embedded with technologies and software to manage and exchange data. It incorporates cross-functional capabilities, including intelligent machines, advanced predictive analytics, and human-machine collaboration.	Efficiency | Integration | Collaboration | Flexibility	(Braglia et al., 2020; Ghobakhloo, 2018; Kamarul Bahrin et al., 2016; Kamble et al., 2018a; Koh et al., 2019; Lu, 2017; Oztemel & Gursev, 2020; Qader et al., 2022; Rad et al., 2022; Spieske & Birkel, 2021; Xu et al., 2018)
Robotics	Robots are being developed to safely interact with and learn from people and to stimulate and display human behaviour.	Autonomy | Flexibility | Cooperation | Reduced inventory costs | Productivity	(Ghobakhloo, 2018; Kamarul Bahrin et al., 2016; Kamble et al., 2018a; Koh et al., 2019; Oztemel & Gursev, 2020; Rad et al., 2022)

Technology	Description	Benefits to SCs	References
Simulation	This technology enables the creation of actual scenarios or scenarios that are likely to occur. It makes it possible to analyse and anticipate the impact that certain outcomes or future changes may have on typical operational processes.	Prevents errors | Evaluation of potential outcomes | Productivity	(Braglia et al., 2020; Ghobakhloo, 2018; Kamarul Bahrin et al., 2016; Kamble et al., 2018a; Oztemel & Gursev, 2020; Rad et al., 2022)

Table 1 - Technologies 4.0

2.1.2. Barriers to the implementation of Supply Chain 4.0

The vast majority of organisations must face the fact that their current infrastructure lacks the capability or capacity to support the digital transformation required by these new technologies (Lu, 2017). However, only the largest companies with extensive resources can afford this technological support (Raj et al, 2020). This is mainly due to high initial costs, uncertain short-term benefits, and concerns about profitability are among the most prominent problems (Müller et al., 2018).

To optimise processes, organisations must adjust their organisational structures to promote flexibility and enable the seamless flow of information (Buer et al., 2018). Through data analysis and integrated systems, massive amounts of real-time data will be generated (Xu et al, 2018). Nonetheless, the increasing integration also highlights the unanimous concern about the threats of information sharing, as it exposes organisations (Kamble et al., 2018b; Müller et al., 2018).

Ensuring data quality poses a challenge when dealing with huge amounts of data, as data can be accessed quickly and collected from multiple sources (Kiel et al., 2017). This may be closely related to the lack of knowledge and employee readiness (Manocha et al., 2020). New job profiles are essential to handle these technologies (Buer et al., 2018). Consequently, the demand for increased skills in Supply Chain 4.0 may lead to the disappearance of existing jobs (Benešová & Tupa, 2017). Thus, the value of manual labour decreases, whereas the value of IT skills rises (Müller et al., 2018).

Top management must develop an organisational culture that promotes innovation and provide appropriate training and education (Horváth & Szabó, 2019). Additionally, organisations need to establish strategic goals, prioritise initiatives, and allocate resources according to the requirements of integrated value creation (Kamble et al., 2018b). This must facilitate the development of strong vertical and horizontal relationships throughout the supply chain (Kiel et al., 2017).

Table 2 provides an overview of the major obstacles to the adoption of I4.0 technology.

Barrier(s)	Description	Author(s)
Challenges in Ensuring Data Quality	The interconnectivity fostered by I4.0 increases the amount of data available and the flow of information, which means that data can change across the supply chain. Thus, ensuring the consistency and accuracy of information can be challenging.	(Buer et al., 2018; Kamble et al., 2018b; Kiel et al., 2017; Lu, 2017; Raj et al., 2020)
Disruption of existing jobs	These new technologies have the potential to affect certain jobs. As technology adoption advances, it is expected to gradually replace more predictable, automated, and routine tasks.	(Benešová & Tupa, 2017; Buer et al., 2018; Horváth & Szabó, 2019; Kamble et al., 2018b; Müller et al., 2018; Raj et al., 2020; Roblek et al., 2016)
High implementation costs	Most organisations need to make substantial investments in technological equipment and infrastructure to effectively develop and use this type of technology. However, only a limited number of companies are prepared to invest the necessary financial resources.	(Buer et al., 2018; Horváth & Szabó, 2019; Kamble et al., 2018b; Kiel et al., 2017; Müller et al., 2018; Raj et al., 2020)

Barrier(s)	Description	Author(s)
Lack of digital skills	Employees may question the fundamental principles of I4.0 due to a general lack of understanding and knowledge within the organisation. These emerging technologies require employees to acquire new skills. Consequently, the qualifications required to fill the same position will necessarily evolve.	(Benešová & Tupa, 2017; Buer et al., 2018; Horváth & Szabó, 2019; Kamble et al., 2018b; Kiel et al., 2017; Manocha et al., 2020; Müller et al., 2018)
Lack of infrastructure	Organisations need reliable technology infrastructures to ease communication among SC players. Nevertheless, most organisations lack the necessary resources to meet these requirements.	(Kamble et al., 2018b; Lu, 2017; Müller et al., 2018; Raj et al., 2020; Xu et al., 2018)
Lack of internal digital culture and training	The spirit and culture of innovation, creativity and research should be encouraged from the top of the pyramid to the bottom.	(Horváth & Szabó, 2019; Kiel et al., 2017; Manocha et al., 2020; Müller et al., 2018; Raj et al., 2020)
Organizational and process changes	The involvement of lower levels within the organisations in the decision-making process will become more significant, leading to a shift towards decentralised decision-making.	(Horváth & Szabó, 2019; Kamble et al., 2018b; Monostori et al., 2016; Müller et al., 2018; Raj et al., 2020)

Barrier(s)	Description	Author(s)
Privacy and security issues	The frequency of cyber-attacks has increased, posing a serious challenge to organisations in terms of data protection and security. The interconnectivity between actors in the supply chain has led organisations to reinforce their security and prevention measures.	(Buer et al., 2018; Kamble et al., 2018b; Kiel et al., 2017; Lu, 2017; Manocha et al., 2020; Müller et al., 2018; Pereira et al., 2017; Raj et al., 2020; Roblek et al., 2016)
Value-chain integration and compatibility	These new systems need to manage, process, and produce value for the various levels of management. Ensuring the integration, interoperability, and optimisation of multiple systems and technologies is crucial.	(Buer et al., 2018; Kamble et al., 2018b; Kiel et al., 2017; Lu, 2017; Müller et al., 2018; Raj et al., 2020; Thames & Schaefer, 2016)

Table 2 - Barriers to the adoption of technologies 4.0

2.2. Relationship between supply chain visibility and Sustainability

The foundation of Supply Chain 4.0 involves integration, interconnectivity, visibility, and traceability based on real-time information which fosters the integration between lower-tier suppliers and customers (Dubey et al., 2020). SC integration enables organisations to immediately gather and manage real-time information by communicating with all the relevant SC partners for improved decision-making (Messina et al., 2022; Rad et al., 2022) while improving the traceability and transparency of the processes (Kalaiarasan et al., 2022). By promoting information sharing within the supply chain, visibility improves supply chain resilience (Núñez-Merino et al., 2022). Moreover, to understand supply chain disruptions, supply chain visibility is also crucial (Somapa et al., 2018; Xu et al., 2020). SC disruptions can be minimised, and control actions may be established with the help of visibility into supply and demand, inventory level, and consumer feedback (Spieske & Birkel, 2021).

Visibility is the ability of the supply chain partners to access the right data at the right time and place (Qader et al., 2022). This ability of supply chain partners to access and exchange accurate, pertinent, and relevant information when required is known as supply chain visibility (Messina et al., 2022). And the ease and frequency of partners' access to this data can be assessed by supply chain visibility (Kalaiarasan et al., 2022). Just as importantly, information must be delivered in a suitable format to meet organisational needs and deliver value (Caridi et al., 2010). Furthermore, learning and sharing knowledge is possible due to supply chain visibility (Somapa et al., 2018). SC partners can access and exchange data that has been collected over time, as well as, real-time data, and future trends (Spieske & Birkel, 2021).

Information technologies are combined to develop value-added networks that improve integration and inter-organisational communication throughout the supply chain (Brusset, 2016). Tracking and tracing systems enable decision-makers to detect deviations or potential deviations, as well as their potential causes and impacts (Ivanov & Dolgui, 2020). These systems can be more prepared for contingency scenarios through the collection of data across the whole SC (Braglia et al., 2020). Supply chain visibility is intended to improve agility and flexibility (Kalaiarasan et al., 2022). Cyber-physical systems bridge the virtual space with the physical reality (Berger et al., 2016). Big data offers the opportunity to gain a competitive advantage through improved visibility, real-time capacity adjustments in response to demand

changes, and insights into customer behaviours and patterns (Zhong et al., 2016). A cloud computing infrastructure can store and process a vast amount of data (Xu et al., 2018). This type of knowledge-based risk communication can offer a reliable method for achieving visibility of supply chain ruptures (Cao et al., 2020). By enabling information pipeline systems, blockchain technology can further expand traceability and tracing systems (Ivanov et al., 2018). Quality and reliability of product information are growing concerns for consumers (Roblek et al., 2016). Consumer confidence will be based on information regarding the different origins, characteristics, and environmental impacts of products (Wang et al., 2019). In addition, consumers will be able to track goods throughout the supply chain, supporting product authenticity and legitimacy (Agrawal et al., 2021). All transactions in a blockchain supply chain are identifiable by all players, making any unethical or corrupt behaviour obvious (Queiroz & Fosso Wamba, 2019). These factors have put industries under enormous pressure to adopt and develop more sustainable practices (Agrawal et al., 2021).

The development of sustainability in three dimensions — economic, environmental, and social — has been a challenge for supply chains (Saqib & Zhang, 2021). Organisations are expected to aim to achieve in all three dimensions simultaneously (Müller et al., 2018). Nevertheless, a holistic approach is needed, as the different objectives may be interrelated (Suh & Lee, 2018). Sustainability must be integrated throughout an organisation's strategy (Majumdar & Sinha, 2019). Industry 4.0, driven by digitalisation and smart manufacturing, can reduce production waste and costs, irrelevant material flow, carbon emissions, and energy consumption (Wang et al., 2020). New job requirements are expected to arise, demanding further education and training (Horváth & Szabó, 2019). Fair wage assessments and employee motivation are also necessary for companies to preserve and improve human and social resources (Ghobakhloo, 2018; Kiel et al., 2017).

The use of technology can help organisations move towards sustainable development (Koh et al., 2019). Establishing safe and flexible working conditions (Müller et al., 2018). Through integration and collaboration, intelligent production units optimise the allocation of resources and energy (Kamble et al., 2018b). Supporting the development of green supply chains. Further, organisations can achieve increased efficiency (Ghobakhloo, 2018; Rad et al., 2022). Organisations reduce unnecessary costs and improve system reliability for fewer defects (Kalaiarasan et al., 2022). Smart materials and products can independently monitor and manage crucial process variables, as well as quality nonconformities (Núñez-Merino et

al., 2022). Wrong deliveries, damaged goods and lead times can be reduced (Dubey et al., 2020). Therefore, by preventing excessive transportation, carbon emissions can be minimised (Wang et al., 2020). Product lifecycle management is enhanced by easy access to real-time product data (Müller et al., 2018). Reduced inventory levels are also possible due to new production methods such as additive manufacturing, which operates on the pull principle (Kamble et al., 2018a). Demand orientation and process transparency allow smart scheduling of tasks and processes that promotes flexibility, innovation, and customised products (Oztemel & Gursev, 2020). Increased customer satisfaction (Kiel et al., 2017).

2.3. Textile and Apparel Industry

The Textile and Apparel (T&A) sector has witnessed a geographical shift towards developing countries, due to competitive labour costs and favourable government policies (Warasthe et al., 2022). Also, it operates as a global hub for sourcing and low-cost apparel production (Choi & Cai, 2020). This complexity makes it difficult to trace and ensure the origin of raw materials and the authenticity of the product (Agrawal et al., 2021). Visibility is an important factor in efficiently managing the challenges associated with sustainability goals in global fashion supply chains (Saqib & Zhang, 2021). Sustainability challenges arise from often weak environmental regulations and unfavourable working conditions (Warasthe et al., 2022). Low wages, forced labour, unsafe working conditions and child labour are all problems that affect employees in developing countries (Nayak et al., 2019). To protect the environment and promote a greener fashion industry, efforts should be made in the apparel supply chain (Jia et al., 2020).

The T&A industry is defined by an extensive selection of materials and goods, intensifying competitiveness, low-profit margins, increased environmental concerns, and counterfeit products (Agrawal et al., 2021; Majumdar & Sinha, 2019). Fashion supply chains are significantly influenced by variable customer demand (Braglia et al., 2020). Moreover, fast fashion has led to a high frequency of impulsive purchases, short product life cycles and high consumption of large amounts of resources and energy (Cai & Choi, 2020). Leading to a huge environmental burden due to high levels of waste and pollution, raising controversy over the sustainability of these supply chains (Jia et al., 2020). Thus, these supply chains are characterised by labour-intensive production, global and complex value chains, multiple partners, and high environmental impact (Kumar et al., 2017).

Evaluating and selecting suppliers is essential to improving environmental risk performance (Saeed & Kersten, 2017). Fashion companies are striving to discover the best techniques for eco-friendly production, renewable energy, and ethical labour practices (Nayak et al., 2019). Reusing and recycling textile waste can save energy and reduce environmental impact (Bukhari et al., 2018). Carbon emissions can be reduced through energy efficiency measures and by reducing clothing usage (Warasthe et al., 2022). Fashion companies need to raise public awareness of sustainable clothing consumption and environmentally friendly procedures (Cai & Choi, 2020). Industry 4.0 emphasises process remanufacturing through

the adoption of information and communication technologies. Innovative technology has the potential to improve both profitability and the environment (Braglia et al., 2020). Moreover, governments should seek to balance the objectives of stakeholders and legislators (Majumdar & Sinha, 2019).

3. Methodology

As mentioned above, the purpose of this study is to investigate how the implementation of technologies contributes to the development of sustainable and resilient supply chains. This seeks to understand the role of increased visibility in supply chains through the adoption of digital technologies.

The choice of research depends essentially on the nature of the research question, the proposed objectives and the focus on a contemporary phenomenon in its real-life context (Yin, 2014). Accordingly, a case study is the best method to achieve the proposed objective. Thus, a multiple case study was carried out in two companies, referred to in this case as A and B, to gain a deeper understanding and knowledge of the impact of implementing technologies along supply chains.

Qualitative research differs from quantitative research based on a very different set of philosophical beliefs. Qualitative research is considered exploratory and inductive, as it allows you to gather detailed and subjective insights from research participants (Yin, 2014). The case study approach allows in-depth, multidisciplinary analyses of complex issues in real-life contexts, providing a holistic view of the companies' experiences of the process of digitalisation. Also, it is particularly useful when there is a need to understand and describe the causal relationships resulting from new processes or developments (Eisenhardt, 1989).

In this case, the textile sector will serve as the specific context that will allow for the exploration and description of causal relationships resulting from the implementation of the I4.0 concept. The goal is to reflect on the subject from different perspectives, to capture multiple points of view, to obtain a comprehensive analysis of the phenomenon and to draw more reliable conclusions (Rowley, 2002). The case study is considered to be a very useful method for developing new theories, from lean production to manufacturing strategy (Voss et al., 2002). Consequently, this study adopts the case study approach, using interviews to gather detailed information about the experiences and perspectives of the interviewees.

3.1. Case Selection

Yin (2014) suggests careful analysis when selecting cases, as they should be aligned with the objectives of the research question to generate significant insights and valuable findings that help to understand the topic under study.

This case study is based on two companies in the textile and clothing sector in Portugal that have recently embarked on a digital transformation process. Hence the choice of an approach that allows for a more in-depth analysis of the strategies, challenges and results of the technological advances in the sector.

Two large companies involved in the STVgoDigital - Digitisation of the Value Chain project have been selected as case studies. Company A has a strong reputation for its commitment to sustainability and innovation. On the other hand, company B is part of a group with a strong international presence. Both companies are undergoing a process of digital transformation and are committed to researching innovative solutions and investing in sustainable practices, pushing the boundaries of technological progress in the textile sector to help drive positive change and accelerate the global adoption of sustainable and innovative approaches in the sector.

The technology-based solutions were developed based on a previous diagnosis, and the aim of this study is also to understand the evolution of this process, identify best practices and capture lessons learned.

3.2. Data Collection

The information for this study was obtained through interviews with elite informants from companies A and B, which operate in the textile and clothing sector in Portugal (focal companies). The primary source of data was semi-structured interviews, which encouraged the sharing of experiences and the discussion of views on opportunities for improvement (Jacob & Furgerson, 2012). These semi-structured interviews were conducted with participants involved in the digitalisation process in both companies. From the first interview, it was possible to gather information from two interviewees with different but complementary areas of activity, such as sustainability and operations.

Interviews have several advantages compared to questionnaires or narratives. Typically, telephone interviews and questionnaires are less detailed (Harvey, 2011). What makes interviews particularly valuable is their ability to provide flexible and personalised communication. Especially if the interviews are open or semi-structured, as the interviewer can explore new concepts and discuss opinions, attitudes and experiences (Hyett et al., 2014). Additionally, it is important to recognise that non-measurable observations, such as tone of voice, hesitation or facial expressions, can add value to the gathered information. Thus, in May 2023, two interviews were conducted in two different companies with the following actors. The conducted interviews are summarised in Table 3.

CODE	ACTOR	DURATION	DATE
A1	Sustainability Manager	58min	05/05/2023
A2	Director of Operations	58min	05/05/2023
B1	Project Manager	30min	31/05/2023

Table 3 - Case study interviewees

3.3. Data Analysis

The interview protocol was developed based on the literature review and aimed to explore the relationship between technology adoption and sustainable supply chains. If relevant information was not initially provided, some questions were rephrased and asked again to check and confirm the quality of the interview. There was also concern about the right choice of words when discussing social sustainability and adequate working conditions. To develop an in-depth understanding of the case, the case study approach usually involves collecting multiple sources of evidence (Voss et al., 2002). In addition to personal interviews, data was collected through secondary sources, such as articles and deliverables from the STVgoDigital project and corporate documents to derive meaningful insights and patterns from the data.

These sources were used simultaneously to foster the triangulation process and to support the findings, seeking convergence of views and ensuring the reliability and validity of the research (Eisenhardt, 1989). As can be seen in Annexes A, the interview protocol also included a consent form, which inquired about the use of the collected information for research purposes, the disclosure of the interviewee's and organisation's identities, and the recording of the interviews.

To ease the analysis process, the interviews were transcribed into Word files. The first step was to manage and analyse all the information to identify the main contributions, where concepts began to emerge by looking for similar patterns. Thus, the content was divided into three main themes, namely: supply chain management, barriers to technology adoption and the relationship between supply chain visibility and sustainability. Subsequently, the different variables were cross-checked with the literature.

4. Results and Discussion

The project, in which the two companies in the study are integrated, aims to promote the transition to a new paradigm of Industry 4.0. This transition involves the implementation of technologies to increase productivity, resource efficiency and flexibility in production. The main objective of this digital transformation process is to increase transparency, visibility and agility throughout the value chain.

As both companies are at identical stages of the process, it is an opportunity to reflect on theory in terms of validity in similar events but within different contexts. Additionally, it also allows them to gain a deeper understanding of the paradigm shift they are going through, analyse patterns between concepts and between data, identify relationships, and suggest directions for future research.

The greater the number of case studies that show replication of findings, the greater the rigour and evidence for the theory (Rowley, 2002). Nonetheless, the two case studies provided valuable and interesting insights and contributed to a deeper understanding of the research topic.

The first company (Company A), selected to undergo a detailed analysis to provide a comprehensive understanding of the industry, is a family business with 50 years of experience in the fashion textile sector. It manufactures men's and women's clothing, exports ready-to-wear textile products to global brands and provides end-to-end services for the production of high-quality textiles and clothing. They focus on customised and innovative products through a core of long-term selected suppliers, sustainable policies, investment in technology development, and multidisciplinary teams.

The second company (Company B) has more than 50 years of experience in the textile sector and exports about 80% of its production, mainly to Europe. It is part of a set of complementary organisations integrated into a larger group, which allows it to offer a wider and more complementary range of home textile products. They invest in the specialisation and differentiation of their products, but also in the internationalisation of their brand, operating with their structure in Spain and Germany, as well as commercial delegations in the rest of Europe, ready to respond with quality and fast service. Table 4 gives a summary of the main characteristics of companies A and B.

	Company A	Company B
Number of employees	201-500	501-1000
Years of operation	>50	>50
Activity sector	Textile (exports ready-made products worldwide)	Textile (exports ready-made products worldwide)

Table 4 - Characteristics of Companies A and B

4.1. Supply chain management 4.0

Industry 4.0 and digital transformation are closely related, as Industry 4.0 represents a paradigm shift in the manufacturing sector through the integration of digital technologies, interconnectivity, and automation, reshaping how organisations operate and innovate (Qader et al., 2022). On the other hand, digital transformation involves combining digital tools, technologies and strategies that support greater integration, closer relationships and transparent information flow between the organisation, its suppliers, customers and employees. By leveraging these digital resources, organisations can strengthen collaboration, optimise processes, and promotes the efficient exchange of information (Núñez-Merino et al., 2022). Moreover, the cases examined suggest that the adoption of the technologies highlighted in the existing literature is still largely at an early stage. Nevertheless, there has been notable progress as these companies have allocated resources to integrating new technologies into their operations. Importantly, they have also shown a strong interest in investing in the systems used by their principal supply chain partners. Today, technology can easily replace unproductive and low-value-added tasks. The human effort required to load data onto platforms is no longer feasible.

The textile sector is characterised by intensive use of labour, lack of technology and rising costs. This has raised some concerns about its competitiveness, especially given how challenging it is to use technology. There is undoubtedly an interest in automating the most repetitive and routine activities because of the volume of production. Nevertheless, the idea of fully automating the process may be utopian.

"We have some automated phases, and sure, we have equipment with some programming. However, the majority of it is labour" (Director of Operations, A2).

Digital transformation is not a destination, but an ongoing process that brings together people, digital technologies and processes, all with the overarching goal of delivering greater value to stakeholders. In the past, software systems tended to be more closed and organisations had a conservative philosophy regarding technology adoption. Notwithstanding, as an ongoing process, it requires an action plan. It is a process that involves a mindset shift and requires organisations to adapt processes and adopt new ways of working that are aligned with the capabilities and opportunities provided by digital technologies (Rad et al., 2022). The cases illustrate that the transition often starts with

leadership and management acknowledging the importance of embracing innovation and actively supporting its acceptance throughout the organisation.

"The organisation's culture is where this transition starts. It will be a top-down process as companies embrace this culture" (Director of Operations, A2).

The introduction of highly flexible production and the ability to offer mass-customised solutions strengthens the innovative spirit within the organisation. This combination encourages organisations to achieve higher levels of personalisation through leveraging data to gain a deeper understanding of customer preferences and behaviours. Therefore, organisations can quickly adapt to changing market demands and provide customers with tailored solutions and experiences. Furthermore, this symbiotic relationship enables closer relationships to be established with customers, as organisations can respond to unique customer needs and provide customised products and services that were previously unavailable.

By leveraging data-driven insights, organisations can carry out analysis and gain a comprehensive understanding of their production requirements. It is also important to have a better knowledge of the needs of each partner, to reduce material flows and avoid unnecessary costs. Similarly, in the fashion industry, it can mean less waste. This provides opportunities to optimise production volumes and improved demand forecasting, which has a direct impact on optimising inventory levels, leading to cost savings and enhanced operational efficiency (Ivanov et al., 2018). It is important to have a continuous assessment, monitoring and search for relevant indicators. The organisation needs to proactively bring new data into the system to effectively integrate information and make informed decisions.

"We need to feed new data into the system because we are always looking for new indicators" (Director of Operations, A2).

The cases show that organisations are continually seeking and recognising the benefits of incorporating new relevant data into all areas of supply chain management, from research and development to distribution, to improve their ability to understand and make decisions. Thus, organisations can improve their ability to respond to market demands and trends, optimise resource allocation, and have the flexibility to diversify their range of product offerings.

4.2. Barriers to the implementation of Industry 4.0

Industry 4.0 holds significant opportunities for organisations to create value by integrating emerging technologies into their manufacturing and processes. However, organisations must overcome numerous challenges to effectively manage this digital transformation.

To undergo digital transformation, organisations need to allocate resources to develop a technical infrastructure that can effectively accommodate emerging technologies and facilitate the seamless exchange of large volumes of data between multiple actors within the supply chain. This investment requirement represents a significant challenge (Kamble et al., 2018b).

"We are investing in something that will make us more efficient. In the medium term, we recover that investment through a major impact on the organisation" (Director of Operations, A2).

While the initial costs are substantial, future cost savings, process optimisations, and additional revenue growth streams can surpass those expenditures in the long run. It is of utmost importance to perceive Industry 4.0 as a strategic investment that can drive sustainable business growth, and strategic differentiation, enhance competitive advantage and foster innovation in the digital era. In particular, those in strategic roles within the business, need to see the value of digital transformation as an asset.

Although the volume, velocity, and variety of accessible data and information flows have increased significantly as interconnectivity is encouraged, the cases indicate that challenges still exist in fully achieving a seamless integration of technologies across the supply chain. Thus, organisations must analyse the data to ensure its consistency, relevance, and value for extracting meaningful insights (Raj et al., 2020).

"Data incompatibility exists mostly because different companies label the same raw material differently" (Manager, B1).

Gathering, analysing and sharing data in real-time enables well-informed decisions. The seamless flow of information facilitates improved collaboration, transparency, and real-time communication between the various players in the supply chain ecosystem. But gathering data from a variety of sources raises issues around cybersecurity, data protection and the extent to which data can be integrated (Agrawal et al., 2021). Furthermore, the information

flowing through the chain needs to be normalised so that a relationship can be established between what is required and what is requested, as well as, the systems through which this data flows. The cases reveal that each participant has been operating independently and developing their system, which can lead to fragmentation and become very time-consuming. Whereas sharing information is important for customers and suppliers, it is highly dependent on the needs and perspectives of each player.

The literature suggests the need to adopt a common strategy for addressing employee qualification and acceptance obstacles. Organisations are facing a shortage of professionals with the specialised skills and expertise to manage and use cutting-edge technologies, including for the textile industry. This shortage poses a significant concern and constraint for the current needs, particularly small and medium-sized enterprises within the sector (Kumar et al., 2017). The extent of technology adoption and digital literacy depends on the scale of each supplier as their systems or software may be more or less robust, sophisticated, and developed. Consequently, there is a pressing demand for a workforce with a wider range of technological knowledge.

"It is also up to us to promote this training and this personal development" (Director of Operations, A2).

The greatest associated difficulty has been with human resources, as people have shown resistance to change. People must feel that they are an integral part of the organisation and possess the right motivation to engage in a process of continuous learning and development. Accordingly, organisations have an important role to play in promoting this transformation, as they need to effectively communicate the reasons behind the necessity for innovation and persuade their employees to embrace it. When this does not happen, barriers can arise because people feel unprepared or lack motivation. Hence, it is important to invest in the training of workers and to address issues such as upskilling and reskilling (Müller et al., 2018).

4.3. The role of supply chain visibility in Sustainability

Supply chain visibility relies on transparency to improve communication both upstream and downstream (Roy, 2021). While upstream communication involves the flow of information between suppliers and the organisation, downstream communication concerns the flow of information between the organisation and its customers. Consequently, through leveraging data-driven insights, organisations have the potential to achieve end-to-end visibility. This provides easy and timely access to the location and condition of goods and materials throughout the supply chain. As a result, greater visibility leads to better collaboration and helps to manage risk more effectively.

Organisations can quickly act and make adjustments that are needed to mitigate risks and take advantage of opportunities by timely detecting possible dangers, deviations, and changes in demand patterns due to transparent information flow (Cao et al., 2020). By analysing and understanding production needs and requirements, organisations can more effectively align production with demand and optimise inventory management. This allows production schedules and stock levels to be adjusted quickly to meet fluctuating demand.

Both suppliers and customers are already asking for the production elements, seeking open communication and process transparency. Sharing is important for customers and suppliers to build trust and promote collaboration, and effective communication between supply chain partners. However, it is important to comprehend that the exchange of information may vary between actors, as each party has different needs and levels of access to information.

The cases highlight that as supply chains become more complex, it is not always easy for an organisation to exchange information with lower-tier suppliers, or even to influence them to make changes to improve transparency.

> *"We buy one tonne of cotton, with an origin that has to be traced. This can result in garments for five different customers and products" (Sustainability Manager, A1).*

In terms of market visibility, this is particularly important for identifying new consumption patterns and trends. Consumers are becoming more interested in the transparency and sustainability practices of their suppliers before making a purchase and are requesting more specific details regarding supply chains. Especially, younger generations, are increasingly

aware of and concerned about the sustainability of the products they purchase. They want to understand the entire journey of a product, including the origin of the raw materials, the environmental impact, the manufacturing processes and the places that are involved in the production of the product. Accordingly, they also seek information on the origin of products, their environmental impact and their authenticity.

"Can be very important, namely, at the level of changing consumer behaviour, as it directly impacts the choice of raw materials" (Sustainability Manager, A1).

Additionally, consumers want assurances that human rights are respected throughout the supply chain, including the fundamental right to fair wages (Brun et al., 2020). The textile industry in general has been much scrutinised on social sustainability issues, particularly in the light of fast fashion. Regular supply chain audits are therefore essential to ensure compliance with these standards. Requirements such as safety, promoting a motivated workforce or encouraging training are beginning to be taken into account when selecting suppliers. Growing environmental awareness, ethical considerations and the search for sustainable alternatives are driving consumer behaviour. It also emphasises the importance of transparency and trust between suppliers, the organisation and customers.

The digital textile passport will have information on the environmental impact and a description of the different stages of the product. Building trust to share huge amounts of data and ensuring transparency of processes will be key drivers in meeting the requirements of brands and European legislation regarding traceability and environmental information.

Digital transformation enables end-to-end traceability and transparency within the supply chain, as organisations can track and record all transactions and movements of goods, from raw materials to finished products. This increases transparency, reduces counterfeits and enhances regulatory conformity.

"The process of digitalisation is crucial for us to be able to track all the environmental steps of a raw material or good" (Sustainability Manager, A1).

By driving initiatives that address sustainability challenges, organisations that exploit the benefits of supply chain visibility can create greater value for customers and the environment.

5. Conclusions

This study investigates how the adoption of digital technologies contributes to the development of sustainable supply chains. In particular, it shows that visibility plays a crucial role in this relationship. Organisations should strive to comprehensively integrate the flow of information, processes and materials between their suppliers and customers, meaning that access to information should be equally easy and timely both upstream and downstream should be equally easy and timely. Accordingly, SCV can anticipate market changes, manage SC relationships and achieve a common view across the supply chain.

Nonetheless, the research also shows that by leveraging digital technologies, organisations can exchange information in real time with supply chain partners, driving highly flexible manufacturing systems and resource efficiency, which requires greater transparency and process integration. The combination of flexible production and mass customisation encourages continuous innovation and enables a level of customisation that meets customers' needs. The consumer experience is enhanced, as is brand loyalty.

Top management should ensure that the implementation of Industry 4.0 concepts is aligned with the organisation's strategic direction, as well as promoting training and personal development. Organisations are seeking to transform their relationships into long-term partnerships. Assessing and monitoring suppliers based on their environmental performance is key to reducing environmental impact, addressing environmental challenges and promoting more sustainable practices in the textile sector. This is a sector that is particularly exposed to sustainability scrutiny, and the challenge is to improve performance along the triple bottom line. Hence, this digital transformation goes hand-in-hand with the concept of Industry 4.0, reflecting a strategic approach that emphasises trust and collaboration as key principles for a more agile, resilient and competitive supply chain. Trust is emerging as an essential concept, given the volume and relevance of the data required.

5.1. Theoretical and Practical Implications

The study contributes to the discussion on how the implementation of I4.0 technologies impacts supply chain management. It sheds light on how this digitalisation process influences the characteristics of Supply Chain 4.0, which facilitates the identification of the broader benefits of adopting these technologies for the supply chain. Nevertheless, these opportunities can only be realised if the associated challenges are addressed and accepted. These barriers have also been identified.

In the textile sector, companies actively strive to identify best practices by converging green manufacturing, environmentally friendly materials, ethical labour practices and the use of renewable energy. The application of blockchain technology, albeit little explored, has been identified as a possible solution to respond to the current challenges of traceability by ensuring the integrity, and reliability of data and traceability of processes throughout the supply chain. Given its characteristics, it may emerge as an innovative means of improving traceability and transparency in supply chains. Furthermore, the concept of a digital passport is starting to emerge in response to European Union requirements for access to reliable information on the sustainability of textile products. This is a measure that will allow consumers to know under what conditions and with what materials their product was manufactured. It also establishes criteria for extending the life of textile products and reducing their environmental impact.

5.2. Limitations and Future Research

Notwithstanding the valuable contributions and insights, this study has some limitations that may suggest avenues for future research. The adoption of a limited number of case studies limits the broader contributions that can be made from the findings. This intrinsic characteristic of the methodology often attracts criticism regarding the lack of generalisability and objectivity of the results. Therefore, future research can adopt approaches to improve the reliability of the study.

First, expanding the case study to include other companies within the sector would increase the representativeness and diversity of the research. Consequently, conducting further interviews with different actors in the supply chain. This approach would have provided meaningful insights into the perspectives and opinions of actors at lower stages of the supply chain. Additionally, it would certainly be valuable to include other industries in the analysis, although the textile sector is highly relevant due to the challenges it has faced.

Alternatively, there is growing literature on human centricity and the importance of keeping people at the centre of organisations and decision-making, as well as on the emerging concept of Industry 5.0.

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Annexes A

Guião da Entrevista

Mestrado em Gestão (MiM) FEP 2022/2023

Pedro Guedes up202100971

The impact of digital technologies on the development of sustainable supply chains: the role of visibility

Considerações Éticas

Esta entrevista é realizada no âmbito da tese – "The impact of digital technologies on the development of sustainable supply chains: the role of visibility" do Mestrado em Gestão da Faculdade de Economia da Universidade do Porto. O tema desta dissertação pretende explorar de que forma a adoção de tecnologias digitais capacita as cadeias de abastecimento de ferramentas e processos, que permite torná-las mais resilientes e sustentáveis. Para este efeito está a ser desenvolvido um caso de estudo sobre o setor têxtil, em Portugal. No sentido de obter informação de suporte à literatura estão a ser desenvolvidas entrevistas como um dos elementos de recolha de dados principal.

Todo o processo da entrevista é confidencial, assim como a identidade dos participantes. As questões são de resposta opcional o que significa que, caso não se sinta confortável com alguma questão, pode não responder e passar à questão seguinte. Toda a informação destas entrevistas será apenas utilizada para fins de investigação.

Parte 1 – SCM 4.0

1. Na vossa opinião, como é que a adoção de tecnologias tem ajudado no desenvolvimento de cadeias de abastecimento sustentáveis (social e ambiental)?
2. Atualmente, quais as tecnologias indispensáveis para o bom funcionamento da cadeia de abastecimento?
3. Por favor, indique o nível de implementação destas tecnologias na sua empresa, usando a escala em baixo:

1 = A tecnologia não está implementada, de todo, na empresa.

2 = Iniciação — a implementação da tecnologia está numa fase inicial (ad hoc, emergente, incompreensão).

3 = Repetível/Consistente — a tecnologia está suficientemente documentada (existe uma metodologia estabelecida para a implementação, a implementação da tecnologia tem sido controlada e coordenada, reativa).

4 = Estabelecida — a tecnologia está implementada, mas as suas contribuições são ainda muito limitadas (padronizadas e documentadas, pró-ativas).

5 = Controlada — a tecnologia está implementada, mas as suas contribuições são limitadas (foram estabelecidas métricas de qualidade, a tecnologia é fiável).

6 = Otimizado — a tecnologia está completamente implementada e contribui para a otimização/melhoria dos processos (melhoria contínua).

7 = Consolidada — a tecnologia está completamente implementada, deu provas da sua contribuição e está integrada nos processos e cultura da empresa (partilha de conhecimento e informação).

	1	2	3	4	5	6	7
Augmented Reality	○	○	○	○	○	○	○
Additive Manufacturing (3D Printing)	○	○	○	○	○	○	○
Big Data Analytics	○	○	○	○	○	○	○
Blockchain	○	○	○	○	○	○	○
Cloud Computing	○	○	○	○	○	○	○
Cyber-Physical Systems	○	○	○	○	○	○	○
Internet of Things	○	○	○	○	○	○	○
Robotics	○	○	○	○	○	○	○
Simulation	○	○	○	○	○	○	○

4. Por favor, indique a frequência de aplicação das tecnologias, anteriormente mencionadas, nas seguintes áreas de gestão da cadeia de abastecimento.

	1 - Nunca	2 - Quase Nunca	3 - Raramente	4 - Às Vezes	5 - Normalmente	6 - Quase Sempre	7 - Sempre
Research & Development	○	○	○	○	○	○	○
Procurement	○	○	○	○	○	○	○
Manufacturing	○	○	○	○	○	○	○
Distribution	○	○	○	○	○	○	○
Services & Support and Recovery	○	○	○	○	○	○	○
Outro(s)	○	○	○	○	○	○	○

Parte 2 – Barriers to SCM 4.0

1. Quais as principais barreiras que a empresa tem experienciado no processo de implementação das cadeias de abastecimento 4.0?
2. De que forma as alterações estruturais e os altos custos iniciais inerentes à implementação das tecnologias dificultam/dificultaram este processo?
3. Por favor, indique se concorda com as seguintes barreiras.

- [ ] Challenges in Ensuring Data Quality
- [ ] Seamless Integration and Compability Issues
- [ ] Disruption to Existing Jobs
- [ ] High Implementation Costs
- [ ] Lack of Digital Skills
- [ ] Lack of Infrastructure
- [ ] Lack of Internal Digital Culture and Training
- [ ] Organizational and Process Changes
- [ ] Privacy and Security Issues
- [ ] Outro(s)

Parte 3 – SCV

1. Ordenar pelo grau crescente de importância a partilha de cada um dos tipos de informação com os principais parceiros.

	1	2	3	4	5	6	7	8
Capacidade de produção	○	○	○	○	○	○	○	○
Processo produtivo	○	○	○	○	○	○	○	○
Inventário	○	○	○	○	○	○	○	○
Ordens de compra e venda	○	○	○	○	○	○	○	○
Mercado	○	○	○	○	○	○	○	○
Track and trace	○	○	○	○	○	○	○	○
Sustentabilidade ambiental	○	○	○	○	○	○	○	○
Sustentabilidade social	○	○	○	○	○	○	○	○

2. Como avalia a **quantidade** de informações partilhadas com uma empresa parceira?
    - Muito insatisfeito
    - Insatisfeito
    - Nem satisfeito, nem insatisfeito
    - Satisfeito
    - Muito satisfeito

3. Como avalia a **qualidade/precisão/ausência de erros** de informações partilhadas com uma empresa parceira?
    - Muito insatisfeito
    - Insatisfeito
    - Nem satisfeito, nem insatisfeito
    - Satisfeito
    - Muito satisfeito
4. As informações relevantes são partilhadas em **momento oportuno**?
    - Discordo totalmente
    - Discordo
    - Não concordo nem discordo
    - Concordo
    - Concordo totalmente
5. Quais as tecnologias que suportam a visibilidade/rastreabilidade na cadeia?
6. Quais as maiores dificuldades/barreiras: tamanho das empresas (e recetividade perante as tecnologias), falta de recursos financeiros, distância geográfica, falta de interesse dos fornecedores, falta de confiança…?
7. Quais os resultados/expectativas com relação ao projeto STVgoDigital (plataforma) relativamente à melhoria da visibilidade (qualidade, quantidade e "oportunidade" das informações partilhadas? Como está o processo?

Parte 4 – SCV & Sustainability

1. Qual a vossa avaliação da visibilidade especificamente para questões relacionadas à sustentabilidade (social e ambiental)?
2. De que forma conseguem obter informações e conhecer as práticas dos fornecedores dos fornecedores (além do tier 1)? Quantos "tiers" de fornecedores a empresa conhece?
3. Como avalia a **facilidade** em aceder a este tipo de informação?
    - Muito insatisfeito
    - Insatisfeito
    - Nem satisfeito, nem insatisfeito
    - Satisfeito
    - Muito satisfeito
4. Na vossa opinião, de que forma o comportamento do consumidor influencia as decisões de investimento para o aumento da visibilidade/rastreabilidade? Ou seja, os clientes querem estas informações? Têm influência na decisão de compra?
5. Sentem alguma mudança no comportamento dos consumidores nos últimos anos? Procuram saber a origem dos produtos?
6. A indústria têxtil de uma forma geral (e especialmente em função da fast fashion), tem sido questionada em relação às questões de sustentabilidade ambiental e social. Consideram estes aspetos na seleção de fornecedores?
7. Considera que o projeto STVgoDigital (em especial a plataforma para partilha de informações) pode contribuir para a sustentabilidade da empresa e da cadeia? Se sim, de que forma?