Data design for sustainable fashion

PROCESSES AND STRATEGIES
FOR SYSTEMIC INNOVATION DESIGN

Cristina Marino

FrancoAngeli
DESIGN INTERNATIONAL

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Contents

Preface

In the contemporary context, fashion is at a crucial turning point, facing complex issues related to sustainability and the digital transition. Cristina Marino's volume offers an original and multidisciplinary reflection on the intersection of fashion design, sustainability, and data science, which demand continuous attention, research, and innovation for radical change. The starting point is systemic innovation, beginning with contextual knowledge and the use of data. Beyond serving as informational tools, data become genuine creative materials capable of steering the design process toward more conscious and responsible solutions.

The volume outlines the research journey conducted by the author within the Innovation Design Lab, initially at the Department of Architecture and Design and subsequently at the Department of Engineering and Architecture, respectively, at the Polytechnic University of Turin and the University of Parma. The relationship between sustainability and fashion has always been a contentious one, sometimes considered an oxymoron, but it is now a phenomenon central to all business strategies in the industry at an international level: from

the creative process to production, from communication to provoking behavioural change among consumers.

In line with this orientation, the boundaries of the discipline have expanded significantly and continue to evolve, as does the profession of the designer within the fashion sector. Beyond the design of physical objects and clothing items heavily characterized by functional and aesthetic values, designers are now required to act as catalysts for change, operating on multiple social, economic, and environmental levels. This systemic vision of design finds one of its most significant expressions in the concept of sustainability, no longer seen as a mere objective but as a transversal methodology that permeates every phase of the creative process, from conception to realization, up to interaction with the broader context.

Fashion is the sector that has been the last to address sustainability issues. The reasons for this delay are numerous: disinterest and lack of awareness among various user groups, scepticism from entrepreneurs, a greater focus on perceptive and emotional issues, and poor understanding of the real impact of production processes on the environment and society. Today, however, this is no longer the case: interest in sustainability is solid and widespread, sometimes driven by entrepreneurial ethics, sometimes by mere communication, marketing, and sales concerns. Nonetheless, the latter should not be entirely demonized, as the power of fashion to convey messages is undeniable and has probably persuaded and involved a more significant number of people in a much shorter time than other sectors.

As with the food industry or product design artefacts, fashion has taken its first steps toward sustainability by promoting alternative production and logistical models: slow fashion, craftsmanship or DIY, natural materials, and reuse. These are undoubtedly exciting practices, occasionally innovative in the contemporary context, but rarely impactful on a large scale regarding economic issues and competition with industrial giants.

From this honest observation of the fashion sector, the volume proposes a fashion system model that leverages data knowledge to manage the system's inherent complexity. At the core of the theory proposed by the author lies data integrated into design processes to enhance production sustainability, promote the circular economy,

and increase efficiency throughout the supply chain. This extends even to the user experience and, consequently, impacts the final product design.

Through a detailed analysis of available methods and tools, the volume explores how design can contribute to reducing waste, optimizing resource use, and creating products capable of lasting over time in harmony with sustainability principles. The proposed systemic approach allows for evaluating the impact of each phase of a product's life cycle, from design to production, consumption, and disposal, thus offering an integrated and global view of the environmental challenges and complexities linked to the fashion world.

The central role of data in the creative process represents one of the most innovative aspects of this volume. In an era characterized by information overload and the proliferation of digital systems, data provides designers valuable tools to better understand consumer needs and behaviours, anticipate trends, and improve production process efficiency. However, this book does not limit itself to exploring the functional use of data; it also questions how data can become an integral part of the creative language of design, fostering a new aesthetic and redefining design methodologies.

This perspective is based on the idea that data are not static or purely technical entities but can be interpreted and transformed into dynamic, innovative solutions capable of addressing sustainability challenges. The volume thus proposes a design approach that integrates both analytical and creative tools, demonstrating how data science can interact with design disciplines to tackle the complex problems of contemporary society.

The volume describes and advocates for an interdisciplinary and systemic approach to fostering innovation, facilitating a dialogue between design and other disciplines such as data science, engineering, and social and environmental sciences. This interdisciplinary approach is essential to addressing our time's complex and interconnected challenges, requiring collaboration across different areas of knowledge to develop effective and sustainable solutions.

Moreover, the volume serves as a guide for designers, entrepreneurs, managers, heads of strategic and sustainability departments, and researchers who wish to explore the potential offered by

emerging technologies such as artificial intelligence, the Internet of Things, and machine learning applied to design processes. These technologies improve product quality and efficiency and open up new creative possibilities, providing designers with tools to create more personalized, intelligent, and sustainable solutions.

This volume profoundly reflects on the evolution of design in the digital age and the importance of integrating data and sustainability into the creative process. Through a series of case studies and a solid theoretical foundation, the researcher presents an innovative framework for understanding how design can respond to contemporary challenges from an aesthetic, ethical, and social perspective. The future of design, as outlined in these pages, is one where creativity, technology, and sustainability converge to create a positive and lasting impact on the world.

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Introduction

Over the past decade, the *data revolution* has progressively announced its intention to transform our ways of living, working, thinking, and engaging in economic activities (Mayer-Schönberger & Cukier, 2013; Kitchin, 2014a). Data, evolving into ontological and epistemological objects of research (Schäfer & van Es, 2018), has prompted a renewed debate within the design field regarding the roles of tradition and innovation in design thinking. Terms such as *Datafication* (Lycett, 2013), *Data-ism* (Brooks, 2013), *Data Revolution* (Kitchin, 2014), *Dataveillance* (van Dijck, 2014), and *Datafied Society* (Schäfer & van Es, 2018) are among the neologisms that have emerged to describe the pervasive culture of data as an all-encompassing phenomenon affecting many aspects of the world, increasingly supported and driven by large data infrastructures. This growing ubiquity of digital data progressively expands the number of variables designers must consider when interpreting complex problem domains.

To comprehend the logic by which data science is currently impacting, and will continue to impact, design disciplines, it is essential to examine how designers over the past century have approached

complex problems associated with new technology developments or in response to modern challenges. Buchanan (1992) and later Margolin (1995), when referring to and analyzing the indeterminacy of *Wicked Problems in Design Thinking*, draw upon the Four Orders of Design: a schema that frames design thinking and the issues to which design disciplines have been applied. The Four Orders represent a fundamental evolution in design professions: from graphic communication design to industrial design, advancing through interaction design and integrating system, environmental, and organizational design.

To succinctly outline the steps leading to the representation of this schema, it is necessary to trace the narrative back to the early 20th century. During this period, design responded to the challenges of mass communication by delving into the world of graphics, producing texts and images for print. This era began the graphic design profession, which later expanded into visual communication, communication design, and information design. In this context, today's data visualization or data journalism fields can be seen as extensions where designers tackle the problem of communicating large, heterogeneous datasets. Their skills encompass the graphical representation of information and the use of visual elements such as diagrams, charts, and maps, providing accessible means to discern trends, identify outliers, and recognize recurring patterns.

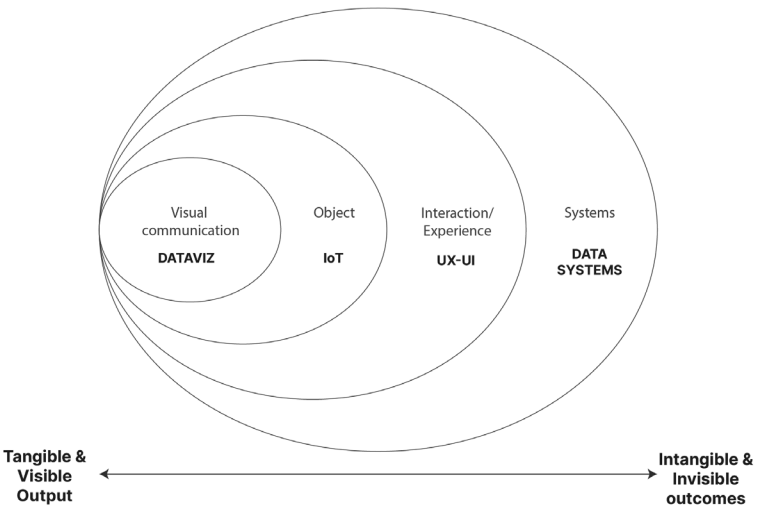


Figure 1.
Model of the Four Orders of Design.
Source: developed by the author based on Buchanan, 2001.

During the same historical period, other designers addressed mass production challenges by creating models, forms, and mechanisms for all physical artefacts produced in factories worldwide. This era marked the formal inception of industrial design, often linked with engineering, evolving into what we now call product design, with increasing emphasis on the relationship between design, engineering, and marketing (Buchanan, 2015). These professions now also reflect on the potential of contemporary data science. Consider, for instance, IoT products equipped with sensors capable of collecting and communicating data. Designers are capable of designing these products but must also engage with data collection in complex contexts, data-heavy technology in 3D printing, and data-driven marketing strategies.

By the late 20th century, the practice of design became associated with the term interaction, promoting the development of human-machine interfaces. Initially confined to screen interactions, this field has since expanded significantly to address increasingly complex scenarios. It now tackles design issues across a broad spectrum of human-environment interactions, demonstrating the field's growth and adaptability.

Since the 1990s, with a similar multidimensional approach, design has focused on services: an evolved form of interaction design centered on user experience, incorporating all other forms of design, from communication to processes. Not long before, designers also turned their attention to system design, considering the complex interrelations between component design and the ecosystem. This shift moved from designing a single product to designing the entire system of relationships within which the product exists, adhering to social and environmental constraints (Bistagnino, 2010).

According to Buchanan (2015), the new form of system design, unlike interaction design which focuses on actions, activities, and services, emphasizes larger aggregates. It incorporates the underlying ideas or organizing principles behind systems, organizations, and environments, as well as collective interactions. In the context of Human-Data Interaction (HDI), contemporary designers play a crucial role. They are responsible for constructing the increasingly pervasive data collection systems that are shaping our lives. These designers must ensure that these systems interact with most people and based

on this collection, establish guidelines to integrate and communicate data that influences human behaviour.

Starting from a primary area of inquiry such as design praxiology or the study of design processes and the development and application of techniques that assist the designer (Cross, 2004), this research revolves around developing a framework to integrate data for design purposes to enhance the sustainability of the current fashion system.

This exploratory book articulates the necessity of a new research agenda to investigate how data can be integrated into the fashion industry's design process. It focuses on the role of the designer in constructing the interaction between data and the user as the *dressed* human being. The findings delineate the boundaries of a theoretical-methodological framework guiding data integration into design practice, emphasizing the need for sustainable and integrated design language and practice.

Systemic Approach, Data, and Sustainability in Fashion

Sustainability is an act of balance. To achieve this equilibrium, the fashion system requires strategies that enable it to endure over time and evolve and adapt in response to environmental challenges. The fashion system is a complex network in which an infinite number of variables move and connect at an ever-increasing pace. In this system, as in many others, the design process must consider numerous factors: the product, its usage, and its users, for instance.

Data, as a powerful tool, aids in describing, visualizing, highlighting, and making known many, if not all, connections within the fashion system. This systemic thinking applied to data usage empowers us to examine the entire situation surrounding a business model or a single consumer behavior, focusing on understanding how the parts of a system influence one another.

Understanding the entire system and its intertwined life cycles is crucial for defining sustainability strategies. It helps professionals visualize their role within the system and communicate their specific roles and contexts more effectively.

In this research journey, data serves as a tool akin to a thread that holds the entire system together, acting as a lens through which the path to sustainability is found. Data-driven processes are viewed as

sewing machines, uniting components into a model that resembles a sustainable garment.

The research is organized into three key areas: data science, design, and sustainability, each of which is analyzed and explored in relation to the others. This transformative approach guides the current paradigm from contemporary unsustainability toward future sustainability. Finally, this research illustrates some emerging strategies where the use of Big Data with a systemic approach proactively stimulates and highlights sustainability trajectories, offering a comprehensive, though not exhaustive, overview of case studies and best practices.

This research's particular scope and strength lie in synthesizing knowledge from various fields, from data literacy by fashion design disciplines and the associated industry to sustainability theories, with a particular focus on the context of environmental sustainability driven by design and data at a systemic level.

Designing with Data, Designing for Fashion Sustainability

The primary goal of this book is to integrate data into the design process to achieve fashion sustainability. To reach this objective, the initial approach hypothesised that a data-driven systemic approach would facilitate new insights into the complex behaviour of people across different research scales, from design to engineering (Bourgeois & Kortuem, 2019).

The use of data at this level (i.e., the process level) represents a development for the discipline still in its infancy. Despite growing research interest in this field, it was necessary to understand how product, service, and system designers could utilise data as "creative materials for design". Beyond a few key publications, the literature must be improved to integrate data into the design process. The main issues identified relate to collaboration among the various professional figures involved in the research themes as noted by contributions from King *et al*. (2017) and Girardin and Lathia (2017): designers tend to adopt a reductionist approach, using data to *simplify/enrich* complex contexts, whereas data scientists might find the design process driven more by intuition than a precise objective.

Another significant aspect of the literature is the need for more support for novice designers in data-driven design, a recent phe-

nomenon and trend. There is limited guidance on which data to use and for what purpose, and the competencies designers should possess to interact effectively with other disciplines remain unclear and not self-evident. The emerging issue from the literature is the need for true data literacy (Wolff *et al*., 2016; Gray *et al*., 2018), which can systemise the technological potential of a data-driven approach with design tools.

The initial literature, produced by Speed and Oberlander (2016), highlighted how data usage and the development of Machine Learning were transforming designed products and services. This transformation, from a more systemic perspective as presented by Dubberly (2014), focuses on the processes that these new technologies offer through new tools and materials, while also changing the design process and the role of designers within it. Consequently, designers have shifted from a position of expertise toward adaptation to other roles, depending on the project's context and the design phase.

Who this book is for?

Data-driven innovation is transforming society and the economy. The objective, therefore, is to support the design of systems that enhance human interaction with data. This research is a convergence of many fragmented areas of the fashion system, seeking to connect them through a holistic vision. It spans from management to fashion design, including purely technological disciplines, underlining the interdisciplinary nature of the project. The central concern is that the design of new data flows sustains and enhances human values. The technologies explored within the research range from the Internet of Things, blockchain, and artificial intelligence to data visualization, interaction design, and social computing.

The broad multiplicity of actors involved results in a wide range of recipients for this doctoral research, which can fundamentally be divided into six macro areas.

1. *Design specialists*: this group includes professionals employed in academia and industry, as well as the emerging figure of contemporary designer-entrepreneurs capable of developing new ideas for products and services within the realm of sustainability.

2. *Fashion manufacturing companies* are engaged in the digital transition and seek sustainability within their production and product development chains.
3. *Cutting-edge digital technology companies*: these companies occupy third spaces, providing services and products that enable new value chains by connecting all the fragmented areas of the fashion system based on data systems.
4. *Sustainability mediators in fashion*: these entities share the ultimate goal of this research and are involved in training and developing skills that are particularly useful in the current scenario.
5. *Research centres*: these centres, whether in fashion, data, or particularly design, can collaborate to generate a data culture for design, contributing to the potential and more profound transformation of the fashion production and consumption paradigm.
6. *Design and fashion design educators*: these professionals can benefit from an operational research tool for managing interdisciplinary collaboration processes through data.

This book aims to bridge the gaps between these diverse stakeholders, providing a comprehensive framework to facilitate data-driven innovation and sustainability in the fashion industry.

1. Fashion Industry as a Data-enabled sector

1.1 Past and Present of Fashion

To understand the sustainability and unsustainability of modern fashion, this chapter places the industry in a complex historical context. It delves into the connection between fashion, context, economy, and politics from the early 19th century onwards. The issues and damages created by the clothing industry are neither new nor particularly surprising when closely examining its system. The driving forces of the fashion system have always been oriented towards speed and convenience. Mechanization and mass production have intensified to produce cheap, disposable garments, which have become excessively common in the industry. The problems related to fashion production have intensified over the 20th century, creating deeper roots that have locked the system into a state of unsustainability. Therefore, it is helpful to take a retrospective journey before discussing what is wrong with the clothing industry today and how we envision a transition towards a sustainable future.

1.1.1 Socio-cultural context

Fashion, as frequently noted, is a complex phenomenon. Two changes have characterized it in recent decades: a change in depth and a change in scope. In terms of depth, fashion is no longer something exceptional and separate from everyday life; in terms of scope, it is becoming an increasingly global phenomenon (Riello, 2012). In the last twenty years, fashion has reorganized and separated places of production, sale, and promotion. Production, aiming at ever-lower costs, is not necessarily located in a specific place due to tradition or access to material resources but shifts globally. Sales are separated from production and creation, and finally, promotion can move anywhere on the web. Fashion that follows the path of globalization involves commercial, productive, and creative flows. Large, organized distribution chains, such as the older H&M and the younger Zara, have adopted a new production and distribution model in which concepts and forms that were once exclusive to high fashion products are now offered to a mass audience. High-end products tend to be *copied* even though the materials and creative content are inferior. However, the internationalization of fashion is only partially a process of geographical extension. Simona Segre Reinach (2011) calls this process «cultural globalization», which has become a means of economic and cultural control by wealthy states over poorer ones. The volume of clothes consumed increases the textile industry's impact, and the fast fashion model is, by its nature, a quick response system that encourages disposability (Fletcher, 2008). The cultural paradigm of overconsumption is situated within the context of economic growth. The pressure for growth is expressed in economic practices that increase consumption. These practices include cost reduction, sales increase, market expansion, and investment attraction. Every aspect of our daily lives, including fashion, is subjected to this pressure, which affects the fashion sector problematically (Thorpe, 2012). The increase in consumption changes so profoundly that even the consumer's perception of value changes. The possibility of having more and more at ever-lower prices has devalued the emotional and actual quality of fashion products. Buying more clothes becomes cheaper and emotionally easier. The opening of production markets and the advent of outsourcing for foreign companies have disrupted the

strong bond between customer and seller until the last century. There is no longer trust in individual producers and sellers, and there is a new relationship with the brand of organized distribution. Viewed this way, the emphasis on novelty becomes understandable as modern consumers reproduce the cycle of desire-acquisition-use-disillusionment-renewal of desire in their continuous attempts to bridge the gap between an imperfect present and a perfectly imagined future. The practical effect of this activity is the creation of a permanent disposition to seek what is strange, new, or unfamiliar (González & Bovone, 2012). In this era, fashion trajectories are multiple, crossing atlases and imaginaries, articulating in the places of design, creation, production, and consumption of their products. They indicate, direct, and redraw maps, highlighting the territories in which fashion is rooted in its most complex forms. The bond fashion has with places is indispensable, not only to understand its history and dissemination but, above all, the mechanisms that regulate its existence (Frisa, 2015). Part of the history of the fashion industry is made up of places and distances. The following map shows how production sites have changed over the years. Clothing is one of the world's oldest and largest export industries. Since the 1950s, the textile and clothing industry has undergone several production migrations involving Asia. The first industry migration occurred from North America and Western Europe to Japan in the 1950s and early 1960s when a strong increase in imports from Japan supplanted Western textile and clothing production. The second shift in supply occurred from Japan to the *Big Three* Asian clothing producers (Hong Kong, Taiwan, and South Korea), allowing this latter group to dominate global textile and clothing exports in the 1970s and 1980s. In the last ten or fifteen years, a third production migration has occurred, this time from the Big Three Asian countries to a series of other developing economies. In the 1980s, the main shift was to mainland China, but it also involved several Southeast Asian countries and Sri Lanka. In the 1990s, the proliferation of new suppliers included clothing exporters from South Asia and Latin America (Khanna, 1993; Gereffi, 1998). The distances created in the consumer's perception between production and sale have led to further geographical confusion following all these changes. For the consumer, the difficulty arises in the relationship with the brand and the ability to understand

the meaning of a label correctly. Outsourcing or offshoring production and new forms of cooperation create an identity problem for consumers with brands and products. The fashion and brands they engage with result from multinational strategies coordinating industry complexity. This shift from small-scale domestic fashion to one based on international finance and complex managerial structures causes and is supported by a continually evolving cultural and consumer context that lacks the foundations and knowledge to manage it. It should be noted that this new global system relies on new forms of creation and distribution, such as fast fashion and luxury brands, whose product and location flexibility responds to the needs of increasingly differentiated customers, not only geographically but also socially and culturally.

1.1.2 Economic-political context

From an economic-political perspective, it is crucial to highlight the difference between European and American business models in this field. European economies not only allow but also provide incentives to fashion multinationals for their ownership of cotton farms, for example, as well as textile mills, clothing manufacturing factories, and retail outlets. Conversely, the American business model, based on production specialization, i.e., outsourcing operations and ownership to specialists to increase specialization and, consequently, efficiency, relies on a lower degree of vertical integration and a higher degree of outsourcing. Vertical integration for fashion conglomerates has been discussed as a significant competitive advantage that European fast-fashion houses lack in their global proliferation strategies because it allows unprecedented speed in product positioning. The order of events in the last century reveals the sharp decline in domestic production and brand sales with the introduction of free trade and export processing zones in developing countries, which provided greater freedom to produce abroad in areas not subject to environmental and labor constraints adopted in the developed world. Export Processing Zones (EPZs) are areas within developing countries that offer incentives and a barrier-free environment to promote economic growth by attracting foreign investment for export-oriented production (Papadopoulos & Malhotra, 2007). Groups such as the Interna-

tional Labour Rights Forum (ILRF) have noted that in some developing countries, the majority of EPZ workers are women, representing 90% of the low-wage labor pool. Many economists have concluded that employment in EPZs involves low wages, high labor intensity, unsafe working conditions, and the abolition of labor rights.

1.2 Technological Evolution and Industry 4.0

A context that must be examined more thoroughly in light of the themes of this volume is the technological evolution of the clothing industry, focusing particularly on three aspects: sales characteristics, production, and raw materials. Fashion historians estimate that the first documented garments were constructed between 500,000 and 100,000 BCE using naturally available materials such as skins and furs, selected to offer early humans protection from the elements (Brown, 2012). Unlike the history of clothing, the history of the tools used to develop the foundational elements of the fashion system can help establish how these past technologies connect to the present and future values of ethical and environmental responsibility in the industry. To highlight this connection, a necessary starting point is the 18th century. It is during this period that modern fashion becomes a mass phenomenon and a source of pleasure. The 18th century saw the birth not only of modern consumerism but also of modern distribution, characterized by fixed locations replacing itinerant vendor stalls, where clothes were displayed, and consumers could look, try on, and interact with the items they desired to purchase.

The concept of the shop is not new, as similar establishments existed in the Middle Ages, but in the 18th century, this becomes a well-defined space, distinctly separated from the outside street and equipped for the first time with a display window. The function of the display window is twofold: on one hand, it delineates the space and creates a division that vaguely recalls a private area where the merchant often lives with his family; on the other hand, the display window is part of a transparency strategy that allows for viewing the merchandise before entering the shop, enabling the consumer to understand if the product is suitable for their social class or fin-

ances. From the 1970s onwards, the display window remains one of the features of modern consumption, as it combines the search for desired objects with voyeurism. Initially, shops sold all kinds of items, but only at the beginning of the 18th century they started specializing and becoming curated spaces to create comfort for exclusive clients. Shopping becomes a hobby for the affluent classes. The relationship between the customer and the shopkeeper was often intimate, and it was not uncommon to rely on the advice of an expert or a trusted shopkeeper. The shop space facilitates more or less close relationships between sellers and customers.

Another important innovation of the 18th century is modern marketing and advertising strategies. Newspapers included several pages dedicated to advertisements. However, the early 18th-century newspapers were not illustrated, and visual culture had to wait until the end of the century to establish itself in the fashion world. This gave rise to the first fashion publications with images or drawn prints, the forerunners of modern fashion magazines. Fashion requires spaces where it can be viewed, tried on, and purchased, so it must be represented through books, magazines, and images. This is a significant development for fashion, which is not consumed only through objects but also through its representations. Fashion becomes not just something to buy and wear but gathers aspirations and discussions within society.

A peculiar aspect of 18th-century clothing is undoubtedly that, for most people, clothing had a high material value. In many cases, it was the only possession they had, but it is important to note that clothes could be quickly converted into cash if necessary. This highlights an important aspect of the economy: clothes had a wide range of prices, from used to new. The purchase of low-priced clothes began in the 18th century, not only due to the large presence of a second-hand goods market but mainly because of the introduction of a new product: ready-made or pre-made clothing. Before this innovation, clothing was cut and sewn to the order of a known customer, with whom the tailor had a personal relationship and who was the protagonist of the new clothes market. In the 18th century, bespoke and standardized production coexisted almost symbiotically: prêt-à-porter clothing was nothing more than a garment made by the tailor

and remade for an unknown buyer. The appearance of sizes and the success of ready-made garments were due to military use. The military was the first social form of mass-produced clothing, as it had to dress thousands of men quickly and economically. Size lost its function as a necessary measure to produce an object that fits the individual and became a measure necessary to find the pre-made object that suits them. From a cultural perspective, however, standardized clothing did not receive immediate approval, as it was considered suitable only for poorer regions. Part of the process through which ready-made clothing became part of modern everyday wear is based on the variety of the offer. The arrival of ready-made items literally transformed consumption: for the first time, the consumer had the opportunity to compare and evaluate different objects. The object becomes the center of the purchasing process.

Ready-made fashion also necessitated the dissociation of production locations from shops. As previously mentioned, the fashion revolution is closely linked to industrial and production revolutions, which are undoubtedly related to the arrival of a new material: cotton. Many scholars agree that cotton fabrics, perhaps more than any other invention or innovation, contributed to making fashion a mass phenomenon (Riello, 2012). The enormous demand for this fabric from India stimulated the development of mechanical devices that allowed for the spinning of cotton at modest prices and on-site. Functioning spinning wheels, looms, carding machines, and pre-industrial artifacts increased the speed and scale of supply chain operations, connected to the existing and future values of ethical and environmental responsibility in the industry. In the 18th century, fashion became an industry and a part of everyday life with shops and advertisements; all these changes made fashion a social phenomenon. However, clothing was still entirely handmade. At the beginning of the 19th century, clothing production was at a standstill: greater demand for clothes and easier availability of fabrics did not correspond to a greater production capacity, still largely tied to the workforce.

We must wait until 1846, when the American Elias Howe invented the sewing machine, perfected only five years later by Isaac Singer. The sewing machine played an extraordinary role in the history of clothing, increasing the speed of garment creation and allowing for

innovative interpretations of fashion at home. Home garment production declined only after World War II and in Italy starting in the 1960s. The sewing machine had the relentless task of bringing clothing to professional production but did not necessarily lead to industrial production. The division of labor increased, but the system relied increasingly on the intensive exploitation of female labor. As we will see later, this exploitation remains a legacy of those times in Asia, Africa, Eastern Europe, and Latin America.

With the opening of department stores and women's emancipation, a reform of clothing was necessary. The history of these custom reform groups, movements, and women's associations has been accomplished in recent years, but the slow change in clothing was created by sport and leisure culture. Sport in the last century is one of the activities that most influenced fashion development and brought it within everyone's reach. Sport emphasizes a broader trend: the need for both sexes to wear more functional clothing for movement. Later, in the early 20th century, transportation created new forms of clothing: for example, the first passenger flights highlighted the need for garments suitable for short and long journeys. After World War II, vacation clothing became necessary. All these changes towards more mobile-friendly clothing were also made possible by the fact that technological and chemical research entered the service of fashion. Synthetic fibers gradually replaced the four main natural fibers: silk, cotton, linen, and wool. The first synthetic fiber to appear was viscose, invented in 1883 and produced on a large scale starting in 1906. Rayon would then become the yarn for almost all garments worn in the 20th century, while nylon was the predominant fiber for leg-related clothing thanks to the invention of pantyhose. To these synthetic fibers, polyester and Lycra were added, allowing for shapes and colors not achievable with natural fibers.

Fashion sociologist and philosopher Gilles Lipovetsky (2007) defines the period from the invention of the sewing machine to the arrival of polyester as the «century of fashion». Fashion has the ability to influence the production of clothing worn every day by millions of people. High fashion and mass fashion stand in opposition: high fashion offers innovation and creativity, while mass production can meet the demands of expanding production and the growing desire to participate in consumerism. In 1908, seasonal collections were born,

and the production process began to be regularized every six months. Haute couture gives fashion mass discipline precisely when mass fashion begins to create unprecedented innovation and creativity (Lipovetsky, 2007). Fashion not only adapts but becomes a bureaucratic system. Today, it is characterized by complex processes and institutions and, more than any other industry, seeks to demonstrate that it is not merely a financial sector with a significant environmental profile but that it connects every corner of the planet.

After World War II, however, this type of fashion system began to present two main problems: fashion had become an aspirational phenomenon, and the upper classes represented the ideal customer. Thus, while in the second half of the 19th century, a basic style linked to production constraints sufficed, during the 20th century, the demand for low-cost but always new clothes grew. By the late 1980s, the fashion clothing industry was dominated by several large retailers who increased market competition (Barnes & Lea-Greenwood, 2006). To survive the competition, other fashion clothing retailers transitioned from product-driven chains to buyer-driven chains, developed alliances with suppliers in different markets, and promoted their distinctive brands (Tyler, Heeley & Bhamra, 2006). This led to increased profits through unique combinations of research, design, high-value sales, and marketing, allowing them and manufacturers to act strategically by connecting with overseas factories (Gereffi, 1999). Tyler, Heeley, and Bhamra (2006) illustrated that the fashion clothing industry developed an infrastructure around the late 1980s, emphasizing the promotion of quick response through the reduction of lead times and the maintenance of low costs. All these factors, along with the availability of an inexpensive fiber like polyester, fuel this new type of industry based on higher profits, low quality, and fast production. This marks the beginning of the fast fashion model. Two phenomena that have changed the face of fashion in recent years are the development of major luxury brands, which combine couture ideas and mechanisms with those of fast fashion, and the birth of fast fashion. Within the scope of this book, we will not delve into defining unsustainability models but will focus on sustainability challenges and technological innovations. The fashion sector has evolved with technological innovations through a history of successes, crises, and

changes, and it is now entering what can be defined as the fourth industrial revolution. The term «Fashion 4.0» refers to fashion practices within «Industry 4.0» (Bertola & Teunissen, 2018), also commonly referred to as the «fourth industrial revolution» (Schwab, 2016). This revolution builds on the assumptions of the third industrial revolution, namely the pervasiveness of digital technology and the birth of the «information age» (Castells, 2010). We will analyze in detail the main incentives of Industry 4.0, including datafication (Mayer-Schönberger & Cukier, 2013; van Dijck, 2014), decentralization, and the use of blockchain technologies in Web3, and the merging of physical and digital worlds with advances in artificial intelligence (Sheth & Thiru Narayan, 2012; Schwab, 2016; Hernandez, Vogel Steller & Sieler, 2020). Fashion 4.0 incorporates these principles and manifests in smart factories, networks, and products, touching all aspects from design to research, production to retail, products to inventory (Bertola & Teunissen, 2018). Within this scenario, Fashion 4.0 restructures operations and relationships within the fashion industry, reshaping the competencies and professional roles required.

1.3 Defining the Sustainable Imperative

The evolution of the fashion sector, both economically-politically and technologically over time, has brought a series of impacts for which the fashion industry is frequently criticized. However, it is clear at this point that fashion has always been a global affair, and its position appears unsustainable in both the medium and long term. The production and consumption of fashion represent the two extremes of a very long, fragmented, and complex supply chain that transforms fiber into yarn and fabric, mediated by designers, manufacturers, and buyers into clothing offered at retail. There are issues to be addressed at every stage of the process, long before the customer makes their choices, wears, washes, and eventually discards the purchased item. Nonetheless, although the impacts of fashion on society and the planet are evident, the challenge of sustainability has not spread vigorously but rather with mild pushes struggling to take off. On one hand, globalization has allowed and even forced the relocation of

fashion production centers; on the other, it has paved the way for and facilitated the exploitation of the planet's human and material resources, with the complicity of local governments.

1.3.1 Sustainable Fashion: A Complex Definition

In light of the complex analysis of the fashion sector, it is necessary to clarify what is meant by sustainable fashion, or sustainability in fashion, within the scope of this book. During the research, a collaboration was established with the Union of Concerned Researchers in Fashion, and among the association's activities, a wiki-edition of the expression *Sustainable Fashion* on Wikipedia (2024) was undertaken. The following is the definition of sustainable fashion developed during this activity, along with the entire translation of the page into Italian:

> *Sustainable fashion*, in English, refers to a movement and a process of fostering change towards greater ecological integrity and social justice in the fashion system. The desired change is not directed solely at the textile supply chain or fashion product but encompasses a paradigm shift for the entire system. This means addressing interdependent social, cultural, ecological, and financial systems (Fletcher, 2012), considering fashion from the perspective of many stakeholders-users and producers-and all living species that are part of the present and future terrestrial ecosystem. The definitions of *sustainable fashion* or *fashion for sustainability* thus indicate awareness of systemic influences and long-term interconnections among material, social, and cultural contexts in fashion. Sustainable fashion belongs to and is the responsibility of citizens, as well as the public and private sectors. A key example of the necessity to think systemically in fashion is highlighted by the fact that the benefits of product-level initiatives, such as substituting one type of fiber with a less environmentally harmful option, are negated by the negative effects of increasing volumes of fashion products. An adjacent term to sustainable fashion is *eco-fashion*. In contrast, the approaches and definitions of *green fashion*, *ethical fashion*, *sustainable fashion*, and *eco-solidarity fashion*, although indicating a willingness to address environmental and social issues, tend to have a limited approach to solving individual problems, neglecting the systemic perspective.

This definition was agreed upon by applying principles of systemic sustainability that require collaborative efforts to achieve sustainability, considering multiple factors. Throughout this book, this approach to sustainability is fundamental, as the goal is to use data to understand, monitor, measure, and deepen the issues and solutions for the fashion system in a holistic manner.

This definition aligns with the development of sustainability in the fashion industry, and as we have witnessed the emergence of various strategies, the terminologies describing the phenomenon have also evolved. Although it is beyond the scope of this book to provide a definitive definition of what sustainable fashion entails, it is essential to understand that different terms are often used interchangeably but may have slightly different meanings. The following table summarizes the key terms used and their meanings in this context. However, throughout this book, the most appropriate definition for sustainable fashion is one that encompasses a systemic approach to sustainability issues.

Method	Examples	Description	Authors
Enviromental Sustainability	Eco, bio, organic fashion	Emphasis on reducing the environmental impact of clothing production. Choice of sustainable raw materials, reduction of chemical agents.	Niinimaki (2010); Carey & Cervellon (2014)
Social Sustainability	Ethical fashion	Focus on workers' health and their rights. Choice of materials that are non-toxic, and can protect animals.	Joergens (2006); Reimers *et al*. (2016); Blazquez *et al*. (2020)
Social and environmental focus	Eco-sustainable fashion	It incorporates aspects of planetary limits and looks at both social and environmental sustainability.	Fletcher (2008)
Systemic Approach	Sustainable Fashion	The logic defined as *Earth Logic* by the authors moves away from the growth paradigm and capitalist view. The principles are: Less, Local, Learning, Language and Governance.	Fletcher & Tham (2019)
	Circular Fashion	Focus on waste elimination and circularity of the materials used in production.	Niinimaki (2017); Lissaman (2019)
	Slow Fashion	It urges to the localization of productions and the slowdown in consumption to lengthen products' life.	Fletcher (2008); Clark (2008)

Table 1. Terminologies related to sustainable fashion. Source: Henninger *et. al*., 2022.

1.3.2 Historical Evolution of the Concept of Sustainable Fashion

Many scholars believe that the roots of the sustainable fashion movement can be traced back to the 1960s and 1970s, coinciding with rising environmental concerns. However, the polemic years of the

1960s and 1970s, with new forms of expression from various youth subcultures, first displayed *antagonistic* viewpoints towards predominant development models based on mass consumption. The sense of discomfort and youthful rebellion was also expressed through criticism of traditional clothing symbols. While London youth were divided between rockers and fashion, the hippie looks emerged in the United States. These new trends were based on alternative education, food, and social relationships, soon becoming powerful and significant elements for the masses. Moreover, the theme of *sustainability* appeared for the first time in public debates. The eco-fashion movement had its previous incarnation in this free expression of rebellion, which began to be considered even as an anti-fashion stance.

The need for significant change in fashion production was established in the 1960s. Often regarded as the foundation of the environmental movement, Rachel Carson's book *Silent Spring* (1962) specifically referenced the use of pesticides for fiber growth and the damage caused by fabric finishes. By the end of the decade, the *natural* look of the hippies was associated with environmentalism. Several elements of their clothing choices, such as earth tones, hemp fabric, and patchwork, were considered prototypes for some of today's sustainable fashion models (Farley, 2015). However, it is only in its second wave that the eco-fashion movement took on a more commercial connotation. In the 1990s, visionary designer Lynda Grose designed the first Eco-collection for Esprit and invited all designers to «look beyond the surface of fashion and discover the social and environmental impacts of clothing production» (Esprit, 2011). During the same years, the United Nations Conference on Environment and Development, known as the Earth Summit, took place in Rio de Janeiro. This was a landmark event in the contemporary history of environmental awareness, particularly for its ripple effects in future political, social, and economic innovations, including establishing working groups on climate change and biological diversity (United Nations, 1992).

It is worth noting that in the 1990s, the global boycott campaign against Nike was so successful that it became a lesson on how large companies can be held accountable for their actions by ordinary consumers. Rob Harrison, editor of Ethical Consumer, explains:

«Nike was targeted by campaigners because it was the world's best-selling brand and initially denied responsibility for any misconduct occurring in its subcontractor factories». During these years, the toxic responsibility of fashion came to the forefront, but it took until 2013 to see more concrete bans implemented during Greenpeace's Detox campaign. Another social milestone influencing sustainability in fashion occurred in 1999, when anti-globalization NGOs, unions, and concerned citizens protested against multinationals during the World Trade Organization meeting in Seattle, Washington. Opposing trade agreements that compromised global workers' health and safety, protesters demanded fair trade, sustainable development, and attention to human rights (World Trade Organization, 2011). For this reason, it was not the activist campaigns that caused the Rana Plaza collapse in Dhaka, Bangladesh, which contributed to raising awareness and was one of the motivations behind initiatives aiming to tell the true story behind the clothes we buy and wear.

On April 24th, 2013, the Rana Plaza, a building housing several textile and garment factories, collapsed, causing thousands of deaths and injuries, but factory employees were forced to return to work even after news of the disaster began to spread. This episode, which shaped public opinion, became the motto for the foundation of Fashion Revolution, which annually commemorates the victims through a series of events and invites people to ask who made their clothes. In the same year, Greenpeace asked major Italian and French fashion brands to explain what measures they would adopt to ensure the absence of hazardous chemicals in their products. The project ultimately produced a ranking based on individual companies' environmental commitments.

In the last decade, many individuals and institutions have committed to making fashion more sustainable: research, publications, and virtuous behaviors have been collected, naturally, both through actions that resulted from specific communication strategies and those that did not. One of the first examples is undoubtedly the brand From Somewhere, which reuses scraps from the best Italian textile industries to create high-quality garments that are not only eco-friendly but also creative. The success of this brand grew to the point that in 2013, one of their dresses was worn on the Red Carpet

by Livia Firth: the actress decided to support the cause not only with her personal commitment but also with a creative project within the Ecommerce initiative. Thus, she designed the first collection aimed at raising online users' awareness of the need to respect the environment. Commitment and recognition of an ethical and social duty still have a long way to go: the first university education program to start a research program was the London College of Fashion, which founded the Center for Sustainable Fashion in 2007. The goal is to intelligently assimilate the principles of quality design and environmental awareness within the early stages of fashion design, training conscious individuals oriented towards designing garments where sustainability is not an added value but an intrinsic characteristic. Among the members, Sandy Black, author of *Eco-Fashion: The Fashion Paradox* (2008) and *The Sustainable Fashion Handbook* (2012), and Kate Fletcher, sustainable fashion activist and leader of the *Fashion Ecologies project* (2017), stand out for their commitment and research capabilities. It was she who coined the term *Slow Fashion* in 2007, opposing the frantic design mode of the fast fashion model.

From a terminological perspective, a range of labels has become available to consumers to support the commitment to sustainability in various shades. In recent years, words such as *ethical, organic, green, bio, fair trade*, and *eco* have been paired with the word fashion to certify environmental behavior. Shortly thereafter, the Fashion Institute of Technology's exhibition, *Eco-fashion: Going Green*, displayed examples of fashionable garments, shoes, and accessories from 1760 to 2010 (Farley & Hill, 2010). The exhibition highlighted past technical practices to strategically correlate behaviors that influenced the contemporary approach to sustainability in fashion. However, in the long run, the greatest commercial impact comes from the differences that major high street and brand companies can make to the entire decision-making process and value chain, thanks to their purchasing power and economic importance (Black, 2012). The Swedish giant H&M has just developed the *Conscious* line, which uses organic materials, cotton, wool, and other recycled materials. After launching a collection of camouflaged clothing outlets in 2013, H&M launched a new denim line in September 2015,

Close the Loop, made with recycled cotton from the previous two years' collections.

In Italy, in 2012, the National Chamber of Italian Fashion signed the *Manifesto for the Sustainability of Italian Fashion*, developed following the work of the Ecology and Environment Committee chaired by Anna Zegna, celebrated by Michelangelo Pistoletto in his imposing *Il Terzo Paradiso* (2003). The latest institution worth mentioning is the Global Fashion Agenda (GFA), a global forum on fashion sustainability founded in 2016 and operating around the Copenhagen Fashion Summit, the world's leading event on fashion sustainability for industry decision-makers. Global Fashion Agenda carries forward the mission of mobilizing the fashion industry and the international fashion community throughout the year to transform how we produce and consume fashion. Considering all these events, the link between the environment and fashion is no less negligible. The environmental aspect that connects fashion to planetary changes in recent years adds to the growing need to inform and raise consumer awareness: the sustainability of a garment must become a natural fact that the consumer does not need to worry about recognizing. Sustainability in the fashion industry must move towards a transformation that makes it a constant background in every creative, productive, and consumer action.

1.4 Technology for Sustainability

Although steeped in craftsmanship and tradition, the fashion industry is also highly progressive in driving creative innovations in how we design, create, distribute, and consume tangible products, augmented reality projects, and intangible services. Contemporary consumers consider purchasing opportunities both in physical settings and virtual landscapes. The gap between fashion and digital technologies is rapidly narrowing, leading to radical transformations in all aspects of the sector: from basic creation to augmented production to virtual presentations. This section aims to explore the relationships that impact all aspects of fashion influenced by technology. The objective is to open and explore new arenas in

aesthetics, functionality, processes, production, and retail, and how these contribute to a fashion ecosystem straddling physical and digital realities.

From a sustainability perspective, the fashion industry, like all ecosystems, is complex and dynamic. Encompassing intangible and tangible aspects, it produces significant consequences. The linear structure of this system, used throughout the 20th century and defined as *take, make, waste*, has established artificial boundaries and created a wedge between all involved actors. This has led to the textile and fashion industry often being cited among the most polluting in the world, overshadowing its structural and cultural potential as a powerful vehicle for social and environmental change. This book aims to highlight the opportunities generated by design, understood as the key to reorienting the fashion system and reuniting its most fragmented, undervalued, and unsustainable parts.

Design research and practice can generate new ways of understanding, being, and doing *fashion* that recognize the complexities and varieties of fashion in an authentic 21st-century context. This exploratory research work incorporates a multidisciplinary approach to mixed methods and a systemic lens to the fashion system to examine the boundaries of conventional fashion practice and encourage more complex interrelationships between and around garments. The concluding theoretical framework is informed by systemic thinking and the critique of the growth paradigm, supported by the integration of new technologies. It invites us to ask, through design research, what a holistic, thriving, and responsible fashion and textile system might look like for the 21st century, expanding the parameters of the fashion system to critically examine the tension between analytical and systematic thinking for fashion. This study serves as a catalyst for a conceptual model that shows how the fashion system can reconnect, and fashion design can engage with a higher order of design to include sustainable practices. The following text supports understanding the relationship between fashion, technology, and sustainability. The goal is to recognize challenges, opportunities, and gaps in how technology can support sustainability strategies at multiple levels of the value chain.

1.4.1 Technologies in the Fashion Process

Over the years, fashion and technology have often collided, approached, and contaminated each other in an attempt to test mutual limits, ensuring more performing products and systems with the sole objective of improving each other. According to the Cambridge English Dictionary, technology is «the study and knowledge of the practical, especially industrial, use of scientific discoveries». This definition encompasses almost all ways in which we create fashion, from using a simple tool like a sewing needle to more complex systems using multiple devices, such as a dyeing plant or a cotton farm. Technology allows us to create fashion products at home, at a tailoring level, or industrially, adding increasingly automated functionalities. Even in relation to distribution and media, technology facilitates multi-level creation and dissemination, such as photography, cinema, journalism, or communication; it connects us with other users and fashion experiences through the Internet, social media, or even augmented reality.

In the past, the relationship between fashion and technological innovations has been synergistic and profitable: from the first industrial revolution, which profoundly changed the textile sector with the invention of the Jacquard loom, to the birth of new industrial and distribution models (Tenuta, 2020). This has repercussions on the entire value chain: from agriculture, mining, to the development of serial textile production, in logistics in the strict sense, and in the transport and distribution system. Technology has shaped retail systems and textile industry disposal systems. It has made global and fast supply chains as we know them today. Without technology, neither fashion production systems nor communication processes would exist. Often we believe that the idea of fashion and technology working together is a new concept. In some ways, this is true: collaborations between large technology companies and fashion brands are incredibly recent when talking about integrating elements such as sensors, batteries, cloud computing, and more. However, the fashion industry, as we know it today, would not exist if technology had not permeated all related processes. On the other hand, the history of the relationship between fashion and technology is not only made of positive progress: this union has also given rise to significant developments in the history of capitalism, starting with the industrialization of textiles in Northern

England in the beginning of 19th century continuing with Fordism and assembly lines in factories, and then strengthening the development of sometimes unsustainable materials and, in modern times, supporting the creation of global supply chains. Therefore, although technology offers the fashion system new ways to make products, efficient processes, and innovative interactions, for many years the impact of the relationship between fashion and technology in the ecological sphere was not considered in the development and usage modes.

Raw Materials

The impacts of technology along the entire fashion supply chain begin with the development and production of raw materials. Agricultural technology, for example, has given us the ability to commercially cultivate raw materials such as cotton, linen, and other fiber plants, from which vegetable fibers can be extracted and turned into yarns; and has facilitated the breeding of animals or insects for their fur, wool, leather, or silk fiber. Later, extraction technology and chemical science generated synthetic fibers derived from fossil fuels, bio-based oils, or even milk (Rex *et al*., 2018). However, this same availability of fibers on an industrial scale, although offering many creative possibilities to the fashion industry, also contributes to extensive environmental degradation. For example, irrigation systems, fertilizers, and pesticides are commonly used technological interventions in cotton cultivation to increase yield and protect crops from insects, allowing us to grow more cotton than ever. But these technologies also contribute to water scarcity, create pollution, and have a negative impact on soil fertility, pest resistance, and biodiversity.

Fiber Processing and Textile Production

Once raw materials are extracted, harvested, treated, or otherwise obtained from natural sources, they are turned into usable fibers and fabrics. Some of these technologies are millennia old: the earliest evidence of silk dates back 8,500 years (Gong *et al*., 2016); others are currently being developed. Textile production technologies, from weaving to dyeing to printing, are a significant form of cultural expression. They tell stories of local history, capture significant socio-political changes or shared traumas, reflect cultural values and identities in visual form, and keep artisanal histories alive.

However, like raw material production, commercial textile technologies are often not developed with the environment in mind. Technologies used in washing, bleaching, dyeing, softening, emulsifying, anti-pilling, water, or stain resistance and other processes cause pollution of soil and water bodies in production facilities and harm the health of workers, local communities, and animal and insect populations.

Design and Manufacturing

From a manufacturing perspective, it is difficult to imagine the fashion system without envisioning a sewing machine. Modern clothing production, except for some stages such as cutting machines, sergers, and some buttonhole machines, still relies almost entirely on sewing machines. Although zero-waste design approaches are used, production shaped by sewing machines still generates waste. This waste increases with mass production: from cutting pieces to be assembled manually, canceled orders when production is already underway, and the quantities of unsold items for various reasons. Technologies such as rapid prototyping, zero-waste knitting, 3D printing, and on-demand production systems (just in time or on-demand) seek to solve production waste problems, while solutions like circular design aim to address post-consumption issues. The technological component also offers a source of creative expression in the design phases through image creation. Cameras and digital software allow designing or sharing projects through photos, films, illustrations, and other visual communications.

Logistics and Supply Chains

The global fashion system is characterized by high fragmentation and complexity in supply chains and logistics. These features enable not only the sourcing of materials from one part of the world, their transformation into fabrics in another, the dispatch of fabrics to various factories for production, but also the distribution of goods to distribution centers and retail stores worldwide. The system's impacts on the supply chain are mostly related to political issues (labor costs, distant supply chains, uncontrolled emissions); however, it is technology that makes material movements possible, as well as hardware and software logistics systems capable of managing supply chains.

Retail

One of the most influential applications of technology in retail is e-commerce. With the commercialization of the Internet in the 1990s (Tian & Stewart, 2008), companies like eBay and Amazon created a new type of business that offers consumers an online marketplace. After the COVID-19 pandemic, e-commerce assumed an increasingly dominant role. While «brick-and-mortar» stores globally continued to close, digital sales channels were considered «the silver lining presenting the greatest opportunities in 2021» (BoF & McKinsey, 2021), with technology providing new ways to engage the public and sell products.

E-commerce

Among the most relevant negative impacts in terms of sustainability of the e-commerce market is undoubtedly the shipping of individual products to individual consumers. Thanks to fast fashion giants enabling seamless and free returns, the relationship between consumers and the possibility of returns has become unhealthy. Research by Barclaycard found that 30% of shoppers deliberately over-purchase and then return unwanted items, while 19% admit to ordering multiple versions of the same item to decide at the time of delivery. The study estimates that between 30% and 40% of clothing purchased online is returned to the seller. The environmental impact of this massive problem is twofold: on the one hand, the carbon footprint of additional transportation, and on the other, the impact of returned items that are not resold. Fashion currently uses a *push* model for production and sales: marketing campaigns, advertisements, trends, and retail experiences are all designed to incite us to buy more, leading to waste, rarely worn products, and unsold stock.

End-of-Life of Fashion Products

Within the life cycle of fashion products, technology can also contribute to supporting logistics during the end-of-life stage, ensuring that products and materials are directed to the most appropriate locations, such as recycling or composting plants; new wearers, new designers, or new factories capable of disassembling components and using them in something new. Therefore, until recently, landfill or

incineration were the most common options for disposing of unwanted clothing or unused raw materials; today, technological development is moving towards a range of innovative methods to *close the loop* of materials in the fashion system. From recycling waste streams into new fabrics and fibers to recyclable packaging, peer-to-peer resale platforms, and tracking tools, technology offers an alternative to traditional disposal methods.

The push towards circularity utilizes tools such as RFID tags or QR codes on labels that can track the movement of garments and products throughout their lifecycle and store information such as care instructions or material classification for recycling. Some examples, which we will see in more detail in the central chapters, include *circularity.ID* by circular.fashion and *atma.io* by Avery Dennison, tested with Adidas.

Data-Driven Technologies

In this volume, the impact of technology, specifically data science, on all stages of the production process in relation to sustainability is explored. This overview, which highlights how technology can generate both negative and positive impacts, underscores that the sector is currently at a particular crossroads. Not only does sustainability represent a real differentiating element in the eyes of consumers, companies, investors, and increasingly, governance, but technology today can support companies' strategic choices. With the emergence and maturation of new technologies, fashion has a wealth of innovations to draw from for new ways to create, wear, and remake clothing. The following sections present recently matured technologies that, when applied to the fashion sector, support sustainability processes, exemplifying best practices that are transforming the current paradigm. When technology becomes digital, fashion benefits as well, and terms like *digital fashion* begin to invade the contemporary landscape with different meanings. We refer to *digital fashion* when digital tools are investigated to assist in design processes, communication, showroom activities, sales, and experiences. Secondly, digital fashion products refer to both garments and virtual spaces, whether representations of physical garments or garments that incorporate digital technology. Thirdly, *digital fashion* identifies a new fashion culture

that builds its discourse, values, and differentiation strategies, driven by contemporary industry challenges, technological possibilities, and digital culture attitudes. Fashion media, consultants, and fashion technology influencers have been actively writing about the rise of "digital fashion" since 2019 ((e.g. BoF & McKinsey, 2019, 2020, 2021; McDowell, 2019, 2020, 2021, 2022; Milne, 2019;Renwick, 2019; Cosco, 2020). Most of the grey literature on the subject has ranged from issues related to wearing *physically intangible* clothes, to sustainability benefits, monetization opportunities, *digital design* capable of overturning the current industry structure (Godwin, 2019; Milne, 2019; Roberts-Islam, 2020; Lyst & The Fabricant, 2021) to the most recent developments including gamification strategies and the evolution of the metaverse (Yotka, 2020, 2021; Palumbo, 2021; Nguyen, 2022). Prior to this, artificial intelligence was tasked with *replacing the designer* or, at least, shaking up the dynamics of the fashion industry (BoF & McKinsey, 2017, 2018; Cao, 2018). Over the past few years, digital technologies have suggested that topics such as digital hyper-personalization could then become and transform the «future of fashion» (Hobson, 2015).

In academic discourse, the concept of digital fashion generally refers to all digitalized processes of fashion production, marketing, manufacturing, and consumption, from virtual fitting to wearables and the Internet of Things (e.g., Moore, 2021; Nobile *et al*., 2021; Noris *et al*., 2021). In media discourse, digital fashion typically refers to 3D digital fashion created using 3D software and producing 3D digital models of garments (see, e.g., McDowell, 2019). 3D digital garments can be worn by physical bodies on screens, such as in an augmented reality (AR) experience in an Instagram story or fitted on photographs.

As fashion and technology intertwine more and more, the fashion lexicon evolves rapidly. This section introduces the technologies that are currently influencing the sector.

Artificial Intelligence

Artificial Intelligence (AI) is a field of computer science that studies the logic behind human intelligence. The field seeks to understand how we think and recreate this intelligence in machines. By its nature, AI extends to all human activities, making it relevant in

different ways for every sector. The intersection between fashion and artificial intelligence is a rich and expansive space that is just beginning to be explored. AI has the potential to revolutionize the fashion industry and the way consumers shop for and interact with clothing: it can help improve customer experience, automate processes, create new products, and even predict trends. The most obvious benefit of AI in the fashion industry is increased customer satisfaction. AI-based platforms can provide customers with personalized recommendations based on their individual preferences or improve the browsing experience on various sales channels by providing more intuitive product suggestions. Additionally, AI can be used to automate mundane tasks such as product sorting, making it easier for customers to find what they are looking for. Within the business world, AI can be used to create new products and services: it can be used to generate trend forecasts and style recommendations. AI can also be used to create virtual clothing models and fitting tools, allowing customers to get a better idea of how an item will look before purchasing it. Finally, AI can be used to automate various processes in the fashion industry, such as designing and manufacturing products, reducing costs, and increasing efficiency. In customer relations, AI can also be used to automate customer service processes, allowing companies to respond to inquiries quickly and accurately.

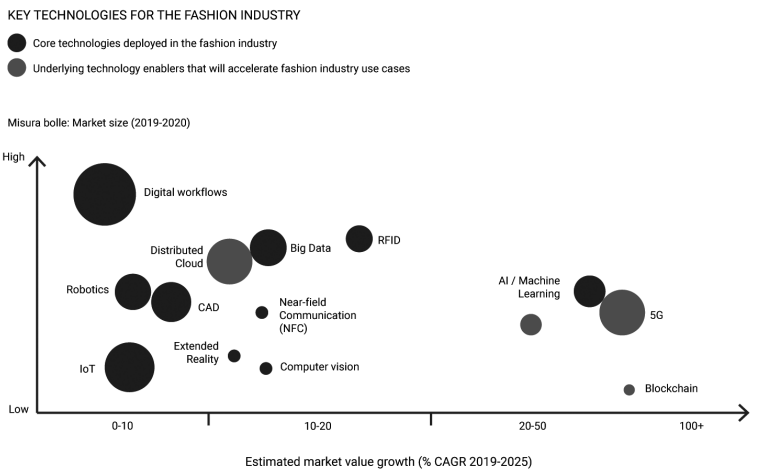


Figure 1.
Key Technologies for the fashion Industry.
Source: developed by the author based on BoF, & McKinsey, 2021.

Big Data

The first attempt to define Big Data dates back to 2001, when Doug Laney described the 3V model, which outlines the three characteristics of new data: variety, velocity, and volume. Today, Big Data refers to large and complex datasets that require the definition of new tools and methodologies to extract, manage, and process information in a reasonable time. In the fashion sector, Big Data insights allow companies to offer personalized communications to customers and predict their preferences.

Blockchain

According to George Harding-Rolls, campaign manager at the Changing Markets Foundation, a statistic is considered false if «there is no reference, if it is lost in translation, if it has been deleted from the Internet, or if no one can access the methodology that supports it». The fashion industry has recited obsolete statistics, wild generalizations, and dubious claims for years because there was no technology capable of monitoring the veracity of some dogmas and myths, both on the impacts and positive progress in terms of sustainability gradually being incorporated into this fragmented and complex supply chain.

Cloud Computing

Cloud computing is the delivery of computing services over the Internet, including servers, storage, databases, networking, software, and analytics. In particular, it can support flexible scalability, allowing companies to increase or decrease computer usage according to their needs. Edge computing is the practice of capturing and analyzing data locally and in real-time, significantly reducing latency. This can help fashion companies accelerate production cycles and speed to market. Edge computing supports Internet of Things systems by enabling connectivity with devices such as mobile phones. Quantum computing leverages quantum physics to represent and process information much faster than traditional computers. In fashion, it could be used to scale AI use cases, but the technology is still in development.

Computer-Aided Design (CAD)

Computer-Aided Design (CAD) digitally produces models and drawings of products. In fashion, designers can sketch and design with 3D CAD programs, reducing the number of physical prototypes and samples, increasing development speed, optimizing costs, and promoting sustainability by reducing or eliminating material waste.

Extended Reality (VR and AR)

Extended Reality (XR) is a concept that encompasses Virtual Reality (VR) and Augmented Reality (AR). VR immerses a person in an alternative world using hardware such as headsets, while AR adds a virtual layer to the view of the physical world, for example, with a smartphone filter. In fashion, AR allows customers to virtually try on clothes and accessories, while VR supports the creation of digital fashion in virtual worlds and games, as well as virtual showrooms and fashion shows. XR extends to digital and physical worlds, helping customers express their ideas and creativity in virtual spaces.

Internet of Things (IoT)

The Internet of Things (IoT) describes networks of physical objects (hardware) connected through embedded sensors and IoT applications (software). These increasingly available and affordable devices can connect with other devices and systems. IoT is enhanced by 5G (fifth-generation mobile network), which offers higher data transfer speeds and lower costs than previous generations. In fashion, IoT is associated with wearable devices (e.g., smartwatches and glasses) and sensors embedded in products. IoT sometimes uses RFID technology to enable information exchange about products, such as materials, origin, or maintenance.

Radio-Frequency Identification (RFID)

Radio-Frequency Identification (RFID) uses radio waves to identify and track objects automatically with an RFID tag (a small transponder that carries information) and a reader (a device that receives signals from the tag). Similarly, but at a shorter distance than RFID, Near Field Communication (NFC) wirelessly transfers data between devices such as smartphones and tablets containing NFC chips. In fashion, both

technologies track products and orders in real-time, helping companies solve problems such as counterfeiting or improve recycling and inventory management.

In trend-driven product categories such as fashion, accurately predicting consumer demand is a complex issue. Historical sales data never lead to consistently better business decisions, while traditional forecasting tools are slow and unscientific. Until now, predicting consumer fashion demand has been the prerogative of *experts*, focus groups, and relatively unsophisticated models based on *small* data. Collecting and analyzing actual customer preferences was too expensive and difficult to achieve. However, with the advent of Big Data, the situation has changed. By collecting and analyzing a much larger amount of data on people's interactions, individual preferences become much more known, complete, and detailed. This provides valuable insights for the fashion industry: through data, it is possible to develop more performing products, know which will sell well in which stores, which products succeed when placed next to each other, and how to optimize retail experiences. Big Data can be used to predict customer preferences. Naturally, as seen in the literature on data approaches, this does not mean that innovative design and original ideas will be replaced by numbers. Rather, numbers can help and support designers in identifying the direction to take, where to push more, and how to excel in customer satisfaction. Big Data predictive insights, however, are not limited to understanding customers; they will allow brands to choose the most promising creative talents with a better success rate. The impact of this technology can also be applied to areas such as marketing and advertising, which can become more efficient. For example, today advertisers truly know how well billboards work because we have few real data on how many people look at these ads. By collecting data on human gaze – just think of neuromarketing technologies – data will also improve advertising. In such a subjective and seemingly unpredictable sector as fashion, intuition is crucial. After all, analyzing customer preferences would not have easily revealed that people wanted to buy cars before they were invented; they might have simply desired a faster horse, to paraphrase Henry Ford. But in the age of Big Data, intuition

cannot compete with data on customer preferences. Rather, human intuition will be necessary precisely because data can never tell the whole story, and surprise and serendipity are fundamental to human nature. Every aspect of business will change, from next season's color to how to produce clothes that fit different body types and how to optimize supply chains.

1.5 The Role of Fashion Designers in Sustainable Processes

As Claxton and Kent (2020) state, «in their conventional role, fashion designers tend to influence the choice of materials, aesthetics, silhouette, finishes, production quality, and fit». Moreover, especially in companies focused on sustainability, fashion designers are interested in concentrating on quality issues and ways to ensure the longevity of a garment, for which technical aspects of durability, consumer emotional satisfaction, and timeless design are essential (Karell & Niinimäki, 2020). A systemic approach and the circular economy add to the designer's work the aspect of the multiple lives of the garment, as well as emerging knowledge on end-of-life processes and the recycling of garments/fabrics into new valuable materials (Niinimäki, 2018).

At a time when the sustainable fashion paradigm is renewing and becoming the new norm – no longer a niche – and a system-level transformation is occurring, new demands are emerging for designers' roles. We believe that this moment can also be seen as an opportunity to extend the designer's work from implementing a narrowly defined design brief to a more strategic role focused on sustainability challenges. Designers can significantly contribute to building a company's strategy and, through this, more closely connect product design work to new business models and the creation of sustainable value, ensuring that the product truly implements the company's sustainable strategy. The product must provide value in a transformable sustainable system.

For this reason, we have investigated the role of the designer in various types of companies.

- In SMEs, and even more so in designer-led companies, the designer plays a more significant role and has greater influence over decision-making and strategy building.
- In larger companies, the designer works closely with sourcing, technical, and production teams to create company-based sustainable guidelines for design, production, and manufacturing processes.
- In other companies (especially larger ones), an R&D team takes the lead in this work, but designers should also contribute because they possess creative skills, design-based insights, production knowledge, and often a user-centered understanding (empathetic design).
- In the most virtuous, but rare, cases, the designer participates in building the company's strategy, and in this case, the design process and the product can truly represent and communicate the company's chosen value base.
- In a study conducted by Claxton and Kent (2020), companies striving for more sustainable goals saw «future opportunities for a competitive strategy based on product differentiation, emotionally engaging the consumer through branding, identity, and the creative concept behind sustainable products». In this case, the product itself and its differentiation through design are no longer sufficient; all other aspects, such as production, garment durability, business models, and environmental impact, must align to convince consumers that they are buying into a truly sustainable brand and product. As Claxton and Kent (2020, p. 3) describe, «design direction has a strategic perspective that is implemented at tactical and operational levels».

Sustainability theories in fashion have long claimed that design's role impacts the system level and should not be limited to aesthetic and material selection alone. Recent theses, such as that of Franconi (2020), suggest that designers should not only design products but also the lifespans of products, products that support alternative business models, or even the sustainable systems surrounding the products.

The designers we address in this book are those who can/want to participate in building a transformative system for products that

enable this transformation. Design-thinking and design-management approaches can enhance system-level transformation, providing new business models and insights for consumers. Moreover, through the vast amount of information available today, fashion design can help account for the environmental impact of fabrics and garments on carbon, water, and the environment. The table 2, taken from Henninger *et al*. (2022), shows all the aspects through which design can be linked to different levels of sustainable transformation and illustrates how designers can work on some of these aspects or more than one to move from a narrow to a more holistic view of sustainability.

The goal is to enable and encourage a new understanding of the fashion system and to create greater balance within it. As John Thackara (2014, p. 45) emphasizes, the political question might not be the best driver of sustainability transformation, but transformation

Design for systemic transformation	Description of strategies
Product Design	Select sustainable materials, choose materials with low environmental impact, work on structural quality, limit the use of chemicals for finishing materials. Consider the style and aesthetics of garments over the long term, prefer eco-friendly standards, choose recyclable materials, define an upstream recycling/reuse/repair strategy.
Production	Pursue energy efficiency, emission neutrality, renewable energy, limit the use of water or chemical agents, limit environmental impact and waste dispersion in the environment, prefer local production, have stostenibility standards, recognize workers' rights, be transparent.
Life Cycle of Garment	Working on: • technical life of the product; • functional life of the product; • emotional life of the product.
Use Phase	Promote care, repairability, emotional satisfaction, avoid following trends, raise awareness to product quality.
End of Life (EoL)	Postpone product end of life as much as possible at all stages, close the life cycle of materials by working on material recyclability.
Business Model	Designing for Product Service System, designing for alternative business models, Integrating circular economy projects, transformative economy.
Systemic Approach	Working on: • time by promoting a slow approach; • scale (decreasing); • more accurate volumes. Taking into account system limitations (environmental, social) Implementing the circular approach, promoting collaboration to solve complex problems.

Table 2.
Design for the systemic transformation of fashion. Source: Henninger *et al*., 2022.

is «a condition that emerges when the effects of incremental change accumulate on many different scales». The sustainability objectives explored in the literature review show different perspectives on sustainable fashion design, from material selection and aesthetic creation to a more systemic understanding of design and production processes, from the aspect of time in sustainability (slowing down) to the importance of responsibility and trust. The objective of this part of the research has been to limit sustainable fashion design principles to those that can intervene at the system level, assuming that classical sustainability strategies are already part of the development of solutions in the business context.

2. Designing with Data

2.1 Data Design: an introduction

We continuously interact with new technologies. Computers, smartphones, and the surrounding infrastructure mediate our communications, influencing not only who we can reach and who can reach us but also what we can say and what we can hear. Communication tools can reconfigure dynamics of language, thought, and business. New technologies affect not only how we «make sense» but also what we mean by «sense» (Dubberly, 2008). The proliferation of sensors connected smart products (IoT), the measurements they generate (Big Data), on-demand processing (cloud), and pattern-seeking software (AI) are changing how individuals and organizations interact. New distributed structures challenge established centralized organizations. The boundaries between inside and outside are increasingly blurred. The COVID-19 pandemic has accelerated this process, making technologies not only necessary for interaction but also an indispensable part of our daily lives. When designing with these new technologies, they offer new tools and materials to work with, but they also

change the design process and the roles that designers play in it. The unprecedented speed at which this occurs invites reflection on these changes in roles and processes in design. If the designer's role is to foresee users' needs and desires before others, with a more holistic vision, including that of ecosystems, it must be remembered today that every action leaves a digital trace that, as designers, we can and must engage with. If we learn to decipher correctly, this vast amount of data can be employed to do almost anything. We are experiencing the evolution of the computer revolution that has emerged over the last 50 years, with successive waves of technology transforming how we communicate, conduct business, and organize our lives. Computers have evolved from rare research tools to corporate mainframes, departmental minicomputers, and personal computers for private individuals. The PC digitized business. The Internet connected everything. And smartphones have made computing ubiquitous: always on and always connected.

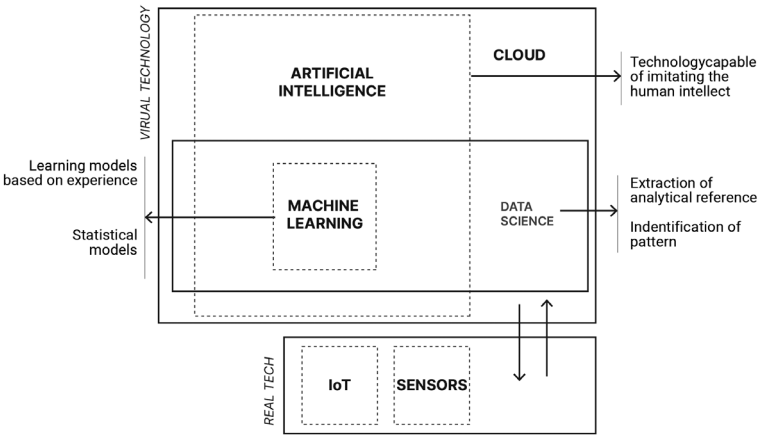


Figure 1.
Technologies supporting the Data Society.

This revolution is mainly enabled by five technologies, each capable of combining with the others.

Sensors

Since 2016, about 1.5 billion smartphones have been sold, each packed with sensors: a touch screen, one or two cameras, a microphone, a humidity sensor, a proximity sensor, a light sensor, a motion sensor, and more. That's a lot of sensors. The enormous volumes

drive down costs and the race for features drives innovation. Most sensors are printed on chips, making them very small and allowing sensors to be installed around us (e.g., in fashion-smart fabrics) and even within us.

IoT

The Internet of Things (IoT) refers to sensors and machines connected to the Internet, from home thermostats to private satellites to cars. In addition to sensors and communication chips, IoT devices contain microprocessors that make them *smart*. These *smart products* communicate via the Internet with centralized services, sharing local data with *headquarters* and receiving instructions in return. Centralized services often support continuous monitoring, remote diagnostics, process control, predictive analysis, and soon even autonomous operations. Along the way, they also generate an unprecedented amount of data.

Big Data

Big Data is the revelation that measuring certain phenomena can be a business opportunity. To define this technology, consider our daily activities: interactions with websites, social media, and the sensors in our smartphones. All this generates an unprecedented amount of data. It is estimated that every two days, we create as much data as we did from the dawn of civilization until 2003 when this technology saw its major expansion. Big Data extracts enormous volumes of data heterogeneous in source and format, analyzable in real time, whose fundamental characteristics are: velocity, volume, and variety. In addition to physical sensors, *virtual sensors* also collect tons of data.

Cloud

The expression *cloud computing* refers to the enormous computing and storage resources offered as on-demand Internet services by Amazon, Google, Microsoft, and others. Again, scaling up has reduced the unit cost – this time bringing the marginal cost of computer processing almost to zero – and has transformed processing into a *utility*. A virtual space where data is stored and categorized, ready to be analyzed promptly.

AI

Artificial Intelligence (AI) refers to a set of software technologies ranging from common statistical methods to convolutional neural networks, sometimes called machine learning (ML) or deep learning (DL). AI systems learn to see and speak: computer vision (CV) and natural language processing (NLP). Essentially, AI systems find patterns. That is, they compare different data until they define patterns. Recent advances are not so much due to improved algorithms but to the enormous amounts of data now available for training.

All five technologies – sensors, IoT, Big Data, cloud, and AI – work together in a broader system that we might call an *AI platform* or, more prosaically, a «data refinery» (Dubberly, 2008). Sensors in connected smart products collect data about the environment, users, and usage. They send the data to servers in the cloud. There, vast *server farms* offer high-volume on-demand processing at low cost, with distributed supercomputers applying software algorithms to find patterns in the data and improve daily operations.

The role of data in innovation processes has thus significantly expanded with the emergence of Big Data, as intensely debated by academics and professionals (Sivarajah *et al*., 2017), but continues to grow due to its direct link with other digital technologies, such as the Internet of Things (IoT) and Artificial Intelligence (AI). Throughout the history of computing, data practices have continuously evolved, sometimes alongside technological development, other times increasing computing power and storage have become so cheap and widespread. In recent decades, significant advances have been made in knowledge discovery and data mining (Fayyad *et al*., 1996), information retrieval (Marchionini, 2006), and information visualization (Card *et al*., 1999). These subfields of computer science have developed their expertise, methodologies, training programs, or degree courses, gradually building a body of knowledge now accessible to everyone. The era of Big Data (Mayer-Schönberger & Cukier, 2013) and the trend towards datafication in various industrial sectors (Lycett, 2013) have introduced new emergencies regarding how data is used in companies. Using previous discoveries in computer science subfields, new types of data use practices have emerged to obtain new inferences and epistemologies (Kitchin, 2014). A clear result of this extension

is the field of *Data Science*, which has been consolidating in recent years (Cao, 2017). Data science unifies emerging practices, data techniques, and know-how in the era of Big Data. Following this contextual part, this section of the research focuses on the use of data in design processes that combine large-volume data systems, diverse in sources and types, and created rapidly through these technologies. Despite receiving significant attention from researchers in various disciplines, such as innovation, marketing, and digital transformation (Lindstrom, 2006; George *et al*., 2016; Nambisan *et al*., 2017; Urbinati *et al*., 2019), little is known about the use of data in the design process, and even less, when data-driven practices enable innovation processes in the context of environmental sustainability. This lack of knowledge becomes more relevant when projects address complex and ill-defined problems (Buchanan, 1992). As anticipated, the more uncertain and complex the problems to be addressed, the more decisive the role that data might or might not play in supporting the definition and solution of the problem becomes.

Problems can be broadly distinguished based on their *a priori* structure, from well-defined to ill-defined (Mumford *et al*., 1994; Unsworth, 2001; Baer *et al*., 2013). In well-defined problems, all information, variables, and stakeholders are fixed and known from the outset. Conversely, in ill-defined problems, information is confused and not well-formulated, and the values of customers and decision-makers are in conflict (Buchanan, 1992).

In this research specifically, we focus on the complex and ill-defined problems of the fashion system and, through design methodologies (Martin, 2009; Brown, 2012; Micheli *et al*., 2019) and the underlying principles, including human-centeredness, creating empathy with users, and a systemic approach aimed at innovation (Gaiardo *et al*., 2022), we seek to direct solutions toward sustainability.

2.2 Context and Concept of Data

Traditionally, a widely used definition in engineering or scientific contexts considers *data* as quantified numbers derived from a sensing device (sensor). However, in the current era of Big Data,

where data are complex, heterogeneous, and ubiquitous, and have permeated everyday life, the traditional notion of data as numbers is no longer sufficient (Mayer-Schönberger & Cukier, 2013). Therefore, it is necessary to define the plurality of conceptions emerging from the literature from an interdisciplinary perspective on data.

Beyond the classic notions of quantitative and qualitative data, the rise of the Big Data phenomenon has created interdisciplinary interests (Boyd & Crawford, 2012; Mayer-Schönberger & Cukier, 2013), expanding the framing of Big Data beyond a purely technical viewpoint and into a multiplicity of notions. Concepts such as *subjective and objective data*, *ethical data collection*, and the *political and economic value of data* carry nuanced meanings that might be of significant interest in the field of design. However, to spark a true interdisciplinary debate on the concept of data, new universally recognized vocabularies are needed.

From the analysis of the literature, the following definitions of data emerge when trying to frame this concept within the realm of design and the design process.

2.2.1 Data as a Material for Design

Topp, a Swedish design and data lab, began using data beyond the traditional method of gathering demographic information or monitoring usage. Topp started using data as a design material, which they believe opens «creative and strategic pathways otherwise untapped». Topp organizes a series of workshops that experiment with design-based ideation and data sketching. Interestingly, imposing a human perspective and our ability to create narratives allows us to «read stories from data», aiming to stimulate ideas and give designers a different perspective and point of view to work from. They argue that the stories need not be statistically significant and discuss data interpretation as fundamental to using data in the design process. On one hand, they assert that one does not need to be a data scientist to draw creative insights from data. On the other hand, they recognize that the ideas generated using data as an ideation tool «would obviously be entirely absurd if we were data scientists».

2.2.2 Data as Boundary Object

The most recent definition comes from Kun (2020), who defines data as a «boundary object» (Star & Griesemer, 1989), applying to data the meaning of an abstract or tangible object, constructed by communicating or categorizing the object. This definition emerges from the context of interaction design and HCI, where the concept of «data as a boundary object» has been particularly important for problematizing data practices, such as data collection and sharing (Vertesi & Dourish, 2011), personal data management (Mortier *et al*., 2014; Crabtree & Mortier, 2015), interaction with local data (Taylor *et al*.., 2015), or the development of algorithmic models (Passi & Jackson, 2017). These examples illustrate the contextual considerations designers must take into account when dealing with data.

However, such investigations provide little guidance on how to incorporate data into design work. Despite the wide variety of examples illustrating contextual considerations on how designers should account for data, only a few works, such as Feinberg (2017), are based on an objective of data as a *boundary object* applicable to design. As Feinberg states: «Design projects in HCI can omit the work done on data, making it seem that data is a stable material to "use"» (Feinberg, 2017). In other words, although there is HCI work focused on data, we know little about the data design practices occurring in the design process.

2.2.3 Data as a Medium for Design

Remondino (2019), in his doctoral thesis titled *The Visual Company*, defines data as a medium for design:

> **Data and information are radically changing work practices, emerging as a medium from which designers can draw insights for design aimed at innovation and sustainability, a medium from which designers can redefine the design process, giving companies the ability to understand the context more consciously and clearly, aligning with consumer needs and the context itself, creating value.**

This statement aligns with that made in the article «The rise of the data artist» by M. Rolston, who states: «The new challenge for design is to

use these data for the same humanistic outcomes we have in mind when shaping products through user interface or their physical form».

Finally, Kitchin (2014) offers a functional clarification:

> **Data […] do not exist independently of the ideas, techniques, technologies, people, and contexts that produce, process, manage, analyze, and store them. They are indeed organized and stored in databases and data infrastructures that constitute the core of complex socio-technical systems.**

With this definition, the author supports the need to consider data as the center of various data systems assembled together, which «frame what is possible, desirable, and expected from data». The goal of conceiving data as part of an assembly is primarily a reminder to recognize the different meanings of data in the context of design.

2.2.4 Data as a Relationship in a System

This definition by Kitchin (2014) helps frame the concept of data as a component of a system, where the strong relational bond between data and context emerges almost naturally. Indeed, if we imagine databases as infrastructures and stock systems, it becomes immediate to imagine how working on data flows means working on the relationship of input and output. Finally, this definition steers us away from viewing data as a measurement tool and helps us recognize the value that can be extracted from them.

The following text encourages an interdisciplinary understanding of data that goes beyond *numbers* to observe and approach the vast variety of data practices in the design process embedded in socio-technical contexts, both in terms of what a data set contains and in terms of considering the contexts and practices surrounding data.

2.3 The Intersection of Design and Data Science

In this section, we first present how the realms of data and design often start from different perspectives, not always naturally compat-

ible, and then illustrate the design approaches that revolve around data. Although design and data science are rooted in problem-solving, their ways of working, mindsets, and approaches to challenges are often quite different. To better illustrate these differences, we briefly present the perspectives below. These perspectives might not encompass all design processes or various disciplinary roles, and the same applies to the definition of data scientists, but we use this generalization to articulate some of the most relevant differences and affinities within this research.

Data science, also known as data-driven science, is concerned with developing models, algorithms, processes, and systems to extract information from large data collections. This work often starts from a defined problem that aims to demonstrate a specific hypothesis or answer a specific question. It might involve, for example, work that aims to confirm the impact of certain characteristics or more exploratory work that seeks to find behavioral insights in large data sets. Furthermore, similar to other problem-solving approaches, data science primarily focuses on understanding what already exists (Cross, 2004). Data science processes are considered well-procedured, where scientific rigor leads to accurate results and thus certainty. It is seen as a reliable and precise craft. Data are rational, and numbers are indisputable (King *et al*., 2017).

According to Zimmerman (2007), design focuses on what can be rather than what is and can generate solutions «in an unknown or only particularly known situation, with demanding and stressed clients and users, with insufficient information, with new technologies and new materials, with limited time and resources». This capability, which at times might seem irrational and imprecise, is attributable to the fact that designers use their empathetic abilities, creativity, and reflective skills (Schön, 1988) to tackle these messy and «wicked» situations. They add domain knowledge through iterative design explorations to build new knowledge and design meaningful experiences for users. The processes applied in design projects are often non-linear, fluid, and creative. Designers who successfully manage complex situations often use an approach referred to as the «designerly way» (Cross, 2004; Nelson & Stolterman, 2012), which asserts that, alongside recognized scientific and academic methods for generating knowledge

(which also have utility for design), there exist more practical and tacit methods of knowledge (van Manen, 2007). Through experiential learning modes, the so-called *learning by doing*, designers can constructively and solution-orientedly address ill-defined problems.

What hinders collaboration between the two disciplines is certainly their tradition and different purposes. It is a common opinion among designers that data reduce their creative freedom and introduce a reductive and simplistic approach, while designers are interested in unique, holistic, and comprehensive perspectives. From the user experience point of view, there is a concern that this quantitative approach reduces human behavior and experiences to *mere numbers*, thereby giving undue importance to minutiae and the optimization of small variations in the design (i.e., incremental innovation, King *et al*., 2017).

Similar (but opposite) concerns apply when data scientists are asked to involve designers in the design. Data scientists appreciate concrete and well-defined problems to which data can provide a univocal answer. Designers not only bring ill-defined problems, but these problems are also dynamic and continually changing. Despite the differences, design and data science work towards a common goal. As King *et al*. argue, «design and data science both aim to create an understanding of the world to create meaningful applications» (King *et al*., 2017, p. xii). Although both fields may have complementary qualities, the approaches that integrate them are less established. For designers to adopt the use of data in their processes, a more design-oriented approach to data is necessary. This would allow them to utilize the qualities of data approaches while respecting designers' ways of working.

2.4 Innovative Design Approaches

The primary authors who have formalized approaches to data-integrated design are King, Churchill and Tan (2017), and Speed and Oberlander (2016). The former defined levels of data integration, while the latter provided a comprehensive framework. The investigation by King, Churchill, and Tan (2017) in their book *Design with Data* is strongly

rooted in industry-based approaches within the predominantly digital sphere, drawing on various examples from digital companies such as Airbnb, Skyscanner, Spotify, Google, and Coursera. Throughout their work, the researchers identify three different approaches to designing with data: data-driven design, data-informed design, and data-aware design.

2.4.1 Data-Driven Design

Data-driven design is an approach used online on a large scale to collect data to validate a specific hypothesis or compare the impact of different features. The simplest example of this method is the A/B testing of two button colors for *sign up*, to discover which has the highest *click rate*. A web company provides option A to a selection of 100,000 users and option B to another 100,000 users and measures the number of clicks in both situations. This is a well-defined experiment, with a measurable success criterion, a representative audience, and simple statistical analysis where the data provide a definitive answer. Users participating in these studies often are unaware they are part of a study, as the experiment is well-integrated into the current solution.

For most digital companies, this quick and iterative method of optimizing the product has become an integral part of their way of working. For example, Google experimented with 41 shades of blue in its logo to find the perfect color based on these analyses. However, the limit of this approach is also found in interpersonal dynamics. A former visual communication manager at Google revealed that he left his job because of a «design philosophy that lives or dies strictly by the sword of data», which allowed very little artistic freedom. Similar examples are available for Facebook (e.g., large-scale experiments with different), Airbnb (e.g., the design of the best price range slider), Skyscanner (e.g., the design of the hotel search screen), and others. However, data-driven design is not limited to digital efforts. Lechner *et al*. (2010) show how similar strategies can be applied to use color analysis to inform, inspire, and validate design decisions in the pharmaceutical field, as they used it to design pills to maximize the likelihood of being taken.

Since the data-driven design approach relies heavily on concrete and measurable experiments, it focuses more on validation, local op-

timization, and redesign of existing features rather than on radically new design directions. In this sense, it shares much of its approach with evidence-based design, which advocates the use of statistical evidence to guide design decisions. For these reasons, data-driven design is probably more oriented toward the data side than the design side.

2.4.2 Data-Informed Design

In response to the reductive and analytical nature of data-driven design, companies have begun adopting data-informed design. Emphasizing the informative features of data rather than guiding ones, they argue that design decisions are often more nuanced than the definitive answers provided by data-driven design. Therefore, in data-informed design, data from experiments (still conducted on a large scale) are used only as a guide for design decisions.

In parallel, other user experience research methods are used to collect qualitative data. Within this approach, the designer does not have to be as targeted and concrete as in data-driven design because this design approach leaves room for interpretation. The main difference between the two approaches is that data-driven design starts with a specific question that data can unequivocally answer. In data-informed design, the question can be broader, and the data are used only to inform the answer, as the designer can also use insights from other techniques or more qualitative research approaches.

2.4.3 Data-Aware Design

Data-aware design (King *et al*., 2017) advocates a more design-driven approach. The idea is that data can not only help make decisions, but design, as a creative practice, must also think about the data themselves. The way a product or service is instrumented, what data are collected, and how they are combined are design issues that define what can be done with the data. Compared to the previous modes of data engagement, King *et al*. (2017) argue that data-aware design is a more multidisciplinary approach that involves designers, data scientists, developers, and business managers to actively design systems that directly inform future strategies. A data-aware mindset means that the designer is well aware of what

other data might be relevant and available and how they can help solve the problem. Therefore, it is a mindset or a *design philosophy* rather than a concrete approach.

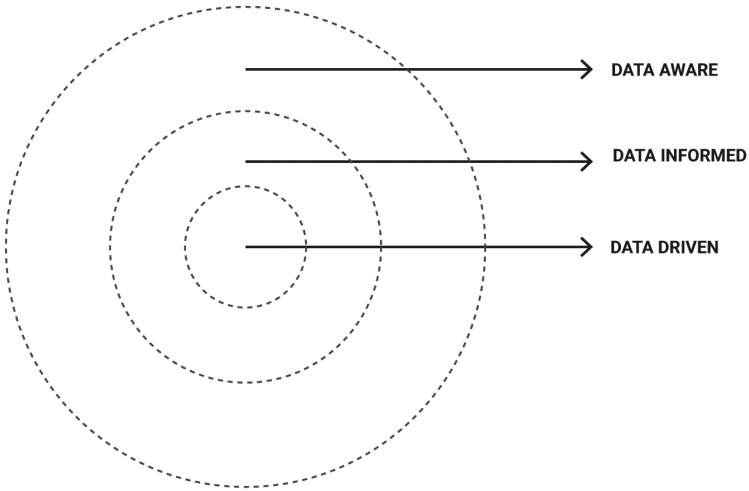


Figure 2.
Approach in data design.
Source: King *et al*., 2017.

2.4.4 Designing From, With, and By Data

While King *et al*.'s (2017) framework for data engagement in the design process focused mainly on industry-based approaches in the digital field, Speed and Oberlander (2016) present a framework more suitable for the design research community. According to them, the relationship between design and data can be defined according to three main approaches: designing from data, designing with data, and designing *by* data. In designing from data, systems are inspired by data that refer to human characteristics, such as user preferences, behaviors, and opinions. In designing with data, systems are supported by access to digital networks that continuously generate enormous amounts of data. Finally, in designing *by* data, *systems are designed by other systems*, that is, products and services designed by intelligent agents, such as machines, algorithms, and data-intensive technologies.

Designing from data means some data inspires the design process. This can be any type of data. For example, data on how long people spend in a restaurant to inform the design of a new restaurant chair or sales data of a series of watches to inform the design of a new watch. Designing with data describes a design process in which

data are used as material for the design, and in this category fall data visualization approaches, where data are used in the process to explore and experiment with which data visualizations are most effective. Finally, designing by data presents a more futuristic scenario where data, supported by algorithms, become the designer. Parametric design and generative design are examples of approaches that use algorithms and data to design with data. Based on data, such as those related to product use, the product could update or (re)design itself. As these solutions become self-learning and self-developing, data begin to play an evident role in this process.

All the approaches collected in the literature respond to specific objectives at different stages of the process in which they are employed. From Deutsch's definition, more related to the field of architecture, to King *et al.*'s (2017) close to the world of enterprises, or even Speed and Oberlander's integration of the world of creative computing, each of these approaches has the clear merit of advancing the research for clarification of concepts.

If King *et al.*'s (2017) perspective emphasises data from (semi) controlled experiments, Speed's perspective is more rooted in design research, supporting the role of data as more supportive. In this paragraph, we discuss the approaches and terminologies in light of our challenge to integrate data into design processes for fashion sustainability. Reflecting on King *et al.*'s work (2017), their data-driven design approach is probably less suited to the complexity and breadth of our design challenge, as the latter requires a more exploratory than evaluative approach.

Data-informed design leaves more freedom to the designer and thus allows for formulating more open-ended questions, but still starts from a rather defined goal (which poorly defined design problems often do not have. For our challenges, we see a clear value in the data-aware philosophy, which considers the role of data from the beginning and throughout the process. However, this philosophy is only briefly introduced. In Speed's work (2023), we see the value of all three ways of engaging data. Since all three approaches use data to inspire and inform the starting point of the design process, data can help identify some of our more confused, broad, and complex challenges. At the same time, the engagement of these data throughout

the process could help us better understand what we are designing (i.e., be data-aware), which could iteratively inform new interventions.

However, in their work, designers who work with data are more focused on designing business models and integrations into the world of visualization or designing smart solutions for the ecosystem that learn and adapt based on these data. Finally, data-based design offers an interesting potential future but describes more a solution itself than an approach that designers can use to design.

2.4.5 The Nature of Data

The data discussed so far are characterized by large volume, variety from multiple sources, and velocity (in relation to data processing speed) (Laney *et al*., 2001). Examples of such data can come from sensors, such as GPS location tracking or equipment logs, but also from social media data. As such, data tend to be numerous but usually lack context. The growing ubiquity of data and the trend towards datafication (Lycett, 2013) can open a promising path for design, and the goal of this research was to verify that these data can be integrated to develop sustainable fashion strategies. This approach, which provides context and applies a process of *humanizing* data, would allow for acquiring new knowledge about people's complex behavior both at the scale of research, design, and engineering of human-centered systems, otherwise unavailable with more traditional methods (Bourgeois & Kortuem, 2019). Thick data, such as qualitative data from interviews, sessions, and observations, have been applied in the design process for decades (Creswell, 2017), and for this reason, the importance of data itself is recognized, and many research methodologies have been developed to activate qualitative and contextual data (Bryman & Burgess, 1994). On the other hand, data generated in large quantities from many connected products, services, and systems open opportunities for large-scale data collection and analysis, providing precise and timely insights into human behavior (Lazer *et al*., 2009; Thorpe *et al*., 2012; Feinberg, 2017).

In design, these *big* data are commonly used in analyzing customer reviews (Suryadi & Kim, 2019) or product usage and are widely used in fashion to predict trends. Despite their distinct characteristics, *big* and *thick* data can offer a comprehensive understanding of

users, their behaviors, and the context. While Big Data can provide generalized insights representing a broad population, thick data can be used to deeply understand the context, emotions, and needs of users. Recent literature highlights that designing with data is often a hybrid approach, where Thick Data and Big Data are applied sequentially and seamlessly. The latest approaches combining data throughout the design process include data-enabled design (Bogers *et al*., 2016), participatory data analysis (Bourgeois & Kortuem, 2019), and data-stimulated design (Dove & Jones, 2014), where data are used to prototype and generate knowledge from data-driven objects (Giaccardi *et al*., 2016) and through evaluation methods such as A/B testing (King *et al*., 2017). These approaches highlight the importance of blending thick and big data throughout the design process.

It is important to note that each of the different data design approaches uses different types of data. Based on the various approaches, we can further distinguish research data and solution data. The examples from King *et al*.'s book, which address digital products and services, add an additional level of recording or detection for the sole purpose of answering a research question. This type of data used is not part of the solution itself but serves to make decisions and plan/design a solution.

We can define research data as an additional layer of data added to a solution solely to answer a research question posed by a research team. In the work of Speed and Oberlander (2016), however, we found during the visiting period that the data are used differently. The data they mean in the framework and include in the design process are already part of the solution or will become so. In this, they differ strongly from the research data used by King and colleagues. Solution data, in fact, can have different formats: they can be raw data (e.g., directly from sensors) but can also be metadata generated by algorithms from raw data (e.g., event duration). They are also the data shared between devices and services in the smart ecosystem and thus also influence interactions in the ecosystem. Even if research data are never used to drive the solution, solution data can be useful for research purposes.

A practical example is the Netflix platform, which tracks users' browsing behavior to determine which movies interest them. These

solution data can also be used by the design researcher (i.e., as research data), for example, to understand how users' tastes evolve over time. Solution data are data that are an integral part of the solution and drive interactions in the smart ecosystem. Removing or modifying them would have a direct impact on the interactions.

The different approaches used to integrate data into design also give us a different perspective on the concept of data analyzed in the previous chapter. In data-driven design, data are seen as an objective and indisputable measure, and for this reason, the same data always have the same meaning and are comparable for research purposes in an objective and A and B scenario. This type of data can be identified in any field of design, including fashion, and can provide an unconditional answer, a valuable perspective on data that can be used to evaluate product characteristics. For example, some characteristics of clothing items can be evaluated by users, and they can provide an objective answer: if during the launch of a collection, a blazer is presented in two colors, users can establish before production which color is more in line with users' preferences in a given territory.

In contrast, in data-informed design, the perspective on data is one that leaves more room for subjectivity and interpretation. In this case, qualitative data are combined with quantitative measures to provide a more contextualized understanding of the data. This approach argues that quantitative measures alone never tell the whole story because the meaning of numbers depends on context. In the fashion world, we often forget that a significant amount of subjective sensations can be applied to clothing items: we connect to the stories of clothing items, relate to them, generate an emotional bond; and this part of data in the industry is not yet collected.

While both of these approaches focus on research data, the different perspectives they introduce can also be valuable for solution data. In designing smart ecosystems, which aim to be personal and adaptive to people's rich and versatile lives, we can recognize the value of a more contextual and personal perspective on data, especially when interfacing with a complex and layered system like fashion. This shows greater analogies with how data-informed design treats data, as the meaning of data is (partially) created by the interpreter.

In this way, the same data can have different meanings for different people in different contexts.

Lupi (2017), for example, supports a similar hypothesis, as her work magnificently demonstrates the value of attention to the (personal) stories behind the data, rather than the numbers themselves. This broader and more contextual definition of data can help develop smart ecosystems that are personal and context-dependent, as this perspective is more respectful of individual uniqueness and contextual richness. These two characteristics, in particular, fit well with the fashion context that we will analyze in detail throughout this volume.

2.5 A Conceptual Framework for Design

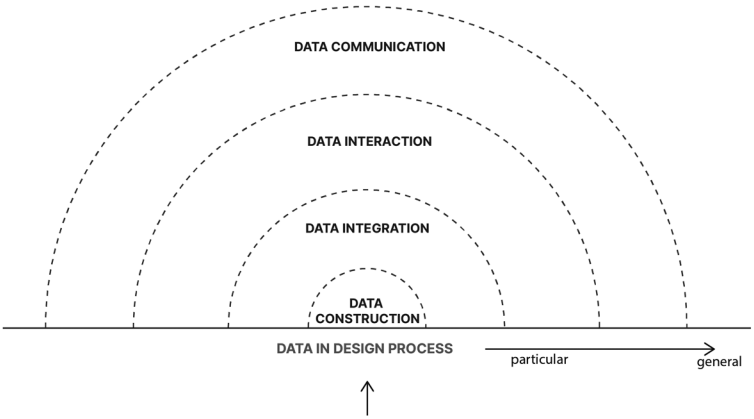
The formulation of the following conceptual framework results from an extensive literature review and aims to outline potential approaches to data within the fashion system. The initial phase of analysis sought to broadly investigate existing models and methods. The findings revealed that the notion of *data* associated with design disciplines is under-theorized and that there is a significant disparity in the literature favoring the field of design engineering. However, such investigations provided insights too superficial to assist designers in integrating data into the design work, necessitating the development of an additional research framework.

All these perspectives address the issue of data through a siloed structure. Therefore, for an interdisciplinary understanding, this research adopts a systemic approach to data that goes beyond mere *numbers*. This approach is essential to observe and approach the wide variety of data practices in the design process, especially to apply them in socio-technical contexts with a sensitivity towards sustainability.

Considering the existing gaps in the literature, this section recommends four perspectives for studying the integration of data into the design process, namely:

1. *Data Construction*: exploring all data collection practices in design.
2. *Data Interaction*: exploring interactions between designed objects derived from data to those resulting from data outputs.

Figure 3.
Conceptual framework
for data design.
Source: Author.



3. *Data Integration*: integrating data at multiple stages of the design process.
4. *Data Communication*: exploring practices for data communication.

By examining theories and concepts through these four dimensions, it becomes possible to identify new ways in which research can explore design practices in conjunction with data science to understand and, more importantly, develop models and methods capable of bridging the two fields. This framework, at this stage, includes only notions belonging to theories and research concerning data in the general design context.

3. Data, Fashion and Sustainability

3.1 The importance of Data in Fashion Sustainability

The fashion industry faces a challenging data landscape. Lack of transparency, isolated data, paywalls, and misinformation abound, hindering the sector's progress toward sustainability goals and impactful change (Ellen MacArthur Foundation, 2017; BoF & McKinsey, 2021). Therefore, it is increasingly crucial to understand data and how to utilize it effectively to be a positive change agent in the global fashion industry. This section analyzes data sources, the current data landscape in fashion, measurement tools, data ethics, motivations for data use, and common data myths.

Fashion brands rely on a certain degree of data for precise, organized, and efficient collection planning. These data vary in source and utility, but each brand has an ideal and personalized formula for optimal collection planning. The greatest challenge in identifying this *formula* is often knowing which sources to prioritize, whether internal or external. Moreover, these sources are not only numerous but also varied. Identifying the best data sources, such as past sales data,

consumer feedback, or market demand, requires specific collaboration between the teams involved in collection planning and, importantly, a method for utilizing the various data sources unilaterally. Data in the fashion industry are essential for trend forecasting, inventory management, consumer behavior analysis, and generally fostering a more data-oriented mindset (BoF & McKinsey, 2019). From the design phase to the marketing phase, data play a crucial role in creating collections, even for brands that are not fully digitally transformed. Indeed, the fashion industry is becoming increasingly digitized at both the brand and consumer levels, and finding a way to integrate multiple data sources can enhance collection planning.

The most evident phase of collection planning is identifying trends to include in the upcoming collection. This process often begins with designers and merchandisers evaluating the market, their competitors, and their personal affinities. Designers particularly draw from trend books, fashion shows, street style, trend websites, social media, and more. Concurrently, quantitative data are involved in various ways, including in-store sales data, online retail sales data, social listening, trend forecasting, and more. These data serve to confirm a designer's intuition or indicate a new direction, and although useful, the volume of information is often very large.

3.2 Measuring Sustainability in Fashion

In recent years, the fashion industry has increasingly turned to data to measure and enhance sustainability efforts. With fashion contributing significantly to environmental degradation, companies are under pressure to implement data-driven strategies to minimize their ecological footprint.

One of the key frameworks for measuring sustainability in fashion is the Life Cycle Assessment (LCA). This approach evaluates the environmental impacts associated with all stages of a product's life, from raw material extraction through production, use, and disposal. The Quantis report, *Measuring Fashion: Insights from the Environmental Impact of the Global Apparel and Footwear Industries*, highlights five key indicators: Climate Change, Resources, Freshwater With-

drawal, Ecosystem Quality, and Human Health. This multi-indicator approach ensures a balanced assessment and helps fashion brands set science-based targets for reducing their impacts (Quantis, 2018; Accenture, 2024).

Regulatory frameworks also play a critical role in driving sustainability in fashion. For instance, the proposed Fashion Sustainability and Social Accountability Act in New York mandates large fashion companies to map at least 50% of their supply chains and disclose their environmental impact. Similarly, the U.S. Securities and Exchange Commission requires companies to provide reliable climate-related data to investors, promoting transparency and accountability (BoF & McKinsey, 2021).

Data-driven sustainability is not just about compliance; it can also lead to significant business benefits. According to BoF & McKinsey, products with multiple sustainability claims grew twice as fast as those with fewer claims, demonstrating that consumers are increasingly willing to support sustainable brands. This trend is further supported by consumer surveys indicating that a substantial portion of the population, especially younger demographics, prioritize sustainability in their purchasing decisions (BoF & McKinsey, 2021; Accenture, 2024).

The fashion industry faces several challenges in achieving sustainability. One major issue is the complexity of supply chain transparency. Many brands lack direct relationships beyond their tier-one suppliers, making it difficult to obtain accurate primary data for emissions and other environmental impacts. This often leads to reliance on industry-average data, which can be inaccurate (BoF & McKinsey, 2021).

Another challenge is the implementation of sustainability initiatives across the entire business model. Effective sustainability integration requires collaboration across various business functions, from design and sourcing to marketing and retail operations. This holistic approach ensures that sustainability is embedded in the core business strategy rather than being treated as an add-on (Accenture, 2024).

Despite these challenges, there are clear pathways for fashion brands to improve their sustainability performance. Transitioning to renewable energy, adopting circular economy principles, and en-

hancing supply chain transparency are critical steps. For example, switching to renewable clean energy sources could reduce the carbon footprint of the clothing industry by 63% (BoF & McKinsey, 2021).

The push for sustainability in fashion is driven not only by regulatory pressures and consumer demand but also by the industry's recognition of its environmental responsibilities. By leveraging data and technology, fashion brands can make informed decisions that drive both sustainability and profitability. This data-driven approach is essential for the fashion industry to meet its sustainability goals and contribute to global efforts to mitigate climate change and protect natural resources.

3.3 Data for Circular Fashion

Textile products are an essential part of our daily lives, but their production and use are currently unsustainable. The textile industry is responsible for producing more emissions than all international flights and maritime transport combined and is the second-largest global consumer of water (European Environment Agency, 2019). The environmental burden of textile products can be reduced through a sustainable circular economy, primarily by extending the useful life of textile products and circulating textile materials at the end of their life cycle. In a sustainable circular economy, supply chains are transparent, and materials and products can be traced back to their origins. To achieve this, having the right amount of information from the right sources – data, in other words – is essential (Kerr & Landry, 2017).

Data also play a crucial role in service-oriented business models focused on extending the life span of textile products. Circular economy systems are complex and require the effective collection, processing, sharing, and utilization of data (Stahel, 2016). Data for circularity are central to projects such as the Circular Design Network, which aims to bring together various stakeholders and enable better use and new circular opportunities based on data (Ellen MacArthur Foundation, 2019). Through a network of actors including company representatives, experts, and researchers, the project works on the different possibilities and challenges related to data in the circular

textile economy, identifying relevant data sets that can be used to narrow and close loops in the production and recycling of consumer and work products.

3.3.1 Data in Circular Economy Models for Consumer and Workwear Products

Data also play an extremely important role in consumer-based circular economy models, such as second-hand trade, clothing rental, and leasing services. In addition to product information, second-hand operators benefit from data on product conditions, as this is crucial in determining resale value. For instance, the startup R4Circular, introduced by Atelier RiForma, and the *Tommy for Life* project collect data on common damage points in clothing products (Ellen MacArthur Foundation, 2019). However, as in other areas such as traceability or measurability in the fashion sector, the challenge lies in the lack of common standards: currently, second-hand operators have their own standards for pricing based on different condition classifications. From a consumer perspective, standardized classification would make it easier to compare product conditions and prices, making second-hand purchases more attractive (BoF & McKinsey, 2020).

In clothing rental and leasing services, product and condition information is particularly important. Data on usage, washing, and repair activities are also crucial. These data enable a more accurate assessment of product conditions, maintenance needs, and potential for further use cycles. Additionally, consumer feedback has been considered a valuable data source for the future. The challenge is to motivate consumers to provide feedback (e.g., on product qualities, suitability, and conditions). The role of automation in data collection will become increasingly important, as this work is currently done manually.

In the B2B workwear industry, such practices are already in place, as manufacturers and suppliers have long applied data for the «clothing as a service» (CasS) model (Stahel, 2016). These best practices could promote the development of consumer-centered service models in other product segments. Closed-loop models, where workwear is intended for recycling or refurbishment by the service provider, could serve as a benchmark for consumer-oriented service providers. From the perspective of workwear customers (such as the

construction industry, hotels, and restaurants), relevant data include product information (measurements, material, potential standards for qualities such as reflectivity, manufacturer and origin, assembly, and environmental impact). A transparent supply chain would enable value-based purchasing decisions. In *clothing as a service* models, maintenance information (number of washes and repair details) is also relevant. Laundries can use data to avoid short-term washes and save energy. However, at the product level, these data are difficult to collect. The quantities of textiles (in tons) in the washing process are important data for laundry operators.

3.4 Value Chain and Production Data

In a linear textile industry model, the use of product information (e.g., materials, origin, and supply chain) has been rather limited. Transitioning to a circular textile economy elevates the requirement for accurate product information to enhance the sustainability of materials and supply chains (Ellen MacArthur Foundation, 2019). Additionally, new data requirements will emerge to ensure effective, economical, and safe product cycles, including the transformation into new raw materials. It has been concluded that during the production process, information is typically transferred from one stage to another but generally does not accumulate further along the value chain.

From a production perspective, data are essential for ensuring product and material traceability, enabling supply chain transparency, and optimizing production processes. Recycling introduces further demands, as the information transferred along the products allows for the selection of textile waste and the appropriate processing and recycling methods. Beyond fiber composition, factors such as colors and finishes, dirt and potential contaminants, hard parts like buttons and zippers, and the fabric structure affect how the textile can be treated during recycling (European Environment Agency, 2019).

Regardless of whether the product is new, second-hand, or made from recycled materials, clothing brands, second-hand retailers, and service providers are interested in the sustainability of products and the stories that accompany them for marketing purposes. As the cir-

cular economy and recycling systems are still emerging and driven by legislation, data collection is also necessary for statistical needs and waste monitoring. From the perspective of production and recycling value chains, a common data system that covers the entire value chain is needed. This system should be flexible, user-friendly, and harmonized. It should include sufficient data for various needs and allow for the comparison of environmental impacts of different activities. Further research and development are needed for waste recovery and recycling to discover new business opportunities.

3.5 Data for Increasing Systemic Sustainability

The literature analysis was extensive, encompassing multiple perspectives from various disciplines. To facilitate understanding of the gaps that led us to identify field data collection, we have categorized them as follows.

3.5.1 Critical Interdisciplinary Relations

From the analysis conducted, the primary challenge identified is the need to develop new skills and engage with methods, tools, and other professions, necessitating continually new definitions of the boundaries of this discipline. While design is capable of integrating and incorporating diverse knowledge, thereby broadening the increasingly complex domains of discipline-related issues, the functional and technical limits of interfacing with data science must be recognized.

The literature demonstrates that integrating data into design cannot be a linear function responding to a single problem. As Seidelin *et al*. (2020) highlight, reflecting the views of many researchers, a more data-conscious design, regardless of the design order, requires that both the data and data practices be made comprehensible to designers in ways that are more synergistic with design processes (Churchill, 2012; Speed & Oberlander, 2016; Feinberg, 2017; Kun *et al*., 2018).

This necessity arises because design often finds itself at the crossroads of various disciplines, sometimes with difficult dialogues between humanities and technology/engineering or creativity and

management. Achieving what Celaschi (2008) calls a «sustainable balance» – the sensitivity to research and operate without significant distortion from one or the other side of the axis, which in this case places the more humanistic characteristics of design at one end and the more technical characteristics of data science at the other – remains a challenge.

This distortion is even more evident when identifying significant case studies in these interdisciplinary relationships, revealing gaps between application sectors and collaboration outcomes. Including a data scientist in design teams to incorporate data analysis techniques, for instance, is the most common practice but often exclusive to large companies with substantial budgets (Kun *et al*., 2018). Conversely, in prosperous business contexts, there are evident attempts to integrate the other dimension by applying design thinking models to data practice, emphasizing that data and design belong together (Minah, 2019); when separated, they represent wasted potential (Kuosmanen & Valmari, 2019); and that data without design is merely raw material (Wettersten & Malmgren, 2018). According to Mortati (2021), it is difficult to envision design overwhelming the field of data science; rather, the potential lies in creating a new conversational bridge between the two areas, integrating current curricula with competencies (or at least sensitivities) that enable this dialogue.

Therefore, despite the recognized need for designers to leverage data and for data science to apply design-driven processes, activating such a dialogue, there is a lack of empirical knowledge in the literature on how designers use and adapt data science practices and methods.

Moreover, current data practices in design are mainly confined to the solution space. However, it is essential to specify that data for design disciplines should not merely represent the solution to a problem or the design of a specific function. Viewing data from a design perspective means that their construction, integration, interaction, and communication represent a multi-layered set of interconnected design activities that do not conclude as the output of the process but produce multiple outcomes. Therefore, we propose construction, integration, interaction, and communication of data as four interrelated perspectives through which to view data practices through the

lens of design. These four aspects, in our opinion, form the theoretical basis necessary for a *sustainable balance* between disciplines, regardless of the application sector or the sought solution.

3.5.2 Terminology and Imperfect Data Collection

Terminology and indicators related to sustainability are complex. The way information and terms are interpreted plays a significant role in data usability. Information on different products must be reliable and comparable. Missing or non-comparable information on product dimensions and fit is a challenge, especially in second-hand commerce. Consumers and all actors in the clothing industry are curious about how recycled fibers affect product durability and quality.

However, data sharing is challenging. Data must be reliable and verified, allowing for comparisons between different suppliers and products. Collecting and sharing data concerning, for example, military or police workwear, may not always be possible. End-users of workwear will also benefit from product information, enabling them to make sustainable and suitable choices and educate themselves on how to wear and care for the product optimally. There is a growing need to collect data and develop the skills to use it as we move towards a more sustainable and circular textile industry. Transparency in production value chains, as well as reliable and comparable data, are considered prerequisites for making more sustainable choices throughout a product's life cycle. This is feasible starting from the product design phases. Data on the environmental impact of products are increasingly important for both consumers and companies. Through data, clothing brands can make better and more sustainable choices and designs regarding the life cycle of their products and develop services for longer life cycles. All actors in circular textile value chains are valuable as producers and users of data. For example, consumers have experience-based information regarding product durability, maintenance, and repair needs. The goal of this volume is to ensure that all this new knowledge can be used by clothing brands to design more sustainable products.

4. Leveraging Data Design in Fashion: Conversations and Case Studies about Data & Fashion

4.1 Best Practices in Fashion Ecosystem

As noted in the literature analysis, the fashion industry is undergoing unprecedented change. On one hand, it contributes to the degradation of global biodiversity and undermines nature's ability to provide ecosystem services to society. On the other hand, it possesses the potential and resources necessary to redesign our cultural paradigms towards a more hopeful and sustainable future. However, alongside the growth in fashion consumption, there has been a parallel increase in the information available to both large and small companies, enabling better management of the complexities of such an interconnected and variable-rich system. Access to millions of data points from various sectors demonstrates that the most recent competencies require a strong awareness to address the world's most complex problems. The *data deluge* is already beginning to transform businesses, public administration, science, and daily life. Sectors such as telecommunications, financial services, retail, healthcare, media, and communication are among the most affected (Banica & Hagiu, 2016).

Today's rich informational landscape is fueled by every sector that moves objects, sells to consumers, uses machinery, generates or utilizes content, and provides services involving money. Therefore, the ability to collect, understand, interpret, and communicate information has become fundamental, with significant consequences and impacts on how we operate and act. This has become a strategic reading of the context, quantifying sustainable and unsustainable aspects not only at the individual level but, more importantly, at the collective level. Applications of data analysis strategies can be diverse, ranging from organizational and strategic decisions to the development of new consumer products and/or services (Banica & Hagiu, 2016).

For instance, Netflix, a service for distributing films, TV series, and other entertainment content, identifies and defines approximately 80,000 micro-genres, thus creating the first personalized TV experience (Marr, 2016). In general, data in companies have not only changed technologies but also processes, management, and the orientation of organizational culture. By investigating and considering concepts such as sustainability, transparency, traceability, and awareness as final goals, this article aims to explore the technical, social, and creative challenges useful for reconfiguring the fashion industry starting from the use of data.

Big Data has been gaining crucial and increasing importance in the fashion world over the last decade. Essential experiments regulate trend forecasting, strategies for optimizing supply chain management, the analysis of online and offline customer attitudes, customer preferences, and the forward-looking definition of their behavior patterns (Tham, 2008). The fashion world today is subject to rapid, continuous, and difficult-to-interpret changes. Customer demands range from personalized styles to homogeneity, requiring millions of people to seek similar types of clothing with only slight differences in detail (Farley & Hill, 2015).

Some case studies, unfortunately still detached from a systemic vision, illustrate how having new categories of data can be useful for creating new services and making the shopping experience more inclusive of consumer needs, more profitable for the company, and environmentally friendly. The methodological approach applied to the case

studies that follow was exploratory, using literature reviews and data from individual websites. The aim was to highlight as many case studies as possible to understand how a data-driven strategy could somehow enhance or facilitate sustainability practices, connecting or increasing the amount of information circulating in the fashion system.

For example, ASAP54 is the most comprehensive dataset of fashion items and can simplify the search for a specific garment. By relying on the app's database, users can photograph a dress or a simple pattern detail to find a match with an item. The system, referencing images from catalogs, can recognize the photographed object. If it is not available in the database, the app will provide a set of similar products. Ultimately, the system can redirect the user to a site where they can purchase the item online. This project offers a search service with the potential to become a shopping portal for multiple sites.

Another service capable of creating a beneficial relationship between information management for the company and the consumer is Arket. Born with the mission of democratizing quality through widely accessible, well-made, and durable products, their design aims to be used and loved for a long time, avoiding the need for constantly new items (Arket Identity, 2018). The Arket system is based on the Arket ID, a unique nine-digit code assigned to and displayed with each product. This system was created to make it easier for customers to find and locate products both in physical and digital stores. The code also functions as a tool for archiving, recording, and preserving the company's products. This system not only allows for the indexing of products and the knowledge of their details but also facilitates the relationship between user searches and corporate information management. However, this useful project lacks substantial contributions in terms of transparency and traceability of the garments. Making the production stages of a garment known would provide consumers with greater ability to make informed choices among their products. In this sector, the case study of Provenance appeared comprehensive. In collaboration with Martine Jarlgaard, a British fashion producer, Provenance tracked the world's first garment with a unique ID containing location mapping, content, and timestamps for each production stage. The information on the garment's journey was made accessible via the smart label of the garment (Provenance, 2017). This case demonstrates that a

significant database could support the implementation of blockchain in fashion supply chains to increase sustainable value.

Working with data in the fashion sector means making the intangibility of the shopping and consumption experience tangible. Amazon achieves this through a collection of collectible photos using its new device to compare outfits and determine which looks better. Among all the projects researched, this is one of the few that considers the consumer experience post-purchase and aims to create a lasting relationship between the customer and their clothes by improving the management of outfits and wardrobes. Echo Look can manage the wardrobe automatically by integrating other data sources such as weather, occasion, season, and even mixing territorial and personal data.

The Stitch Fix platform bases its business on the personal experience, the way we dress, and how we present ourselves to the world. By collecting data on fundamental elements of a customer's preferences and condensing them into an algorithm, Stitch Fix provides personalized recommendations for each of its clients (Stitch Fix, 2018). This radically changes the shopping experience. In the traditional sales model, customers enter a store, search for available garments, and look for items that best fit their general style. With data-driven personalization, machine learning systems, and AI better understand customer psychology. The company, therefore, acts as an intermediary between the client and their personal style, focusing on various aspects of the shopping experience, such as emotional value, rather than relying on a weak relationship based on consumption trend logic.

The customer is then sent a box of pieces, and human input and their personal decision-making process become integral parts of the algorithm. Ultimately, the entire process is based on the idea that data-driven decisions are functional not only for customers but also for the entire company. Similar to other companies, Stitch Fix leverages data to automate both internal and external processes. However, the true strength of this vision is never neglecting the human factor in the entire system design process but rather integrating it, making the entire process adaptive to this variable.

Another case where the contribution of personal data is crucial is the Data Dress developed by Google in collaboration with Ivyrevel.

The app records the user's activities and lifestyle, creating the perfect Ivyrevel dress for the occasion (Coded Couture, 2018). Users need only specify the type of event: business, party, or gala. By integrating the user's personality into the design process, the system creates a custom digital dress.

This rapid overview of case studies demonstrates a significant lack of scientific consideration for data related to clothing use and the impact of production on sustainability. New technologies can offer a new value chain that, through the collection and analysis of data, allows actors not only to engage potential customers or increase sales regardless of their location and activities but also to guide production towards a sustainable path and style in line with user characteristics.

4.2 Best Practices for Revolutionize the Fashion System through Data

The case studies were classified according to the following framework. Specifically, the first level of analysis concerned the type of focus, distinguishing between case studies centered on the product, service, or the overall system. The second level of classification included the technology employed. Specifically, the eight technologies identified from the literature review were analyzed: IoT, Artificial Intelligence, Machine Learning, Augmented Reality, RFID, Blockchain, and generically Cloud, when data stored in the network became an asset for the enterprise. Based on the technology and focus, the types of information were identified. Finally, the framework included the phases of the product life cycle and a description detailing the investigated case study and the year of its establishment.

1. *Nike Advanced Apparel Exploration 1.0*
Nike has combined computational design with its innovative knitting technology to create a capsule collection of men's apparel. The *Advanced Apparel Exploration 1.0* collection is the first in a series of data-driven clothing lines to be designed by the sportswear giant. This convergence allowed Nike to integrate data-mapping-based design with its Flyknit technology, which enables the weaving of nylon

and elastane yarns into varying thicknesses within a single piece of fabric. Designers collaborated with Nike Flyknit's engineers and computational designers to transform these body maps into a dataset, which was then fed into the company's knitting machines. The result is a seamless single-layer garment that features enhanced ventilation on the back and increased coverage on the chest.

- *Organization*: Nike, Flyknit
- *Keywords*: knitting, product, data-informed design
- *Technology*: Big data
- *Year Founded*: 2017

2. *Brarista*

Brarista is an AI-driven bra fitting tool that allows consumers to find the perfect fit using their phone's camera. In collaboration with behavioral psychologists, the project tests and improves user interaction and experience, aiming to ensure consumer trust in a virtual bra fitting service.

- *Organization*: Brarista
- *Keywords*: fitting phase, no returns, design phase
- *Technology*: Big Data; Artificial Intelligence
- *Year Founded*: 2021

3. *Jacquard by Google*

Jacquard is the first wearable technology platform embedded in jackets, backpacks, and shoes, enabling connectivity between clothing and smartphones through simple gestures. This technology aims to integrate wearable elements into everyday objects, such as clothing, in a discreet and intuitive manner without significantly altering their original appearance. The first product, launched in 2017 in collaboration with Levi's, was the *Commuter Trucker Jacket* featuring Jacquard technology. This wearable and modular device offers an innovative experience that fosters a long-lasting relationship between the consumer and the product, thereby delaying obsolescence, and enhancing consumer trust in the brand.

- *Organization*: Google, Levi's, Saint Laurent
- *Keywords*: Data experience, wearable, IoT, tracker
- *Technology*: Big Data, IoT, Cloud
- *Year Founded*: 2017

4. *Tech Polo Shirt*

The Ralph Lauren *Tech Polo Shirt* is a high-performance smart shirt that provides active biometrics through a wearable garment. Produced in collaboration with the Canadian company OMsignal, which comprises experts in neuroscience, sports medicine, and engineering, the shirt is equipped with a sensor capable of collecting the wearer's data. Through connectivity with a smartphone, it is possible to read biological and physiological information. The captured data, such as movement, direction, heart rate, respiration, stress levels, and energy output, are stored in a *black box* and transmitted to smart devices via the cloud.

- *Organization*: Polo Ralph Lauren
- *Keywords*: Data experience, wearable, IoT, tracker
- *Technology*: IoT, Cloud
- *Year Founded*: 2016

5. *Tommy for Life*

Tommy Hilfiger has launched several circular business models through *Tommy for Life*. The project takes used TOMMY HILFIGER and TOMMY JEANS garments and retail-damaged items to repair and resell or remix into new, unique styles. To implement the take-back program, the company partnered with The Renewal Workshop (TRW). Products collected by TRW are cleaned (using waterless cleaning technology), repaired, and then sent back to *Tommy for Life* to circulate among users. *Tommy for Life* provides Tommy's product teams with data on the most common damage points of an item, which can be incorporated into the design process to create more durable products in the future.

- *Organization*: Tommy Hilfiger
- *Keywords*: Data experience, wearable, IoT, tracker
- *Technology*: IoT, Cloud
- *Year Founded*: 2016

6. *Data dress by Ivyrevel*

Ivyrevel, in collaboration with Google, developed the *Data Dress*, a smartphone app capable of creating customized dresses. The development process of these dresses relies heavily on smartphones: the app records the user's activities and lifestyle to create the perfect Ivyrevel outfit for any occasion. Once the type of event is specified,

the app handles the entire outfit development process, whether for business, a party, or a gala. The dress model shown in the image reflects the user's usual routes, shifting the focus of the data to an idea of extreme personalization.

- *Organization*: Google
- *Keywords*: personalization, Data dress
- *Technology*: Data Analytics
- *Year Founded*: 2017

7. *Aware™*

Aware™ validates the sustainability claims of textile products by providing unique and verified data through tracking and blockchain technology. A simple scan can distinguish genuine sustainable fabric from counterfeit material, and it allows access to all traceability data. This information and certainty enable brands to be transparent.

- *Organization*: Aware™
- *Keywords*: authenticity, traceability, fashion materials
- *Technology*: Blockchain
- *Year Founded*: 2022

8. *8 by Yoox*

Yoox's design team launched their personal line called *8 by Yoox* using advanced and patented artificial intelligence tools. The creative team and data scientists analyze social media content and online magazines in major markets, particularly focusing on fashion influencers. The insights gathered in this research phase are cross-referenced with predictive indicators related to trends, site sales data, customer feedback, and industry purchasing trends, as well as text search and image recognition. Based on this trend table, the creative team starts working on the collection, meticulously inspired by the data collected, covering aspects from shapes to colors, sleeve lengths, neckline shapes, fabrics, textures, heel heights, and price levels. This case study represents the first fully data-driven collection for clothing.

- *Organization*: Yoox
- *Keywords*: Data science, Machine Learning, creative insight
- *Technology*: Machine Learning, Data science
- *Year Founded*: 2018

9. *iMirror*

The *iMirror* by NOBAL utilizes advanced omnichannel technology to transform the customer experience in the retail sector. The software employs Machine Learning, Virtual Reality, Artificial Intelligence, and analytics to deliver a high level of personalized experiences. The virtual fashion mirror offers an engaging and innovative way to collect valuable customer feedback, making it a perfect addition to any event or a permanent fixture in retail stores, especially in fitting or dressing rooms. This technology enables customers to enjoy a personalized, interactive shopping experience, allowing them to virtually try on different outfits and explore various styles with the convenience of a mirror.

- *Organization*: Nobal
- *Keywords*: omnichannel, retail, device, experience
- *Technology*: Machine Learning, Artificial Intelligence, Virtual Reality
- *Year Founded*: 2017

10. *Project Muze*

Project Muze is an experiment by the online fashion platform Zalando and Google that explores the creative use of machine learning in fashion. It allows users to become the muse for their own clothing, using their personality and interests as inspiration for unique designs. *Project Muze* is based on Google's open-source platform TensorFlow. Together with Zalando and the British production company Stinkdigital, they developed a predictive *design engine* consisting of two parts: a neural network – an algorithm modeled on the human brain – and a set of aesthetic parameters. The goal was to enable the neural network to make creative decisions. The algorithm was trained on the color, texture, and style preferences of over 600 fashion experts. Over time, it learned to connect these preferences to others with similar interests. Finally, through a series of aesthetic parameters derived from the Google Fashion Trends Report and Zalando's deep knowledge of fashion and trends, the models were refined to ensure they were cutting-edge.

- *Organization*: Google, Zalando, Stinkdigital
- *Keywords*: creativity, predictive analytics, design
- *Technology*: Machine Learning
- *Year Founded*: 2016

11. *Cap-Able*

Born from the intersection of fashion and engineering, Cap-Able has developed an advanced fabric – Cap-Able – that reproduces an adversarial image capable of deceiving facial recognition cameras. Originating in academia, the *Cap-Able Adversarial Knitted Fashion* project has produced the first collection of jacquard fabric designed to deceive cameras and protect the wearer's identity. The jacquard knit cotton garments are characterized by colorful, animal or geometric-inspired decorations that reproduce an adversarial image with imperceptible disruptive elements to the human eye, confusing the facial recognition algorithm, which can only detect the decorative patterns and not the wearer's face.

- *Organization*: Cap-Able
- *Keywords*: biometric data, privacy
- *Technology*: Machine Learning
- *Year Founded*: 2021

12. *WearMe30Times*

WearMe30Times is an initiative related to slow fashion, aimed at promoting the durable and continuous use of fashion products to counteract the throwaway culture of fast fashion. The initiative requires customers of participating brands to photograph themselves with the purchased product 30 times, demonstrating its prolonged use. Each time the customer takes a photo, they must log the operation via the QR code on the label. Blockchain technology ensures that all these operations are saved in a virtual database.

- *Organization*: EcoAge
- *Keywords*: Data standard, traceability, consumer behavior
- *Technology*: Blockchain, QR
- *Year Founded*: 2017

13. *Atma*

Atma is a cloud-based platform that creates, assigns, and manages unique digital identities that persist throughout the entire value chain of any physical object. The platform can distill all the nebulous data hidden within a product's value chain into insights for consumers and businesses. It shows exactly what a product is made of, where it has

been, its various footprints and certifications, and the correct end-of-life actions. Designed to be open, easily integrable, and highly flexible, *atma.io* solves the *market pain* of supply chains using different digital triggers on products, such as UHF RFID, NFC, or even QR codes, enabling the linking of all item-level events and product data into one end-to-end platform. The *atma.io* app store allows brands to tap into an ecosystem of applications to unlock all conceivable connected product use cases, and developers and partners now have the opportunity to build on the *atma.io* end-to-end platform and unlock new growth channels.

- *Organization*: Avery Dennison
- *Keywords*: Data standard, traceability
- *Technology*: RFID
- *Year Founded*: 2019

14. *Le Tote*

Le Tote is a fashion rental service that offers a monthly subscription, sending customers a personalized box of clothing and accessories which they can wear as they please and then return at the end of the month for a new selection. This allows customers to keep up with the latest fashion trends without constantly needing to renew their wardrobes. Le Tote's algorithm, Chloe, processes large amounts of data generated by each customer as they interact with Le Tote online and on mobile devices. By analyzing everything from sizes to order history and favorite items, Chloe can predict the products customers are most likely to be interested in each month, making the service highly personalized to the user's experience.

- *Organization*: Le Tote
- *Keywords*: rental service, preferences prediction
- *Technology*: Artificial Intelligence
- *Year Founded*: 2017

15. *Re-Fashion*

Re-Fashion is a second-hand clothing website that, through collaboration with EVRYTHNG, encourages consumers to recycle their unwanted garments by providing information via codes on care labels that can be scanned with a mobile phone. Active Digital Identities utilize data stored in EVRYTHNG's Product Cloud and allow clothing

manufacturers and retailers to create a unique digital profile for each product. With personalized and real-time information for each item, it is possible to track garments from their point of origin to their point of use, including recycling or resale.

- *Organization*: EVRYTHNG, Re-Fashion, New Look
- *Keywords*: marketplace, circularity, recycle
- *Technology*: RFID, Cloud
- *Year Founded*: 2011-2021

16. *Create2Stay*

Create2Stay is a re-commerce platform with a fully integrated plugin, white label, within Shopify, Magento, and Commerce Cloud. Create2Stay offers a solution that complements a brand's current e-commerce offerings, helping brands extend the lifecycle of their products. Create2Stay handles logistics, imaging, cleaning, repair, and recycling.

- *Organization*: Create2STAY
- *Keywords*: marketplace, circularity, traceability
- *Technology*: Blockchain, Artificial Intelligence
- *Year Founded*: 2022

17. *Zyosh*

Zyosh has developed an innovative technology in the form of a label that attaches to clothing like a regular sewn tag, informing the user of the *optimal recycling time* to avoid fabric weakening and minimize microplastic emissions. Zyosh creates the tag for companies tailored to the composition of their garments. They encrypt this information and transform it into a QR code. When sewn onto a garment, the QR code is invisible until the user washes the clothing, at which point the code becomes visible. Scanning the QR code provides information on where to recycle the item, whether the retailer offers a collection service, or whether to contact Zyosh to arrange a collection. Additionally, the label explains best recycling practices that can be used for all garments, not just those with the Zyosh label, such as removing buttons and labels at home.

- *Organization*: Zyosh
- *Keywords*: recycle, QR code, materials
- *Technology*: Big Data, Cloud
- *Year Founded*: 2022

18. *Resell Tag*

To promote the recycling of its garments, Scandinavian fashion brand Samsøe Samsøe launched the *Resell Tag*, a label sewn onto clothing featuring a scannable QR code to facilitate the resale of garments. The code triggers a series of automatic digital actions: once scanned with a smartphone, it connects to Meta's marketplace on Facebook and Instagram, automatically creating a listing template based on the clothing's data (style, size, color, age), complete with images. After previewing the auto-generated listing and adding the desired price for the item, the user publishes the listing, creating a hyper-localized campaign to promote the item to potential buyers.

- *Organization*: Samsøe Samsøe
- *Keywords*: resell, marketplace, social media, second-hand, circularity
- *Technology*: Big Data
- *Year Founded*: 2022

19. *Scircula*

Scircula is a startup focused on technology and Big Data to promote circular fashion. Through a data-driven approach, the startup supports fashion brands in eliminating fit-related returns to build a more profitable and sustainable business. Unlike other fit solutions on the market that focus on reducing returns in e-commerce, Scircula is intentionally designed to address fit issues throughout the entire value chain. By collecting data on sizes, fit, and consumer purchasing behavior at the SKU level, as well as in-depth information on each garment, Scircula can optimize fit, radically reducing waste: time, money, natural resources, and CO_2 emissions.

- *Organization*: Scircula
- *Keywords*: marketplace, circularity, awareness
- *Technology*: Blockchain, Artificial Intelligence, IoT, Machine Learning
- *Year Founded*: 2017

20. *Circularise*

Circularise's blockchain-based supply chain software platform acts as an information highway that connects supply chains from sourcing

to manufacturing and recycling, facilitating the transition to a circular economy. The company's system can be used in virtually all product value chains and collects valuable market data without violating customer privacy. This enables value chain actors to know where products or raw materials are located, predict where deposits will accumulate, and schedule logistical and recycling activities for specific materials.

- *Organization*: Circularise
- *Keywords*: marketplace, circularity, awareness
- *Technology*: Blockchain
- *Year Founded*: 2016

21. *Bendi*

Founded in 2020, Bendi is a startup with the mission to provide an integrated system that helps brands acquire, analyze, and act on data from their supply chains. The cloud-based application is designed to integrate with existing systems, including those used by suppliers worldwide, to create a single point of truth for sustainability data. Bendi examines both social impacts, such as working conditions in garment factories, and environmental impacts, such as the amount of greenhouse gases emitted or waste generated during production. This information can be displayed as part of product descriptions on a brand's website.

- *Organization*: Bendi
- *Keywords*: marketplace, impact, awareness
- *Technology*: Big Data, Cloud
- *Year Founded*: 2020

22. *PEAS*

PEAS (Product Environmental Accountability System) is a traceability and gamification system that provides information to encourage the prolonged use of garments. This innovative project, supported by Regione Lombardia, Politecnico di Milano, and companies MOOD, 1TrueID, and WWG in collaboration with WRÅD, makes all information about the origin and impact of our clothes visible. Additionally, through an algorithm, it communicates how the initial environmental cost of a garment is amortized over time through its use, encour-

aging long-term usage with a game. PEAS processes scientific data obtained through a Life Cycle Assessment, which calculates the environmental impact of all production stages required to transform a cotton boll into a sweatshirt.

- *Organization*: WRÅD, Regione Lombardia, Politecnico di Milano, MOOD, 1TrueID, WWG
- *Keywords*: marketplace, circularity, traceability
- *Technology*: Blockchain, Artificial Intelligence
- *Year Founded*: 2022

23. *Provenance*

Provenance is a social enterprise founded in 2013 with the aim of giving buyers an insight into where products are made, what they are made from, and by whom. Users have the opportunity to question the details presented by companies on the site. By using the label, consumers can scan the garment to see every stage of the production process, from raw materials to the final product. This level of transparency, which implements sustainability principles related to traceability and the conditions under which products are made, can provide consumers with the information they increasingly want to know: how and where their clothes are made. Utilizing data and technology not only demonstrates the product's authenticity but also its provenance, making the entire lifecycle of the garment 100% transparent, where it is currently 100% opaque.

- *Organization*: Provenance
- *Keywords*: transparency, traceability, supply chain
- *Technology*: Blockchain
- *Year Founded*: 2013

24. *TrusTrace*

TrusTrace is a SaaS provider that helps companies understand and take responsibility for the entire social and environmental footprint of the products they sell, enabling consumers to make informed and better choices by creating fully transparent value chains down to the origin of the products. Powered by AI, IoT, ML, and blockchain, the technology is simple, efficient, and tamper-proof, ensuring data accuracy and ease of collection while revealing the true cost of

everything from production, sales, purchase, and disposal of materials.

- *Organization*: TrusTrace
- *Keywords*: marketplace, circularity, traceability
- *Technology*: Blockchain, Artificial Intelligence, IoT, Machine Learning
- *Year Founded*: 2017

25. *CircularID®*

Circularity.ID® Open Data is a standard for the fashion industry to store, label, and identify digital product data to support circular practices. The project is the result of over seven years of research, pilots, and collaborations across the fashion value chain with companies and startups interested in implementing sustainability and circularity. The insights and requirements for creating a circular product – from material to design, use, and sorting – have been aggregated into the standard to ensure longevity and recyclability at the end of the lifecycle.

- *Organization*: EON in collaboration with Closed Loop Partners, Target, PVH Corp., Microsoft, GS1 US, Waste Management, The Renewal Workshop, ForDays, IDEO, Sustainable Apparel Coalition, Open Apparel Registry, RISE Research Institute of Sweden, Revolve Waste
- *Keywords*: data standard, circularity
- *Technology*: RFID, Open Data Standard
- *Year Founded*: 2017

26. *Stitch Fix*

Stitch Fix is an online personal styling service that finds the right items to wear based on users' tastes and preferences through a scheduled shopping experience. The model is based on a robust set of algorithms that determine key characteristics: size, silhouette, and style of each item delivered to the customer's door. In the updated version of the platform, Stitch Fix is studying predictions not only to understand the compatibility of an item with a single user but also outfits in a more holistic sense. The new function suggests items that *match* a piece of clothing already purchased through Stitch Fix. While the goal may seem to help customers make better use of each pur-

chase, it also has sustainability implications by leveraging matching and a systemic view of the wardrobe itself.

- *Organization*: Stitch Fix
- *Keywords*: personal stylist, e-commerce, planned shopping
- *Technology*: Artificial Intelligence, Machine Learning
- *Year Founded*: 2018

27. *ZeroW*

ZeroW is an ethical platform combating waste in the fashion industry by connecting companies, artisans, and designers to transform leather and fabric scraps into circular products, promoting sustainable Made-in-Italy to a global community of conscious consumers. The company develops a marketplace where these products are sold and facilitates online sales management for artisans, designers, and small entrepreneurs. The recovery process and sustainability of a brand are certified and guaranteed through blockchain. Through technology and storytelling, the consumer experiences a unique blend of quality, sustainability, and Made-in-Italy craftsmanship. The search engine uses AI tools to generate a circular match between producers and waste transformers, creating a dynamic, multi-sector network that fosters increasingly innovative and scalable recovery projects.

- *Organization*: ZeroW
- *Keywords*: marketplace, circularity, traceability
- *Technology*: Blockchain, Artificial Intelligence
- *Year Founded*: 2020

28. *Renoon*

Renoon enables brands and consumers to transparently understand the impact of the products they sell or purchase. Its dashboard automates data processing, which is made publicly available by various brands that Renoon partners with. The tool quickly finds what green consumers need: from style inspiration and price comparisons to information on clothing and footwear materials, ensuring transparency regarding ethical values. This control process allows even small and lesser-known brands and textile producers to be recognized for their commitment to sourcing vegan, plastic-free, or low environmental impact materials.

- *Organization*: Renoon
- *Keywords*: marketplace
- *Technology*: Big Data, Artificial Intelligence
- *Year Founded*: 2021

29. *Visualist*

Visualist is a modern productivity suite for creatives. The platform helps designers centralize and make sense of visual inspiration. Most databases rely on keyword searches and textual metadata to retrieve appropriate results, often disregarding the subjective nature of visual images. This project also employs machine learning (AI) to form new connections between images based on their color palettes, providing a platform for a connected visual database and creating new pathways for designers to explore when seeking inspiration. Visualist uses an innovative approach to gather data directly from its users. Every week, followers participate in color-matching exercises on the startup's Instagram stories, showing how humans perceive them. The results are shared so researchers can compare the algorithm's performance with real users.

- *Organization*: Visualist
- *Keywords*: inspiration, creativity, design phase
- *Technology*: Big Data, Artificial Intelligence
- *Year Founded*: 2020

30. *Amazon Echo Look*

Echo Look is an Amazon device capable of collecting wardrobe data and offering style advice. Launched as a *personal stylist*, the device is equipped with a camera that compares multiple images and collects outfit photos. The new version, equipped with Machine Learning, helps users identify the best clothing items for specific occasions. The platform can recognize what you wear and suggest the best combinations for your look, responding with *Alexa*'s voice (Amazon's digital assistant) and linking to marketplace purchases.

- *Organization*: Amazon, Body Labs
- *Keywords*: personal stylist, wardrobe studies
- *Technology*: Artificial Intelligence, Cloud, Machine Learning
- *Year Founded*: 2018-2022

31. *Arket ID*

Founded with the mission of democratizing quality through widely accessible, well-made, and durable products, Arket's design aims to be used and loved for a long time, avoiding the need for constantly new items. The Arket system is based on the *Arket ID*, a unique nine-digit code assigned and displayed with each product. This system was created to make it easier for customers to find and retrieve products in both physical and digital stores. The code also serves as a tool for archiving, recording, and preserving the company's products. This system not only indexes products and provides details but also enhances the relationship between user search and company information management.

- *Organization*: Arket
- *Keywords*: language, archiving, retail
- *Technology*: Data Analytics
- *Year Founded*: 2018

32. *Robots Reading Vogue*

Robots Reading Vogue is a digital humanities project launched by Yale University Library, exploring the intersection of two seemingly disparate research interests: fashion and data mining. *Vogue* possesses a century of texts, images, and a well-digitalized online archive. Peter Leonard, Yale's new librarian for digital humanities research, along with Lindsay King, an art librarian interested in fashion, initiated a series of digital humanities research projects using *Vogue*'s archive. Below are some exemplary projects from *Robots Reading Vogue*.

- *Organization*: University of Yale
- *Keywords*: archive, data mining, research
- *Technology*: Data Analytics
- *Year Founded*: 2021

33. *Retraced*

Retraced is a German startup that has created a transparency solution allowing end consumers to better understand the sustainable aspects of the fashion industry. The transparency solution is powered by Oracle's Hyperledger Fabric Blockchain platform and presents a new use case for blockchain technology. The first live demonstration with CANO helps connect consumers with fashion creators and offers insights into the

production process and raw materials. Retraced has already engaged several fashion brands to enhance their impact on the fashion sector.

- *Organization*: Retraced, CANO
- *Keywords*: platform, supply chain, transparency
- *Technology*: Data Analytics
- *Year Founded*: 2015

34. *Newlife.IO*

The Newlife ecosystem connects creators and industries through a standardized flow of data, forming creative departments and focus groups at scale. Industries increase their creativity, reduce externalities, and provide new revenue streams for creators. A new ethical data standard for interfacing with creative communities. Discover more than 35,000 trendsetters on the AI and blockchain-enabled *Newlife.IO* mobile app, which offers Direct-to-Creator and Direct-to-Consumer equity data capabilities.

- *Organization*: Newlife.IO
- *Keywords*: platform, mobile app
- *Technology*: Artificial Intelligence, Blockchain
- *Year Founded*: 2021

35. *COSH!*

The Belgian online platform for sustainable fashion, COSH! (Conscious Shopping Made Easy), has launched a new map of Amsterdam that features seventy sustainable fashion stores and thirty tailor shops. *The COSH! project* aims to make local sustainable shopping more accessible to everyone. The map highlights various types of stores, ranging from circular fashion to sustainable fashion, and includes shops for reusing and exchanging clothing items.

- *Organization*: COSH!
- *Keywords*: resell, marketplace, second-hand, circularity
- *Technology*: Big Data, Cloud
- *Year Founded*: 2022

36. *Fashion Data*

The performance of a fashion retailer lies in its ability to simultaneously maintain solid logistics, offer trending products in the right

quantities, at the right stores, and attract a loyal and increasingly digitalized customer base. Founded in early 2019, Fashion Data aims to accelerate the transformation of fashion and lifestyle retailers by providing the best Data and AI solutions in Europe for the fashion world. Through data and artificial intelligence, Fashion Data demonstrates that it is possible to increase the economic performance of brands (each year generating several million euros of additional margin for our clients), while accelerating the transition to Zero Waste and significantly reducing environmental impact.

- *Organization*: FashionData
- *Keywords*: resell, marketplace, second-hand, circularity
- *Technology*: Big Data, Cloud
- *Year Founded*: 2022

36. *Heuritech*

Heuritech is a pioneering company in fashion technology, providing brands with predictive analytics for trends and products. By leveraging sophisticated artificial intelligence (AI), Heuritech transforms real-world images from social media into valuable insights. This enables fashion brands to better predict demand and trends, enhance sustainability in production, and gain a significant competitive edge. Established in 2013 by PhD holders, the company aims to connect the realms of artificial intelligence and business, which are typically distinct. Today, Heuritech remains at the forefront of applying cutting-edge scientific research to the fashion sector.

- *Organization*: Heuritech
- *Keywords*: trend forecasting, predictive analytics
- *Technology*: Artificial Intelligence
- *Year Founded*: 2013

37. *Loop Digital Wardrobe*

Loop is an app integrated into retailers' checkouts to digitize customers' purchases and give them access to the range of sustainable post-purchase services: resale, exchange, upcycling, charitable donation, and return. *Loop* enables direct integration of users' wardrobes with Instagram, a feature that Loop says is particularly popular with Generation Z customers. The plug and play app aims to

make a positive impact by digitizing and connecting the wardrobes of fashionistas and their friends, engaging them in engaging social media-style activities where resale, exchange, charitable donation, or upcycling services are encouraged.

- *Organization*: Loop
- *Keywords*: resale, swap, end-of-life upcycling
- *Technology*: Data Analytics
- *Year Founded*: 2022

4.3 Functions and Potentiality of Data in Fashion

This exploratory work on case studies contributes to identifying information gaps and guidelines for developing an integrated data planning and collection strategy. Three dedicated datasets were recognized, pertaining to the consumer, the product, and the company. The ongoing research, analysis, development, and application of this research present three main types of information identified as crucial for efficient, economical, and sustainable strategies in the fashion system:

- customer information;
- product information;
- information flow.

Customer information is vital to aligning human needs with profitability. Product data can express and share awareness of the underlying processes. Finally, the structure of the information flow is essential. It can be a leverage point in the fashion system if information is provided where it was previously absent, prompting behavioral changes (Meadows, 2008a, 2008b).

In the fashion industry, adding or modifying the information flow among companies in a supply chain or among retailers, designers, and consumers can create significant changes with minimal effort. Unlike current sustainability strategies, which focus on symptoms and support methods that attempt to solve individual problems without addressing existing relationships, the systemic design approach can be an effective tool for restoring the lack of information that affects the entire process and all stakeholders. This broader approach shifts

from a linear perspective, where individual environmental issues are addressed, to a systemic approach, where improvement of individual components, when related, corresponds to improvements for the entire sector.

Data can be involved in this innovative approach during the fashion creation phases, implementing processes and applications in a more sustainable direction. They can become tools and materials for design, being a fundamental component of the project rather than just its objective. This means that through design and a circular approach, it is possible to create sustainable value within the system (Gaiardo *et al*., 2013). It should be noted that these guidelines associated with a systemic use of data across the fashion industry currently lack experimentation, but attempts have been made to visualize data when available.

Often, when we refer to data, the first image that comes to mind is that of a measurement tool. However, data can fulfill many more functions. Understanding these functions allows us to plan their integration into design processes and their implementation in sustainable fashion processes. For this reason, we have decided to include an overview of these functions at the end of this chapter. Some of these functions were extracted from case study analyses, while others remain as prospects for developing framework implementation tools.

Data for Monitoring

Real-time data collection in the fashion industry could shed light on working conditions in garment factories, environmental impacts, emissions, and all sustainability variables currently not disclosed within the process.

Data for Self-Tracking

Wearable trackers can offer self-tracking of moods, feelings, and physical activities. These data can be useful for designers, engineers, and marketers in designing wearable technologies.

Data for Analysis

Trend analysis is only the first step in understanding users and their needs. Systemically, data can be used to analyze business models,

sales, inventory management, and unsold stock, aiming to reduce environmental impact.

Data for Measurement
To transform a system, it must first be understood. To understand it, sustainability goals must be measurable. Literature often highlights issues with the lack of measurability of fashion system impacts. Data, if uniformly processed following shared standards, can significantly improve this aspect of sustainability.

Data for Digitization
The historical and cultural heritage of the fashion system is also a resource for sustainability. In this context, data can be used for digitizing and sharing fashion archives.

Data for Observation
Observation of phenomena is often the first step in design, preceding the identification of needs and problem-solving. Before monitoring or measuring, data can be a useful tool for observing the evolution of certain phenomena in the fashion world.

Data for Exploration
Exploratory data can be integrated into the research and trend forecasting phase. Before developing the collection, designers typically conduct autonomous exploration of trends and contexts to identify needs and trends.

Data for Connection
Connectivity is one of the fundamental characteristics of data. In fashion, exploiting it means connecting the supply chain to the territory, the user to the company, and the user to their clothing.

Data for Control
As discussed in previous sections, controlling the conditions of garments can provide valuable insights for sustainability. This already occurs in workwear supply chains, but this type of data could be useful more broadly.

Data for Communication
Proper data communication, transparency, traceability, and the use of adequate standards are all considerations for ensuring that data can convey information along the fashion sector's value chain.

Data for Optimization
In the initial scoping study, we found that data, besides revealing trends, can optimize stock and manage unsold goods. This enables companies to be more aware of their practices and potentials.

Data for Interaction
Among the case studies, the *Jacquard by Google* project demonstrates that data's potential can also enhance user experience through entertainment services.

Data for Collaboration
There is no sustainability without collaboration. Many of the case studies we collected rely not only on data sharing but also on collaboration between companies, enabling them to network knowledge and expertise.

Data for Visualization
Information visualization is another critical topic for the sustainability of the fashion sector. Often, the visualization of the clothing supply chain's impact does not reach the end consumer and is hidden within complex reporting. Information visualization, along with communication, could significantly impact user experience.

4.4 AI for Fashion

This paragraph presents a study conducted in the spring of 2019, which included an educational experiment, validation with experts from the Italian entrepreneurial fabric, and close collaboration with a trend forecasting company. The aim of this study was to shed light on the current interrelations in some key areas of this book: the fashion sector as the primary field of investigation, data as a predictive factor

of trends and behaviors, and design as a cross-disciplinary force driving both information collection and utilization. The study aimed to explore and understand the potential of trend forecasting to act as a catalyst for sustainability in the fashion industry.

Previous chapters established that, although increasing strategies are in place to limit the environmental impact of the fashion industry through data, these strategies do not adopt a holistic approach to data collection and are limited to operations of traceability, transparency, and information optimization. The major driving forces, such as legislation and financial incentives, do not specifically address areas of greatest impact, such as the usage phase, nor the areas where the potential for positive changes is highest: the ideation and design phases (Franklin Associates, 1993; Graedel *et al*., 1995).

To complete this part of the study, we collaborated with a trend forecasting company. The reason for this selection is that the trend forecaster currently works in the commercial sector of a fashion company, proposing a process of vision and intuition that involves prediction. The study aimed to verify whether sustainability trajectories could exist within the data selection used by fashion companies. After introducing the objectives, the results obtained within the challenge are presented.

4.4.1 Study Purpose

The scope of this study initially appeared broad and complex, primarily due to two factors: the open system in which we set the experiment and the multitude of subjects involved, along with the multidisciplinary nature of the experiment. The purpose of the study was to understand how the three strands function as a system. The strategy of the study was one of progressive focus. It should be noted that, although this study focused on the environmental dimension of sustainability, it recognized that sustainability implies a healthy interdependence between environmental, ethical, and economic concerns. We asked ourselves: is it possible to predict successful fashion trends by integrating sustainability factors? With the emergence of Big Data, the biggest challenge for data scientists today is no longer accessing a sufficient number of data points. The difficulty lies in identifying the right data and the granularity of data to accurately predict trends, especially when dealing with high volatility.

Due to social media and other factors, fashion trends have become incredibly volatile and, consequently, increasingly challenging for traditional forecasting approaches that rely on historical data. In the fashion sector, all stages of the production process – from raw material acquisition to the sale of the finished product – require careful planning and forecasting, as they are influenced by endogenous trends (popularity, prices, promotions, and competition) and exogenous factors (seasonality and weather).

We involved a trend forecasting company that uses artificial intelligence to predict fashion trends: a startup based in Turin and London that helps companies create more effective supply chain and pricing strategies through AI. The challenge we agreed upon as part of an educational challenge aimed to help companies plan resources by more accurately identifying emerging trends in purchasing behavior, especially concerning style.

Table 1.
Composition of teams in the scoping study.

	Partecipants	Background
Team 1 (T1)	n. 6 (3M + 3F) age range between 20-25	2 Engineering and management 2 Mathematical engineering 1 Computer engineering 1 Data Science
Team 2 (T2)	n. 7 (4M + 3F) age range between 20-25	1 Mathematical Engineering 1 Design Sistemico, 1 Mechatronic Engineering 2 Computer Engineering 1 Industrial Production and technological innovation engineering
Team 3 (T3)	n. 6 (3M + 3F) age range between 20-25	1 Engineering and management 2 Mathematical engineering 2 Computer engineering 1 Data Science
Team 4 (T4)	n. 5 (2M + 3F) age range between 20-25	3 Engineering and management 1 Computer engineering 1 Mathematical engineering
Team 5 (T5)	n. 6 (2M + 4F) age range between 20-25	2 Engineering and management 2 Mathematical engineering 2 Computer engineering

4.4.2 Objectives

The main objectives of the study can be summarized as follows:

- analyze the target market and identify relevant data sources, proposing input factors for algorithm development;
- create an algorithm that selects critical success factors and anticipates fashion trends;

- design a user interface with an appealing UI/UX and implement an app that can be used by managers and consumers.

4.4.3 Participants

The study was conducted through observation and mentoring of an educational experiment involving 30 students from five different disciplines. The choice to conduct this study with such a heterogeneous sample is due to the characteristics of the study itself. It was a challenge open to Master's degree students from both engineering and design fields, who were willing to respond to a challenge posed by a company.

4.4.4 The *Challenge by Firms* Format

The *Challenge by Firms* is an innovative educational activity conducted at the Politecnico di Torino, particularly by the CLIK (Connection Lab and Innovation Kitchen) group. Within this format, Master's degree students must develop an innovative idea to solve a challenge posed by a large company, SME, organization, or association. The challenges last one semester, equivalent to 14 weeks, and are conducted during the academic period. The challenges are conducted entirely in English. Students are divided into teams of 5-6 members. Each team is formed based on multidisciplinary criteria and includes students from various degree programs to ensure a cross-disciplinary approach to the solution. Each challenge is overseen by a professor, who is supported by several mentors, typically 5-6 figures chosen from researchers and PhD students, providing both technical and methodological support to the students throughout the challenge. From an educational perspective, the challenge integrates workshops on topics related to the proposed activity. At the end of the activities, each team presents a project pitch, followed by a Q&A session and a demonstration of the proposed prototype or solution. By promoting this activity, the university aims to develop both soft and hard skills through teamwork, stimulate student entrepreneurship, and encourage the transformation of simple business ideas into actual startups.

In the case of the AI for Fashion Challenge, a final presentation was organized in collaboration with the company, involving 10 companies from the Italian entrepreneurial sector to validate the feasibility of the proposed solutions within their specific contexts.

4.4.5 Challenge Process

Phase 1: The first activity of the challenge involved presentations on multidisciplinary methods and approaches. Students were introduced to concepts of Data Science, Design Thinking, Project Management, and environmental sustainability applied to the fashion sector. During this initial activity, students participated in team-building sessions to create and define multidisciplinary teams, to which the challenge was presented: identifying a novel data source and developing an algorithm and platform for managing and optimizing production volumes.

Phase 2: Once the challenge was presented, students had mentoring sessions to develop their concept. The initial brief from the company focused on optimizing production for sustainability and reducing unsold inventory. Students were tasked with identifying new data sources and generating a concept.

Table 2.
Concepts developed during the AI for Fashion Challenge.

	Problem Description	Dataset used
T1	Fashion trends are difficult to predict-even a TV series or movie can influence them.The concept proposes to increase profits by reducing the waste produced by mismanagement of the production process that does not meet microtrends.	Selection of the most viewed films in a specific geographic area. Extraction of film shots (*themoviedb*). Collection of historical data on movies, TV series, short film images, and posters. Image analysis of shots using a neural network to extract useful information such as style, color palette, etc.
T2	Fashion industries are facing a substantial waste of resources due to the difficulty of perfectly catering to consumer tastes. The rise of social media has influenced consumer tastes by making them change even more rapidly.	Collection of images showing clothing items, downloading images related to specific hashtags. Using the most popular hashtags profiles of common users.
T3	The goal is to create a platform that supports the process of designing and creating a new fashion product by selecting some specific features. The user should then receive as output a set of comparison measures between the new product and the market, along with possible suggestions.	The dataset is generated by comparing market trends through image analysis, extracting abstract features, and analyzing hand-pulled labels from images.
T4	Data from test phases in a store are valuable data in the design phase, but they are not collected or exploited. This data at the design stage, may be able to more accurately predict customer tastes and needs.	Collect data from tried but not purchased items through direct interaction with customers. Build a supporting tool that provides the designer with a list of possible features and combinations to decide which concept will be most successful. Combine the collected data, historical sales data, and preference estimation obtained through final surveys to quantify the production of the designed items.
T5	The issue on which the investigation is focused is the similarity between trends over certain time periods. If fashion trends are cyclical, then there will be similarity between what has been produced in the past and what will be produced in the future.	Collect data from runway collections in the current year and compare it to current production and past production. Once the algorithm is created this will be able to predict how close a trend is to returning. In this way the topicality of the collection can be predicted.

Phase 3: Teams were required to analyze or visualize the identified data source. The conclusion of this phase involved an intermediate submission outlining the problem addressed, key insights from the analysis, and input definitions. Students experimented with design thinking techniques such as using user personas and developing the concept textually.
Phase 4: This phase shifted the focus from design to the complete immersion in algorithm development.
Phase 5: In this phase, teams worked on defining the service, visualizing collected data, and communicating their project for the final delivery.

4.4.6 Results

The initial challenge theme was to explore new data sources for the fashion sector, particularly for sustainable collection planning. Within the sustainability theme, teams focused on different aspects of the consumer purchasing experience to explore new value propositions. The design teams took various directions, as illustrated in the accompanying table. The results met the company's challenge, but no significant impact or predictions on the overall sustainability of the system were observed.

4.4.7 Overall Validation of the Study and Research Results

The introduction of this pilot study highlighted the importance of better understanding the dynamics within AI-enabled trend forecasting services to identify which data sources can support the development of sustainability strategies and optimize production planning and volumes. The experimental results were validated by a team of business experts, primarily composed of Brand Managers, as detailed in the following table.

Table 3.
Characteristics of experts involved in validation.

	Role	Company	Company type
E1	Brand manager	Apparel company	Large 6000 employees
E2	Brand manager	Footwear company	Large 5000 employees
E3	Brand manager	Apparel company	Medium 500 employees
E4	Brand manager	Apparel business group	Large 10.000 employees
E5	Brand manager	Apparel company	Large 5000 employees
E6	Brand manager	Footwear business group	Medium 1000 employees
E7	Brand manager	Trend-forecasting company	Startups less than 50 employees
E8	Data analyst	Trend-forecasting company	Startups less than 50 employees
E9	Fashion technologist	Innovation company	Startup accelerator
E10	Fashion technologist	Innovation company	Startup accelerator

4.4.8 Study Findings

The study revealed certain limitations within companies regarding the openness to novel data sources. The relationship between sales data and data related to products tried but not purchased garnered interest among the companies involved in the final phase of the study. This interest stemmed from the fact that such data still falls under the *domain of the company*, meaning it requires technological implementation for collection but not necessarily a third-party service.

Conversely, data related to TV series, fashion shows, or social media profiles were perceived as difficult to obtain, place, and utilize. This disconnect was attributed to a lack of openness within the corporate context and a generally underdeveloped data culture. Developing economically sustainable strategies based on data necessitates a more comprehensive understanding of the approaches, technologies, tools, and potentialities associated with data use.

Therefore, in subsequent studies, we focused on these aspects to propose an analytical perspective that considers the corporate world through various professional figures involved in the design process. Viewing them as a single system helped us uncover the foundational structure supporting data-driven dynamics in the corporate context.

Consequently, this enabled us to develop a framework for managing collaborative design from a future-oriented perspective.

This study proved useful in identifying the elements and relationships underpinning the corporate structure and their needs. Based on these findings, we conducted a series of in-depth interviews with designers and experts. The results were formalized into the design framework presented in the subsequent phase of our research.

4.5 In Conversation with Experts

The overview presented thus far at the intersection of data, sustainability, and fashion demonstrates the necessity of further phenomenological research to understand the perspectives and viewpoints of those involved in data and sustainability within the fashion sector (Leedy & Ormrod, 2010). Phenomenological research opens up the scenario of how individuals are responding to technological changes within the corporate environment. In this case, the scope of the research was limited to experiences related to daily work situations in specific professions: from data scientists to trend forecasters, from designers to creative directors, and not least, those responsible for sustainability within companies.

4.5.1 The Figures Selected for the Investigation

Brand Manager

The brand manager, responsible for product development, is the figure who accompanies each collection from the brief to production. Under their supervision, mood boards are developed by designers, which integrate with insights produced by trend forecasting services and independent research by fashion designers. The role of the brand manager is to act as a *decision-maker*, collaborating with designers on the selection of fashion sketches. They then monitor material choices and their specifications through to the first production prototypes. It is also the brand manager's responsibility to control the costs of each prototype and suggest modifications during the fitting phase. Subsequently, they oversee sample orders and the definition

of all items to be produced. Their expertise ranges from a thorough knowledge of the fashion design process to full operational production capabilities, considering cost and time balances.

Data Scientist

The role of a Data scientist in the fashion industry involves collaborating with corporate and engineering resources to create value from data. This position is of particular interest in this research because their work often requires solving complex problems, transforming large amounts of data into business insights through advanced analytics, modeling, and machine learning. Their background, which is quite distinct from that of designers, includes analysis, mathematical modeling, computer science, and economics. Data scientists proactively retrieve information from various sources and analyze it to better understand the company's performance. Additionally, they model and build artificial intelligence tools that automate specific processes within the company. The solutions produced are implemented to impact business outcomes. They focus on creating value, driving growth, and serving customers with full ownership and responsibility, delivering exceptional results to both customers and the business.

Fashion Designer

The shift of the fashion industry from a paradigm of unsustainability to one of sustainability entails significant changes for fashion companies, particularly for the role of the fashion designer. Current product-level sustainability strategies are rather standardized, and the relationship between fashion designers and brand managers allows both to operate within a well-known framework where the role of the fashion designer is currently limited to the styling of the collection. However, today's technological and scientific focus on sustainable solutions enables designers to make assessments that go beyond the product itself and embrace a more holistic perspective directed at the entire system. As early as 2002, Breds *et al*. positioned their figure iteratively in the design process, at the margins but in close correlation with other trend analysis figures, in the reformulation of a sustainable fashion organization.

Fashion Sustainability Manager

The fashion sustainability manager is a relatively new figure capable of interacting with clients and suppliers within the corporate environment. Among the roles mentioned so far, this figure supports the design office, manages some production functions, and interfaces with marketing and communication roles. Often, their background allows them to understand both materials and production processes, supplemented by skills in managing supply chains (from raw materials to finished products). From an environmental sustainability perspective, the sustainability manager intervenes to reduce waste, minimize negative impacts, and make production processes more efficient. Their role is primarily one of liaison, support, and coordination between various corporate functions, from the design office to production, supply chain management, and communication.

Table 4. Characteristics of experts involved in interview.

	Role	Company Description	Company Size
R1	Brand manager/ Head of design	Italian corporate group operating in the clothing, footwear and accessories industry	Large employees 1000
R2	Brand manager	Clothing and knitwear manufacturing company	Small employees 20
R3	Data scientist	Leading company in big data analytics for business value creation	Startup employees 50
R4	Data scientist	Swedish corporate group operating in the apparel industry	Multinational employees 200.000
R5	Fashion designer	Italian corporate group operating in the clothing, footwear and accessories industry	Large employees 6000
R6	Fashion designer	Clothing and knitwear manufacturing company	Large employees 5000
R7	Fashion designer	Clothing and knitwear manufacturing company	Medium employees 1000
R8	Fashion designer	Italian corporate group operating in the clothing, footwear and accessories industry	Large employees 6000
R9	Sustainability manager	Clothing and knitwear manufacturing company	Medium employees 100
R10	Sustainability manager	Italian corporate group operating in the clothing, footwear and accessories industry	Large employees 6000

4.5.2 Observing Multiple Perspectives

By observing multiple perspectives on the same situation, it was possible at the end of the study to generalize how data is used within the corporate context and to present the viewpoints of insiders (Leedy & Ormrod, 2010). The study of these phenomena, conducted from the standpoint of various professions, aims to examine experiences and situations that the literature review took for granted or merely implied, in order to discover new meanings or validate the knowledge obtained thus far (Laverty, 2003).

In most cases, the interviews were lengthy, lasting about an hour. Participants were carefully selected, and the sample size consisted of 10 participants, all with direct experience in data science, fashion collection design, and corporate sustainability strategies. The study was conducted following a participant observation pilot but before data processing and validation within the corporate context, ensuring that the researcher's personal experience was free from preconceived notions about corporate dynamics. This was essential to understand the typological experience of other disciplinary fields beyond design and how they relate to the phenomenon without the risk of introducing distorted perspectives. This would have posed a common problem in phenomenological research, interpreting the data collected according to preconceived expectations. Throughout the investigation, subtle insights that led the discussion of the overall results into an objective dimension were not ignored (Leedy & Ormrod, 2010).

To conduct this type of phenomenological research, it was also decided not to investigate a single company to avoid bringing to the surface the subjective dynamics of each individual *corporate ecosystem*. Instead, it was decided to listen to diverse voices across different companies to capture objective characteristics that are normally overlooked or rarely considered, precisely because they are transversal to multiple corporate realities. The objective was to expose «taken-for-granted» assumptions and challenge a «comfortable status quo» extensively and systematically, not focusing on a single company but providing valuable insights that can contribute to defining the overall corporate strategy (Lester, 1999).

Between 2021 and 2022, 10 in-depth interviews were conducted with experts in data science, design, and trend forecasting within the

fashion industry. These experts were employed by small, medium, and large established apparel companies. The companies were chosen independently of their vision or a clearly formulated sustainable program. Each interviewee was recruited for the study from Italy through email requests, except for one Italian data scientist who works for a Swedish company.

The interviews were conducted via Skype to address the challenges posed by the COVID-19 pandemic. Table 6 provides a summary of the interviewees' job positions, their experiences in the fashion industry, and brief descriptions of the companies where they were employed at the time of the interview.

The expert interviews were conducted in two phases, applying certain aspects of object interviews (Elliot & Woodward, 2016). In the first phase, an abstract of the research work was sent to the interviewees in the form of a text and a summary presentation of the expected research outcomes. Given that these were in-depth interviews, providing the interviewees with only a summary outline of the research aimed to offer the opportunity for an extensive response, while still being confined to the project objectives. Since this was not a quantitative study, this approach was preferred as it better suited a phenomenological study of the field of investigation.

The participants were selected based on the following criteria:

- previous experience in data science;
- employment in small to large fashion industry companies;
- cross-functional roles in data science, design, and sustainability.

The intention to select participants from different fields, both in terms of company size and roles, aimed to increase the likelihood of collecting rich, unique, and comparable experiences of the same phenomenon (Laverty, 2003). According to Smith (2008), the interview focused on the following questions: how do people experience the corporate context in relation to the three areas of investigation? How do they perceive these experiences? What significance do they attribute to data in their corporate experiences? What meaning do they assign to the phenomenon?

These were not fully structured interviews, where the researcher and the participant worked together to get to the *heart* of the matter.

Participants were asked to describe their corporate context and daily activities related to the phenomenon, and significant insights in their responses were carefully listened to. The major effort in this activity was directed toward uncovering what was not said, or what was said «between the lines» (Laverty, 2003).

The interviews were fully recorded and transcribed. The data were analyzed through thematic analysis (Flick, 2009), aiming to identify common and/or differing patterns compared to the literature review and emerging gaps from it. The most critical issues within data-driven corporate processes were thus highlighted.

The main objective of the phenomenological analysis was to identify common themes in the descriptions of the experiences of the various professional figures involved. Once the interviews were recorded and transcribed, the analysis of the collected data, which were unstructured and non-quantifiable (Yin, 1994; Moore, 2000), proceeded through the following phases:

- Data segmentation;
- Data categorization;
- comparison of different professional roles;
- summary description.

Once the segments, i.e., relevant phrases on the analyzed aspects, were defined, these were grouped into categories capable of reflecting the most significant aspects of the phenomenon as reported by the participants. Each segment reflects a single thought. Subsequently, in accordance with Leedy and Ormrod (2010), the different threads were identified and compared, paying particular attention to the common themes of the experience, despite the diversity of the participants' roles and the corporate contexts analyzed.

The following text summarizes the most significant points of the analysis, reporting the segments, the themes that emerged from the conversations, and some significant quotes.

The in-depth interviews were based on a series of questions predetermined from the literature review. However, the sequence in which the issues were raised during the conversation was formally established to allow participants the freedom to interpret the topic and highlight both challenges and opportunities. Once the participants

were informed about the interview topic through the abstract and presentation, the interview took the form of an informal dialogue.

The interviewees contributed insights on topics such as the types of information involved in the design process and how it is used; the accessibility of certain information across company departments; and the application and monitoring of sustainability through data.

4.5.3 Approach to Data

Since their inception, most fashion brands have relied on a certain degree of data when planning a collection, their design activities, and commercial strategies. Today, the challenge lies in knowing which data sources to use at each stage of the process. From deciding on trends and products to include, to assortment quantities and marketing strategies, collection planning requires a combination of multiple data sources, appropriate for each phase.

The companies selected for the study, both larger corporate groups and smaller production companies, reported integrating classic data sources into their ideation process. Both Respondent 1 (R1) and Respondent 2 (R2) acknowledged that their companies purchase a trend database from third-party companies, which includes information on colors, shapes, patterns (formal characteristics of clothing); seasonality, including peak demand periods and optimal launch times; consumer segmentation, and geography. From these trends, the design department integrates their trend research and tries to adapt them to the company's aesthetic profile.

An example provided by R2 illustrates this:

> **If the purchased data package indicates that beige is the forecasted color for the upcoming season, we adhere to that but select the shade closest to our company's style. The data serves as general guidelines, but we always strive to differentiate ourselves by following the stylistic standards we have developed over time.**

On the other hand, Respondents 3 (R3) and 4 (R4) reported providing the design departments with «standardized data packages» but were unaware of how the designers actually used the data. The data scientists gather data and provide datasets based on the compan-

ies' pre-established objectives, ranging from volume optimization to consumption monitoring, but they do not engage in interpretations beyond the company's scope.

Designers R5, R6, R7, and R8 all agreed on the potential of data within the corporate context. However, especially in smaller companies, they often do not have access to data on the overall sustainability of the collection and supply chain transparency. When asked about the impact of data forecasts on their design process, they responded:

> **Not very much, actually. Internal departments set the direction for the collection. Of course, we think it's important to be aware of what's happening around us and outside our departments, especially during fashion shows. The data in that sense act as consultants, but we know very well that other companies receive the same data sets, so we also gather our own information. We cannot afford to rely solely on those.**

Regarding the approach to data by sustainability managers, it turned out to be transversal across multiple departments, as sustainability managers are often in close contact with both brand managers and data scientists. However, sustainability strategies are often geared more towards collaboration with marketing teams rather than design and production teams.

4.5.4 Sustainable Mindset

From the scenario analyzed prior to the investigation, all the represented companies have defined a vision and criteria for sustainability in their design and commercial activities. These companies have established internal guidelines that designers must follow when making design choices. The findings reveal that brands rely on producing garments that are ethically made, durable, reusable, and/or repairable, primarily made from organic and/or recycled materials.

In line with these definitions, all responses from the interviewees indicate that the sustainability these companies aim for is physical and material sustainability. Specifically, the interviewed brand managers agree on the physical and aesthetic longevity of the collection,

achieved through materials that are explicitly recycled or recyclable and the maintenance of basic collections and timeless designs. All designers interviewed mentioned avoiding trends when designing new collections.

All companies stated that they have a person, or a department dedicated to sustainability issues, and the skills needed to manage this challenge often come from outside the company. Some companies, for instance, have organized mandatory training courses on general sustainability topics for their staff. Even though there is a person or team responsible for sustainability, all staff members are expected to be committed. Additionally, companies participate in sustainability and circular economy seminars, collaborate on recycling projects, or have attended roundtables on these topics.

The individuals who seemed most distant from the sustainability theme were the data scientists. Without explicit requests from companies, they limit themselves to structuring data for profit optimization and sales volume without delving into practical issues or pushing companies towards a paradigm shift towards sustainable scenarios.

4.5.5 Sustainable Fashion through Data

Initially, all interviewees admitted to being somewhat unprepared regarding sustainability strategies that could be supported by data within their respective departments. In trying to imagine together the uses of data concerning the research theme and their professional roles, the emerging quality of the data is seen as measurement tools. The interviewees envisioned solutions to measure the impact of energy efficiency, the impact of the collection, and optimize production volumes. The interviewed fashion designers, on the other hand, proposed solutions to help monitor waste during the design process. In contrast, the sustainability managers, during the conversation, raised the use of data for traceability or communicating the company's sustainable choices, sometimes considering the possibility of using data for marketing and/or combating greenwashing.

4.6 Conclusions

The purpose of this work was to study how various professionals involved in the research themes can contribute and address the issue of data and sustainability in the apparel sector from their perspectives. Based on preliminary results from the scoping study, literature, and case studies, it remains evident that corporate logic dictates approach to sustainability: if the company's commitment is not strong enough, the designer's commitment, who has developed a sustainability culture in their career, remains null.

This aligns with Sihvonen (2019), who found that sustainability does not enter design practice unless the company is strategically committed. Enthusiastic individuals are important but not sufficient. Similarly, data, which should be a fundamental asset in the logic of sustainability managers, have limited potential if companies do not intend to implement sustainable strategies at the same pace.

Material choices and sales volume optimization appear to dictate the sustainability discussion in the companies interviewed for this study. The designers in these companies recognize that reducing waste and monitoring the overall impact of the collection are the variables, in terms of data, that can make a difference, despite acknowledging the innovative potential of data. However, there is a profound understanding of how data could help shift the mindset towards issues such as product circularity or disseminating information on garment sustainability.

A clear knowledge gap is evident both in terms of sustainability and data, and even though designers are motivated to include sustainability in their design practices, they need more practical knowledge to implement it. All study participants agreed that transitioning to a more sustainable system requires a more holistic approach, not only in defining the flow of circulating information but also in the design practice, which needs to be more informed and interdisciplinary. Most importantly, it is evident that the role of the individual is not sufficient to implement data-driven sustainability practices: greater involvement from all stakeholders through an understanding of the foundational skills needed to enable dialogue is essential.

During the in-depth discussions, references were made to the responsibilities of both consumers and companies: while consumers should choose the quality of the company they engage with wisely, it remains the company's duty to offer a quality garment, directing its actions towards the economic sustainability of the company. There was also a reminder of the role of institutions and regulations that should intervene to support companies in the sector.

In conclusion, the interviewees highlighted the difficulties of constantly being subjected to stereotypes that portray them as responsible for a large portion of pollution. They noted their ongoing research into better material alternatives and strategies, acknowledging that this requires significant time and commitment from the company. Pioneering work from a data perspective thus entails a combination of multiple factors and high motivation among design teams, implying continuous development, collaboration, and negotiation.

4.6.1 Interview Limitations

According to Moore (2000), several barriers can interfere with the collection of reliable information. Firstly, participants might attempt to present themselves as more rational than they actually are. This can hinder their ability to reveal their true emotions, opinions, and beliefs. A notable limitation in conducting in-depth interviews was related to the subject matter. Although participants were willing to participate, they sometimes appeared insecure in their responses and allowed their workplace environment's beliefs to influence their answers.

The researcher's primary effort was to encourage participants to articulate objective facts more carefully, separating them from personal daily goals. This was necessary because personal opinions sometimes conflicted with corporate logic. In some interviews, participants feared portraying the company as excessively unsustainable from an environmental perspective while being more sustainable in terms of profit, thus perpetuating stereotypes and myths about fashion companies. This created discomfort among participants when discussing their world.

Moreover, the subject matter of the work proved to be more delicate than anticipated: discussing data within a corporate context made participants wary of demonstrating transparency or traceability

in their processes, raising particular concerns. The investigation initially aimed to involve a larger number of participants but was reduced due to the resistance from potential subjects to accept interviews on sensitive topics such as data and sustainability. This resistance did not surface in the participants' responses, which remained more focused on material sustainability than on *ethical fashion*.

4.6.2 Overall Results

Today, the deluge of big data is more than just a trend or a passing fad, as evidenced by many researchers across various academic and non-academic fields seeking to engage with new technologies and better understand the new landscape. At many levels of interest, data could influence the entire supply chain, and for the fashion industry, it can become crucial. These new possibilities could have a considerable impact from the choice of raw materials to production, and even consumer awareness within the system.

From the initial stages of production, knowing the target customer's preferences allows for short-term forecasts and adaptation to the ever-evolving market trends, mitigating the significant risk of overproduction. However, the utilization of big data remains limited in the absence of adequate technologies that support not only data collection but also management and new production processes that could develop from such a dynamic quantity of data.

This chapter explores emerging technologies and some projects that, in improving and optimizing the fashion supply chain, do not shy away from environmental and social responsibilities, with impacts that are easily traceable. Firstly, data analysis on customer preferences and options can be redirected to design and e-prototyping. Knowing the consumers' physical characteristics is not new for companies: through sales data, companies can manage and optimize the flow of sizes in inventory (Loker, 2008). Despite this, 3D body scanning technology can offer both the customer and the company a new pool of more precise and accurate data, leading to a reduced environmental impact.

As Lorraine Sanders, a Fashion-Tech journalist, asserts: «Fascinating things are happening with human body mapping, and the attempt to create a predictable size through the use of big data could help many sectors – and almost certainly could help the fashion industry»

(Sanders, 2014). New body scanning and sizing technologies, smart scales, and wearable devices can create a significant data pool for this sector. With this data, companies can create perfectly tailored garments, eliminating guesswork modifications. Body scan data can reduce the flow of unsold and returned garments due to poor fit and help build a more sustainable fashion system by providing rapid, consistent, and accurate data that could redefine sizing systems and customer preferences.

Tailored clothing, by definition, involves the consumer in the design and production process to create unique garments based on individual measurements, not only with one or more fitting and matching sessions but also with some decisions on style and fabric. Body scan data can track large-scale anthropometric studies, giving research a measurable impact: from the specific in the consumer's clothing to the general in a territory's perspective or the global impact of a particular collection.

The use of body scanning in the fashion industry can also support medical analyses, with dimensions used to explore related diseases, opening research to increasingly interdisciplinary scenarios and a broader concept of well-being and human-centered design. The goal in both approaches is to reduce the flow in the sustainable fashion system by eliminating the production of unsold garments in a specific territory and improving customer engagement.

In marketing phases, collecting consumer data enables more user-centered design but is not the only benefit. Systematic data use allows companies to bridge the gap between reality and their perception of consumers, measuring, for example, the impact of their advertising campaigns, thus providing a continuous feedback system from their users. Based on results from social media, blogs, preferred product emails, and promotional campaign effects, management can identify new product and service opportunities, optimize prices, and enhance customer loyalty and satisfaction.

Sentiment analysis helps companies analyze every aspect of customer demand by collecting responses (likes, shares, comments, retweets) to a specific product. In this way, not only sales but also marketing and advertising become useful tools for transitioning to sustainability. Interlacing this data with sales at a specific moment

or with activities of certain influencers makes it possible to explore the driver of a target sector and determine a behavioral model. When a company receives feedback on its marketing activities and understands its impact, it can invest more securely in customer experience and sustainably improve its products and services.

Additionally, using sentiment analysis to map consumer behavior can extend to data collection areas still inaccessible to companies. All fashion product usage data is currently not collected and hides enormous potential for sustainability and customer awareness within the system. RFID technology can now monitor the entire supply chain, from production to sale. To enable an information flow strategy, it is essential to recognize the value of this technology for improving aspects like system traceability and transparency, not just logistics.

In this context, an RFID system can capture a vast amount of data. For example, when big data is integrated into a clothing company, it refers to linking location with merchandise flows. Receiving information from a territory about traffic congestion and safe routes, delays, or customer complaints allows management to make the best decision regarding shipment planning, product delivery, and transportation safety.

However, mapping territorial resources and activity management can design an environmentally intelligent and safe transportation plan through real-time data visualization and analysis of supply chain networks. Therefore, it is crucial to adopt information technologies to monitor the product and facilitate communication and information exchange between supply chain partners to meet customer needs, increase operational efficiency, and improve decision-making in the supply chain context (Choi, 2016).

The real value of RFID technology lies in its unequivocal real-time identification, allowing management of the numerous variables the fashion industry must handle. Increased system transparency, thanks to better usage traceability, enables fashion companies to collaborate more productively with their peers and external stakeholders on sustainability. Thus, traceability becomes a prerequisite for identifying and improving the environmental, social, and ethical impact of fashion. It is interesting to explore how to manage data and understand how to use it to enhance sustainable decision-making.

Another aspect of experimentation through Big Data collected with RFID technology is, for example, installing a system to identify garments tried on in fitting rooms to better understand product movements and selection criteria. Knowing which garments are not purchased allows for more systematic reasoning about fashion processes, merchandise layout in the store, and design during production and possible future textile material developments. The data generated by RFID technology is new to both fashion and retail. Learning to make the most of it, especially regarding environmental sustainability, is one of the critical points of this research.

A recent World Economic Forum survey reveals that 92.1% of business leaders believe that by 2025, 10% of people will wear internet-connected clothing (World Economic Forum, 2015). This means we will be able to generate data that can go beyond managing the production process and product mapping in the closet. In this scenario, we will be able to map the entire experience of using and consuming fashion items under strict privacy regulations.

The physical space that opens the possibility of new scenarios thanks to big data use is undoubtedly retail: here, data can capture the true essence that guides the decision to buy or not an item. Retailers have long studied how their customers decide which goods and services to offer. The history dates back to the Victorian shopkeeper, the original one-to-one relationship manager who worked hard to understand customers' tastes and quirks (Strong, 2016). The responsibility of retail in the relationship with the consumer and their awareness of sustainability must, therefore, be linked for obvious reasons: in this sense, retail must affirm its social impact. In a data-driven fashion industry, the retailer has a direct connection with customers and is thus in the best position to know customer options and learn more. In an integrated big data system, retailers have full access to everything about the product they sell and the person who buys it.

However, mapping the customer within retail does not mean creating the perfect sale for the company, and the goal of a data-driven retail strategy is to generate a closer relationship between the consumer and the product to extend the product's life cycle. The research aims primarily to increase awareness to improve the overall consumer experience with the fashion product.

The collection of wardrobe data, which currently does not represent a priority for the fashion system, hides immeasurable value concerning sustainability. They could show consumers an overview that provides a snapshot of their current relationship with clothing to prevent *mistakes* and follow the usage cycle of garments.

The role of design in this data-rich scenario changes radically. Big data is not there to offer a solution like an oracle but to guide insight to the point of always putting the human being at the center of any project related to the fashion industry, which, as we stated at the beginning of this article, has the deepest social nature.

5. A Framework for Designing with Data for a New Sustainability

5.1 A Framework for addressing System Complexity in Fashion

After understanding the data landscape of the fashion industry, the current data challenges, how to leverage data to achieve impactful results, and the value of data-driven decision-making, the acquired knowledge was applied in defining a theoretical-methodological framework. The design method used for development is based on previous investigations, and the framework aims to generate insights to generalize the research results, although future developments of prototyping tools and additional validation methods are not excluded.

The motivations leading to this type of output are fundamentally threefold. First, the indeterminate, fragmented, and complex nature of the field of investigation. Second, the creation of a framework is a global design methodology that incorporates various types of design investigation. Finally, the creation of frameworks has been used in transdisciplinary contexts (Bijl-Brouwer, 2019) and repres-

ents an effective way to incorporate different disciplines into a broad design process.

The framework presented in the following section was specifically developed concerning the data collected within the fashion sector. This theoretical-methodological framework aims to assist designers, brand managers, and data scientists at the disciplinary intersection in developing new data-driven sustainability strategies.

Literature, case studies, and in-depth interviews reveal that although the potential of data in relation to sustainability is extensive, the roles, skills, and objectives in the design process are still poorly structured. The design of data-driven products, services, systems, and strategies remains a complex and multidisciplinary activity. Whether designers are developing a collection or companies are planning a sustainability strategy, engaging with data across multiple objectives and stages of the product lifecycle is complex. In a scenario like fashion, where the designer plays multiple roles beyond that of a stylist and where the fragmentation of professional figures is high, ensuring that data serve as leverage for sustainable strategies requires extreme collaboration across various fields. This same collaboration has always been fundamental to responding to the exponential complexity of systems thinking for sustainability.

Several frameworks, such as the Eco-design Strategy Wheel (Brezet & Van Hemel, 1998), Product-System Lifecycle (Vezzoli *et al*., 2008), and Whole System Design (Charnley, 2010), are well-known for considering the overall picture for sustainable and interdisciplinary decision-making processes. However, these frameworks tend to overlook the different design approaches stemming from the various collaborating disciplines. For this reason, the proposed framework is intended to be both iterative and collaborative, capable of initiating dialogue and mediation within the corporate fashion landscape.

This chapter addresses the research question: *what are the approaches and methods that enable designers to adopt a data-rich methodology?* To answer this question, a theoretical-methodological framework was developed in line with Dorst's thinking, reflecting a more realistic design situation compared to previous studies.

The study highlighted several limitations of companies in embracing new data sources. The relationship between sales data and data on products tried but not purchased piqued the interest of companies involved in the final phase of the study because this data source still falls under the *domain of the company*, meaning data that require technological implementation to be obtained, but not necessarily a third-party service. Data on TV shows, fashion shows, or social media profiles, on the other hand, were perceived as difficult to obtain, place, and use. We attributed this detachment to the limited openness of the corporate context and a not widely diffused data culture. To develop economically sustainable strategies from data, a more comprehensive understanding of approaches, technologies, tools, and potentialities related to data use is needed.

Therefore, in subsequent studies, we based our analysis on these aspects to propose an analytical perspective capable of considering both the corporate world through various professional figures involved in the design process. Viewing them as a single system helped us uncover the basic structure supporting data-driven dynamics in the corporate context, consequently allowing us to develop a framework for managing collaborative design in a future perspective. This study was useful in identifying the elements and relationships underlying the corporate structure and their needs, for which in the next phase, we conducted a series of in-depth interviews with designers and experts, the results of which were formalized in the design framework.

5.1.1 Systemic Innovation Design Methodology for Framework Development

To build a solid foundation capable of supporting the complexity, volume, and variety of information, the overlap of concepts, and the wide scope of disciplines involved in this investigation, a methodology was employed in line with the Systemic Innovation Design Methodology (Gaiardo *et al*., 2022). The starting point for developing the framework was the assumption that neither inductive nor deductive thinking can solve systemic problems, especially when dealing with *wicked* or *ill-defined* problems. This framework design, therefore, targets organizations to navigate complex scenarios and stimulate innovation processes.

Specifically, *framing* practices are an essential component of design. Schön first introduced this concept in 1984, presenting problem-setting as a crucial element for reflective practices. According to his theory, «problem setting is a process in which we interactively name the things to be attended to and frame the context in which we will address them» (Schön, 1984). Later, in the early 2000s, Dorst and Cross also explored this process, analyzing a series of methodologies developed by experienced designers. Their study led to the formulation of their theory on the co-evolution of the problem and solution spaces. As part of this co-evolution, *framing* is a key practice for generatively synthesizing learnings from the solution space to evolve the problem space. Dorst expanded this theory by focusing on design problems and paradoxes (Dorst, 2006), as well as the cognitive aspects of how the habit of framing is developed (Dorst, 2011). According to Dorst, the main characteristic distinguishing expert designers from novices is their enhanced ability to frame and reframe problems constructively to advance the design process. The teachings of this theory are organized in the book *Frame Innovation* (Dorst, 2015), where he presents a methodology for creating frames.

The integration of Dorst's theories and the Systemic Innovation Design Methodology was employed in a design perspective to create the following framework, using three macro-areas: research, design, and development, and eight specific phases. Each of these phases is well-suited to address open, complex, dynamic, and networked problems such as those related to data, fashion, and sustainability. In practice, the creation of framework includes and incorporates various types of design investigation and has undergone a double cycle of interaction through case studies and expert interviews to assess its flexibility and feasibility. The phases of the framework creation process, in reference to the results obtained during this investigation, are described below.

Table 1.
Systemic Innovation Design Methodology.

Phase	Systemic Innovation Design Methodology
Research	Step 1. Needs definition and problem history analysis.
	Step 2. Research existing information – what makes the problem difficult to solve?
	Step 3. Integration of information by stakeholders: • Internal Stakeholders • Contextual Actors
Design	Step 4. Key themes. Investigate themes that emerge in the broader field.
	Step 5. Concept development: Create a framework by identifying how to act on these issues.
	Step 6. Validation of the solution.
Development	Step 7. Test. Analyze changes in stakeholder strategies and practices needed for implementation.
	Step 8. Theoretical integration. Draw lessons from the new approach and identify new opportunities within the network.

5.1.2 Research

Phase 1: Defining Needs and Analyzing the Problem

In the early stages of this research, the primary focus was on the contentious relationship between the fashion industry and technology. The initial emphasis was on evaluating the existing system, along with the solutions and strategies already implemented to combat systemic unsustainability in this sector. The literature review conducted revealed the difficulty in identifying a single owner of the problem within a tangle of actors and roles of various scales and natures. For this reason, the focus progressively shifted to the corporate scale. The literature review examined the solutions already adopted, the approach to sustainability by technologies, and the recent relationship between the design discipline and data science. Among the strategic solutions to the problem of systemic unsustainability in the sector are the careful selection of sustainable materials and the slow approach, which acts on the longitudinal axis of time or production volumes. The problem that emerges is one of a complex system where decisions

are made with little understanding of the internal dynamics of the processes involved, and solutions primarily operate in silos, analyzing one problem at a time.

Phase 2: Researching Existing Information

Once the sequence of actions leading to the problematic situation and a clear understanding of what drives the organizational behavior of the system underlying the problem have been defined, the next step is to investigate the problem definition itself. The main question is: what makes this problem difficult to solve? The second phase of the research delved into the solution area and defined a series of paradoxes that slow down problem resolution. In the problematic situation examined, various issues intertwine, but from an informational perspective, although the fashion system collects a large amount of data and is accustomed to integrating it into various phases of production and design processes, the data is not free to circulate and accessible to the different figures within the system. With this paradox in mind, the subsequent phases of integrating existing information were set.

Phase 3: Integrating Information

The next step in this analytical phase of the framework creation process involves pausing the extensive work done to establish and accurately formulate the central problem correlated with the collected informational heritage to integrate the missing information. What followed was an exploration of the practices of the close circle of key stakeholders previously involved in the problematic situation or those who clearly represent a necessary figure for any possible solution. In-depth examination through interviews allowed us to identify significant influences on corporate behavior concerning data and sustainability and assess whether the strategies they currently use reflect the solutions identified in best practices or the literature. This way, data were collected that provided a general idea of the practices and scenarios that could become part of the solution. The information integration phase was divided into two main aspects: stakeholder analysis and contextual analysis. Once a shared overview with the stakeholders was reached, the investigation was radically expanded towards the context. In this sense, all (potential) actors, including those who might

be connected to the problem or solution at a certain moment, actively or passively, were considered. In the specific case of this research, the contextual exploration of potential actors is related to the scoping study, which explored the roles of data scientists and trend forecasting companies. Additionally, the analysis of case studies revealed how the world of services, products, and systems designed from cloud and data technologies can play a decisive role in the context of the investigation. This type of broad and contextual exploration focuses on emerging and universal values that will inform the formulation of themes in the next phase of the framework creation process.

5.1.3 Design

Phase 4: Key Themes

The research phase revealed areas where shared values among all involved actors could steer the fashion system in a new and promising direction. From this perspective, new significant variables emerge, leading to previously unconsidered opportunities. In the thematic analysis, the factors underlying the needs, motivations, and experiences of the *actors* involved in the system are identified. The thematic analysis concludes with the selection of themes that are relevant to the problematic situation concerning both stakeholders and contextual actors. Since these themes are hidden within the system, they are made explicit during this phase. In this case, the key themes emerging from the analysis of case studies and in-depth interviews indicate a tension between the various stages of the fashion product lifecycle. Decision-making power regarding sustainability strategies is not equitably distributed among the various roles, either within or outside the corporate core. Specifically, the entire lifecycle of the fashion product is scarcely considered when the collection is designed by fashion designers who focus mainly on style or material sustainability. However, case studies reveal that certain product design decisions positively or negatively influence the usage phases or end-of-life of the product, impacting, for example, disassembly or reuse techniques.

Goals and Strategies for Sustainability

The first key theme emerging from the analysis is undoubtedly the

goals and strategies for the sustainability of the fashion sector. Both case studies and literature review highlight the role of a designer capable of going beyond product development, material choices, and aesthetics. This involves a designer who can design for the entire product-lifecycle, supporting the development of alternative business models and system sustainability within the corporate context. System thinking and design management approaches can enhance systemic transformation by incorporating new business models and consumer insights into the open network. Strategic design choices can encourage the creation of timeless collections or systems supporting the repairability or reuse of garments. In this sense, designers can work on many aspects of the product lifecycle, not just collection development, maintaining a holistic vision and systemic understanding of sustainability issues.

In addition to this, the dialogue with data experts emphasized the importance of setting a goal at the beginning of the data collection process. The data science process, in its initial planning phase, involves posing a problem and seeking its resolution through data. Similar to other problem-solving approaches, data science focuses primarily on understanding what already exists (Cross, 2004). Data science processes are considered well-procedural, where scientific rigor leads to accurate results and thus certainty. For this reason, the development of a well-defined goal regarding sustainability was placed as a central theme in the framework construction.

Sustainable strategies	Approach	Design Principles
Reduce	Eliminate overproduction accurate production, Zero Waste, reduction of impacts.	Smaller collections, custom made, made to order, zero waste design, deadstock reduction, local production, etc.
Re-wear	Extend the life of the product.	Multiple users, timeless design, basic design, etc.
Repair	Extend the life of the product.	Reparability modularity, repair kits, upcycling, services, repair, etc.
Resell	Second hand.	Personalization, uniqueness, quality of materials.
Recycle	Closing the circle of materials.	Material recycling, design for circularity.

Table 2.
Sustainable Strategies in Fashion.

5.1.4 The Data Approach

The literature review on various data approaches within the discipline of design yields a conceptual framework that progresses from specific to general through the construction, integration, interaction, and communication of data. These four perspectives are interrelated and holistic ways to view data practices through the lens of design within the fashion system. These four aspects represent the theoretical foundation necessary for achieving a *sustainable balance* between the potential of data and the discipline of design, regardless of the field of application. Within the framework, these four levels of data integration are considered across objectives and the product lifecycle.

5.1.5 The Phases of the Fashion Product Lifecycle

Therefore, in the framework design phase, it was established that the main themes for using data in design strategies should be the phases of the fashion product lifecycle. From a systemic perspective, the product lifecycle encompasses the phases from ideation, thereby covering the role of designers within the corporate context, to its recovery and disposal, integrating all peripheral actors from trend forecasters to second-hand services and the circular economy. The phases that a product undergoes during its life are dynamic and complex, with many levels of detail. Identifying them at this stage as themes not only makes them explicit but also, in a future phase of integration among various roles, makes them subjects of strategic dialogue. The designer targeted by this framework is a systemic designer capable of identifying appropriate data planning and collection for each phase, balanced with the other phases. This approach will compel all involved roles to consider the broader system view. Various frameworks have been proposed in the literature to provide a comprehensive approach to sustainable design (Breast *et al*., 1998; Vezzoli *et al*., 2008), representing a crucial resource for many companies. The model developed by Vezzoli *et al*. (2008) is considered during this framework's design. Their framework, aligned with the systemic approach, introduces the concept of input-output flows of energy, resources, and emissions throughout the product lifecycle (Vezzoli *et al*., 2008). In this research, the input/output considered is informational and is based on the data design theories and approaches explored in the second chapter of the literature review.

Vezzoli's framework comprises five activity phases:

- preproduction (resource acquisition, delivery, and transformation into raw materials or energy);
- production (material processing, assembly, completion);
- distribution (packaging, transport, and storage);
- use (usage or consumption and service);
- disposal (reuse, remanufacturing, recycling, composting, incineration, and landfill).

Each of these phases represents a macro-theme of analysis when discussing data culture approaches. For example, data acquired in the preproduction phases can indicate a brand's transparency level, monitoring deliveries or materials allows for accurate emission calculations and supports supplier selection. Customer insights, acquired through alternative methodologies such as those experimented within the AI for Fashion challenge, can alter product design phases, while data on usage and end-of-life can enable circular economy strategies. These are just a few examples of sustainability strategies that a company, sometimes in collaboration with others, could implement with a more accurate understanding of the data they have or could obtain.

Phase 5: Concept Development

Designing for sustainability is a complex practice and an act of balance. In this research, we have seen that to design sustainability within the system, many aspects must be considered, a collective effort is required, and various professions must be taken into account-fashion designers, trend forecasters, marketing experts, sustainability experts, logistics actors, and those involved in the product's end-of-life. Each of these professions has its own practice model, structure, and, in some cases, distinct objectives and professional codes. Therefore, to bring significant value through data within the system, it was necessary to mediate numerous variables. The primary objective of the framework development phase was to begin viewing data as an asset to bring holistic value. The framework aims, given a shared objective among the various actors, to identify otherwise hidden compromises and to plan a strategy through the use of data across different lifecycle phases.

A more comprehensive understanding of the potential of data, starting from a common objective across different product development phases, not only provides a tool for guiding sustainability strategies but also informs and improves the decision-making process regarding how and what is to be designed. In the concept development phase, the three main themes were considered and applied incrementally.

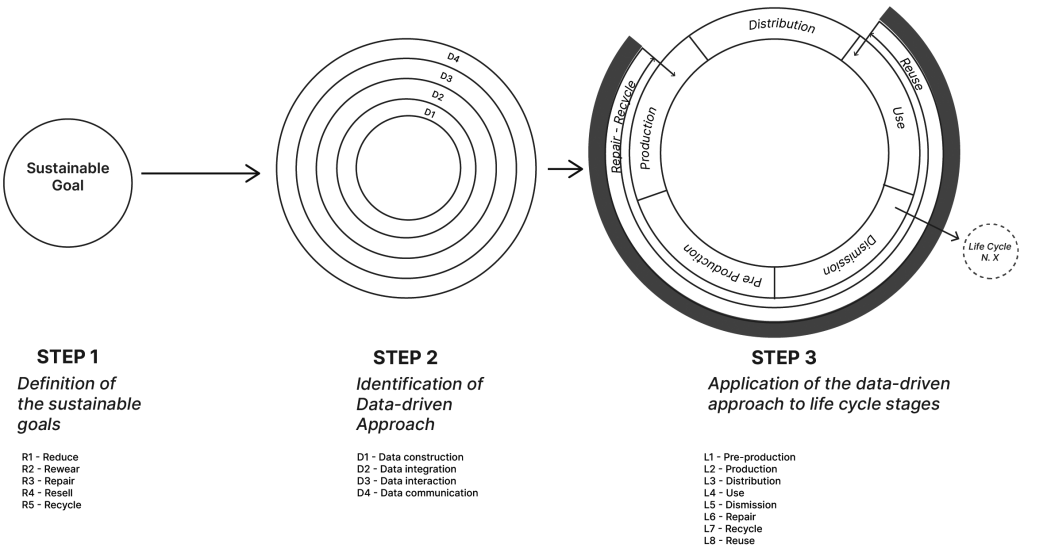
Specifically, the framework has three levels of detail:

- *Level 1* represents the reference objective and must be agreed upon by the various system actors to identify the potential sustainability strategy to be created.
- *Level 2* contains exemplifying and general data approaches that should be relevant for any organization or project, regardless of the main objective selection and the product lifecycle phases. The relevance of these approaches may vary from project to project.
- *Level 3* provides the product lifecycle phases. For each phase of the reference framework, using different data approaches can produce various types of impact.

Structured in this way, the framework serves as a holistic tool to build value through data, an incentive to incorporate data to achieve sustainability goals from the early design phases, and a motivator to create shared awareness among designers, professionals, and stakeholders involved.

However, the framework should not be understood as a prescriptive *toolkit* or a measurement system for strategies. Its goal is not to recommend specific tools or technologies but to make tangible to businesses the fact that working simultaneously and flexibly in terms of data approaches can be a starting point for sustainability strategies. The framework indicates where data work is most likely to be effective because other companies or ecosystem stakeholders have already begun adding value to the supply chain in that way, providing useful suggestions on what types of data could be collected, communicated, integrated, and shared. The framework is designed to function at the design level and to integrate, potentially in a progressive experimental phase, other more detailed toolkits created for specific business needs.

Another characteristic of the framework is that it is neither exhaustive nor rigid in its design. The framework identifies strategies essential for achieving systemic sustainability, but it does not preclude the possibility of modifying or changing transformative objectives based on business needs or the impacts the company aims to achieve. The framework can be adapted to individual projects or the development of innovative entrepreneurial organizations.



Phase 6: Framework Validation

In the final phase of the methodology, interviews were conducted with experts from both academia and industry through guided, face-to-face sessions. This approach involved asking all interviewees the same set of questions while allowing them the freedom to delve into specific issues (Paton, 2002) to validate the proposed framework.

The interviewees were briefed on the methodological process that led to the development of the framework, the research phases, and the results previously obtained. They were then asked to provide general feedback on the model, the dynamics of the individual disciplines involved, and future developments.

The experts selected for validation, similar to the earlier research phases, were drawn from multiple disciplinary fields: data design ex-

perts, fashion industry experts, and sustainable fashion experts. Given that the field of investigation only partially overlapped with the research domains of the involved experts, the framework validation was conducted through face-to-face interviews to adequately explain the nature of their involvement and the ultimate objective of the validation.

In line with the authoritative source Nielsen *et al*., which states that «testing with 5 people allows you to find almost as many usability problems as you would find using many more test participants», five experts were selected. The tables above summarize the disciplinary areas of the experts involved in the validation phase.

	Sector	Nationality
E1	Design informatics	UK
E2	Data driven innovazion	UK
E3	Fashion sustainability	Portugal
E4	Fashion design	Portugal
E5	Fashion management	UK/Italy

All participating experts were asked questions related to general considerations about the framework, specific considerations about their particular fields, and thoughts on future developments and aspects to be integrated.

	General consideration
E1	The framework appears to be comprehensive with respect to the theory analyzed and can be a useful tool for design; however, it might also be useful to integrate the framework into other dimensions of sustainability: not only the productive one, but also the social one.
E2	The process that led to the development of the framework is easily understandable and well structured in its narrative. It is not crystal clear what kind of actors it is aimed at, whether one imagines its use in the business context or in the area of data literacy education.
E3	Excellent use of information flow theory integrated with the systems approach applied to fashion. Sustainability strategies also to be implemented to be understood at the systemic level and not only on the product level.
E4	Framework as a whole effective for design exploration. Compared to strategies for the fashion world these, while embedded in a holistic framework scenario may seem reductive to the product. What would happen if the goal were systemic and not a single one?
E5	The framework is understandable, as is the process that led to its development.

	Disciplinary considerations
E1	The role of data in the framework cuts across project phases, indicating that data can increase the value chain. Acting with data in fact means adding value or taking away value. It will be challenging to get companies to understand what kind of value they can generate for the sustainability of the fashion system.
E2	The framework is interesting for expanding data culture. After a discussion of the methods used or usage that may arise from this framework, it is suggested that it be supplemented with a set of questions for stakeholders to design.
E3	As far as sustainability strategies applied to the fashion industry are concerned, they mainly refer to the product sector, but the interesting thing about the framework is that if iterated, sustainability strategies could be expanded in the direction of services and systems.
E4	The framework presents a theoretical-methodological framework appropriate to the discipline involved. It represents a rare case where strategies and methodologies are combined together in a single matrix.
E5	From a management perspective, one understands the reasons for seeking interdisciplinary dialogue in such a heterogeneous field as fashion. I struggle to imagine the timing of such an activity in the corporate context.

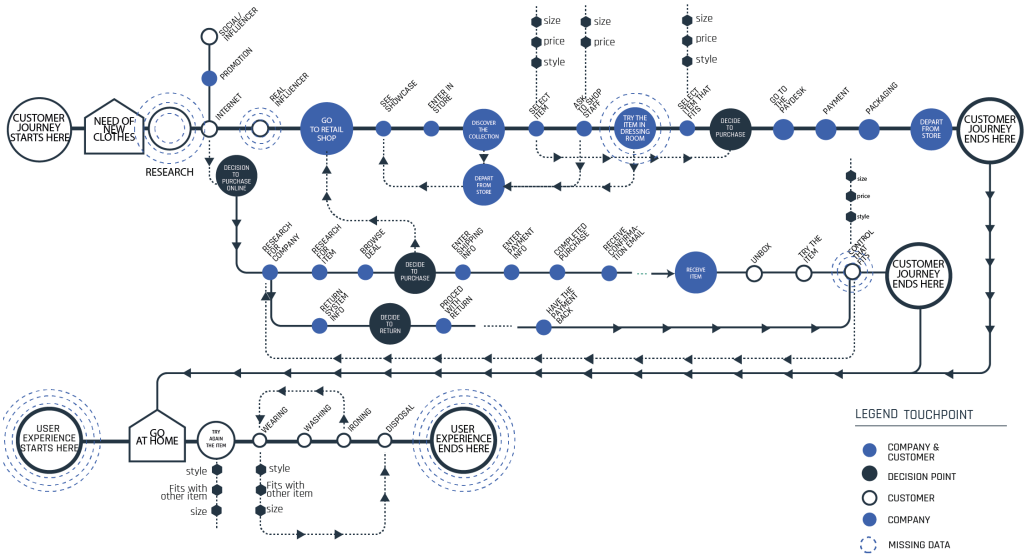
The objective during the validation phase was to ensure that the framework presented to the experts from various disciplines was as *clear* and precise as possible. This clarity was necessary to make the framework effective, as it needed to be well-understood by all key interlocutors. The framework was slightly revised only after incorporating their feedback. The following table provides an overview of the validation results.

	Future developments
E1	The role of data in the framework cuts across project phases, indicating that data can increase the value chain. Acting with data in fact means adding value or taking away value. It will be challenging to get companies to understand what kind of value they can generate for the sustainability of the fashion system.
E2	At the methodological level, the framework is a useful tool. It is suggested that a series of case studies be developed that can easily give the idea and noted the closed nature of companies in terms of data, pose as facilitating by having companies develop strategies on their own.
E3	As far as sustainability strategies applied to the fashion industry are concerned, they mainly refer to the product sector, but the interesting thing about the framework is that if iterated, sustainability strategies could be expanded in the direction of services and systems.
E4	In future developments of the framework, it is suggested that the experimental phase be expanded with a collection of usability data in different contexts. Both corporate and educational ones.
E5	As a future development, I suggest that you explore the link with companies in light of this result and assess the real effectiveness of the methodological tools that may arise from this.

Phase 7: Integration

For each of the following areas, case studies within the fashion system were examined to support the hypothesis that systemic change towards sustainability can be promoted through data and its interconnection. These case studies could represent one of the many solutions that can be designed using this framework as a framing tool. Subsequently, two case studies and two examples of how similar solutions can be achieved will be presented.

Figure 1.
Systemic diagram of the user experience within which to search for new data sources.
Source: Author.



5.1.6 Examples of Projects Based on the Framework

Consider a practical example of utilizing the framework: the initial phase involves a multidisciplinary team first identifying a specific goal to address. This initial decision-making phase requires the involvement of designers, sustainability experts, and data scientists to define the sustainability objective they intend to strategically pursue. Suppose the agreed-upon goal is related to the principle of *recycling*. The team of designers and experts might pose the following questions:

- What data do we have?
- What data could we have but are not utilizing to create value in terms of reduction?
- What factors are we currently measuring?

Additionally:

- Who owns this data?
- Who are the stakeholders involved that would allow us to collect this data?

Once the team has answered questions of this nature, they can deliberate on the data strategy to employ:

- Do these data exist? Are they accessible? The figure on the adjacent page illustrates multiple points within the user experience (highlighted by blue dashed lines) where data are currently not being collected or not made accessible to the user or the company. If the answer to these questions is no, the planning process includes considering the *construction* of this database and determining at which phase of the product life cycle these data can be retrieved.

For instance, consider focusing on the recycling system for garments as part of the recycling strategy. What data can a company access, and what data might be useful for those responsible for correctly recycling a garment? The first step would undoubtedly be to create a database of information useful in the logistics phase: what is the garment made of? What characteristics ensure proper recycling? Once these data are identified, the company can plan to collect them. Depending on its characteristics, it may have an internal department to handle this or rely on external services to build the database. After constructing the database, the company, following the *data construction* approach, can decide to iterate the process. With an existing dataset, the company can explore other areas of the product life cycle where these data might be useful. If the goal remains recycling, the company could, for example, establish a collaboration with recycling firms and direct garments to them through customers who make purchases. In this case, the solution might be a service like the one presented in the case studies: Re-Fashion. Initially, the company, in collaboration with a fashion firm, designed a service that generates data on proper recycling, followed by creating a second digital service, Circular Surplus. By scanning a QR code on a garment's label, it is possible to access unique real-time data for that item. Examples of data collected include:

- number of times it has been recycled;
- number of weeks in possession;
- estimated resale value. These data are used to engage users and encourage reuse.

Phase 8: Theoretical Integration
Based on the results obtained from the validation with experts of the theoretical-methodological framework and the proposed practical example, some future developments highlighted by the experts were considered. For instance, since the framework was not sufficiently exhaustive regarding sustainability strategies that operate according to a circular approach, the characteristic of iterativity in using the tool was added. As evident from the case study, data can support sustainability strategies through various approaches, from the creation of datasets to communication. Therefore, we believe that the tool should function iteratively immediately after the construction of the datasets to return value to the system.

This represents an advantage for all strategies aiming at circularity, and especially because data, contrary to what happens today, should be free to circulate. Therefore, as soon as data on the sustainability of the fashion system become available, it is strictly necessary that they be accessible internally within companies and, importantly, throughout the entire supply chain.

5.2 The Pivotal Role of Design and Emerging Skills

The main objective of this book is to answer the question: *how can data and design interact to improve the sustainability of the fashion industry?* The research explored, by integrating a systemic approach to data, how these can represent a significant component of a system to understand, measure, push, and activate greater awareness in the transition towards a sustainable future, which has been repeatedly defined in this book as an act of balance between different variables.

This research argues that a systemic, data-driven approach can address the complexity challenge so that ill-defined or fragmented

problems can be tackled by companies and stakeholders. The initial part reflected on the technological component of the fashion system, which has assumed a controversial role over the years: on one hand, it accelerates the fast fashion paradigm, while on the other, it has the potential for ecological transition, capable of integrating ethnographic, social, and cultural aspects of a given territory, sometimes preserving local culture and other times providing specific suggestions regarding the target audience.

To overcome the limitations due to the lack of uniform information, the inaccessibility of data within the system, and the tendency to hide, withhold, or exploit them within greenwashing logics, this research proposes an open approach to data. This approach aims to enable data to circulate and bring value throughout the entire supply chain of the fashion industry, supporting technologically advanced systemic innovation processes. Against the idea of a single solution that does not consider the needs of individual companies, the proposed result intends to encourage the integration of data at various stages of the process with an iterative design system guided by a sustainability objective set at the beginning of the design strategy phases.

This requires designers to handle data holistically, not just to translate insights into trends for the collection. As a result, this research proposes a theoretical-methodological framework that equips designers with sensitivity to data culture and an overall vision of the design process. Beyond the technological variables explored in the case study analysis, the framework was conceived to be flexible and open to adoption and adaptation by other designers in the fashion system, drawing on the resources and knowledge of individual companies and stakeholders.

The design outcome proposed by this manuscript is a theoretical-methodological framework. One of its fundamental characteristics is its drive to transcend the simplifications that often underlie conventional problem-solving approaches, thereby addressing the challenges of systemic complexity and unsustainability.

Although it may seem somewhat counterintuitive, as the creation of a framework inherently involves an act of simplification that encompasses both data theories and sustainability objectives, the true strength of the framework lies in its representation of a much broader

and kaleidoscopic matrix within which to seek solutions. As discussed in the initial chapters, the fashion system tends to resolve sustainability issues arising at various stages by treating them individually. In contrast, the framework resulting of this research, functioning as a conceptualization and ideation apparatus, aims to intersect multiple variables and combine different data approaches. This ranges from the construction of novel data sources to their communication to the user, from data supporting circular economy processes to those involving user co-design of collections, thus addressing many phases of the fashion lifecycle.

In this context, the designer, who typically employs a problem-solving approach, is encouraged to abandon the assumption that each problem corresponds to a single solution. Instead, the designer is invited to embrace the complexity of the situation, shifting towards a problem-setting logic. This does not imply that the use of the framework represents an infallible tool that makes the complexity or fragmentation of sustainability issues in the fashion system easier to solve. Certain degrees of complexity persist, such as the extensive and dispersed nature of the production chain on a local/global scale, or the multitude of actors involved in various processes.

However, the framework's avoidance of oversimplification helps manage complexity by operating across different contextual levels. On one hand, there is the shared objective among the design actors; on the other, the levels of data integration; and finally, the phases of the product lifecycle. From the perspective of a systemic approach to solving complex problems, this ensures that variables are initially limited to manage complexity based on the emergent qualities of a specific context. These variables are then reconsidered as relationships between components to keep in mind throughout the entire ideation and design process.

The Nobel laureate Herbert Simon (1982) defined design in the broadest sense of human action as the ability to «devise courses of action aimed at changing existing situations into preferred ones», implying a wide range of processes humans use to plan for the future. However, ten years earlier, Charles Eames (1972), in his video *Design Q&A*, asserted that design largely depends on the «designer's ability to recognize as many constraints as possible and his willingness and enthusiasm to

work within these constraints». These constraints include price, size, strength, balance, surface, time, and so forth (Candy & Potter, 2019).

The current scenario, however, is one characterized by larger, more systemic, dynamic, and pervasive constraints. This research work, alongside a data-driven approach, seeks to highlight the importance of these otherwise invisible or hidden constraints, which could play a significant role in the potential of design within the apparel sector. If design guides strategic choices, objectives, and the planning of actions we undertake to achieve them, data serves as the tool that makes identifying problems within an increasingly complex scenario more immediate.

Similarly, the approach to Systemic Design applied to data becomes the method for developing critical awareness within the contemporary fashion system, demonstrating that focusing on a single problem destined for a single solution is no longer sufficient. Through data, this research aims to provide a tool for designing products, systems, processes, and services.

The entire research work results in the development of theoretical and critical knowledge for the discipline, yet it remains configurable according to the morphological, functional, aesthetic, communicative, productive, and distributive characteristics of the fashion system. These characteristics must increasingly take into account usage modes, individual needs, and community contexts of interaction and enjoyment, which become intelligent and multifunctional through technology.

Thus, the result enables design interventions in the fashion sector, which is often relegated to the concept of style design. In contrast, this research argues that while the disciplines of design and fashion have diverged over a certain period, the urgency of the crisis necessitates their synergistic collaboration. The bond that unites them is a combination of humanistic and technical knowledge that ties design and fashion together indissolubly.

According to King *et al*. (2017) and Girardin and Lathia (2017), the collaboration between data science and design can be problematic. While designers might struggle with a potentially reductive approach to rich contexts, data scientists, who specialize in processing datasets to extract insights, may find the design process too intuitive.

Second, designing with data is an emerging trend, and consequently, there is limited support for novice designers who need guidance on identifying which data to use and for what purpose. It remains unclear what specific set of skills designers should possess to design with data, an issue tied to data literacy (Wolff *et al*., 2016; Gray *et al*., 2018). To evaluate the immense potential of designing with data, approaches that combine data science and design are necessary.

Addressing these questions is thus fundamental to developing design education, tools, and mindsets appropriate for designing with data. In this article, we adopt a designer's perspective to explore the challenges and opportunities for designers when designing with data.

In light of this research, four emerging profiles of roles that a designer can assume when professionally interfacing between data and sustainability in the fashion sector have been identified:

The first is undoubtedly the already known role of *trend translator*. Given the databases provided by trend forecasting companies, fashion designers often translate the received insights into new collections. In this role, designers collaborate almost directly with data scientists. However, for this role to be effective, designers should be integrated into the data collection process and work alongside data scientists to build the most appropriate data sources. To adapt the trends received to the style and aesthetics of individual companies, designers are sometimes forced to extend their research independently, using the data received only as a *starting point* for the collection. To do this, fashion designers should possess knowledge and skills in technical jargon, as well as communication and empathy abilities. This essential *partnership* with data scientists was already highlighted in the research by Girardin and Lathia (2017) and Gorkovenko *et al*. (2020).

But can a trend translator role align with the sustainability pursued in the contemporary paradigm? This question certainly requires targeted exploration within the corporate context, but from the perspective of this research, working on trends does not necessarily mean supporting the growth paradigm. On the contrary, the more capable a designer is in intercepting trends, the more they will be able to meet not only the desires but also the needs of their target audience.

To better understand this emerging figure in practice, it is important to remember that trend research sometimes also involves analyzing culture and has precise indicators: socio-political systems, the production of visual, performing, literary, and cinematic arts, and the production of consumer goods industries. Through the use of Big Data, all these fields are now more rapidly examined, and the more accustomed designers are to dealing with data, the better they can *interpret* this complex scenario. Closely linked to the previous role of trend translator, the role of *contextual empathizer* is also crucial for interpreting the meanings and evolution of contemporary groups. This is even more important if data research involves *situated* or contextual data that considers the characteristics of a territory. In the first pilot study, multidisciplinary groups of designers and data scientists were asked to find new data sources for sustainability in the fashion sector. This role, according to the theory of Bogers *et al*. (2016), is one of the most crucial for designers in the Big Data era. The case studies collected indicate that while sensors can capture experiences and data about users through clothing, it is necessary to adopt the role of contextual empathizers to recover significant insights.

To these roles, which may fall inside or outside the design department of companies, another is added: that of *Data design leader* within the design department. When designing with data, the amount of available information increases exponentially, as does the complexity of intersecting them. The project leader must guide the direction of a project and make design decisions for the entire team. During the interviews, we found that often the contribution of an individual designer in terms of data within the fashion context is insufficient because their role is overshadowed by that of the brand manager, who has more control over both the data and the decisions to be made. Therefore, we hypothesize the need for a leadership role in data design within fashion companies, capable of having decision-making power over both the collection and the necessary data, closely interacting with the company's data analysts. This person should be a designer capable of maintaining a holistic approach and combining factual and intuitive skills.

Finally, the role of *Data design analyst*. According to Bourgeois and Kortuem (2019), designers have always been required to analyze sub-

stantial data as a way to understand users' experiences and feelings. It is considered an essential step before entering empathy. Currently, these responsibilities also include the ability to analyze other types of data, such as the combination of Big Data and Thick Data.

5.3 Designing without Data and Lessons from COVID-19

As highlighted in the Preface of this book, the pandemic has accelerated systemic unsustainabilities. In fashion, this change has led to redefining the terms of slower and more conscious design. During these years of research, the topic of sustainable fashion has increasingly exploded, becoming an urgency both nationally and internationally. With the pandemic, the fashion world realized that excessive production volumes are not useful to anyone, especially when production chains suddenly halted. For this reason, the pandemic situation represented a significant limitation to contact and collaboration from companies.

The entire corpus of research and its focus on the fashion system makes it adept at integrating sustainability into its processes. However, although companies' choices are largely based on data on purchases, inventory, and social media monitoring, they lose significance in a pandemic context where no one knows exactly what will happen tomorrow. In this crisis scenario, certain data clusters are missing. Research, selection, and purchase activities by customers are lacking, interpreting order movements becomes difficult, and there is a lack of certainty about future events. The fashion industry, certainly not immune to the threats posed by an uncertain future, including climate change, resource scarcity, vulnerable economic conditions, and changing consumer behaviors, has seen the need to address and understand these threats within the pandemic context. Essential warnings to take appropriate actions to safeguard the future, protect the environment, and improve the lives of consumers and citizens. With this conviction, we believe data studies should be more widely applied to the fashion sector. Conversely, studies on the past and the critical issues the system promptly responds

to show how certain globally significant events have profoundly transformed this sector. The 1918 influenza epidemic, transforming personal hygiene and cleaning habits, increased the frequency of clothing washing and the use of washing machines. World War II, changing domestic female employment, enabled female workforce participation even after the war. Finally, the more recent SARS epidemic in 2003 led to lasting changes that favored the development of e-commerce platforms (Tham, 2008). Consequently, investigating the effects and implications of COVID-19 means considering all those signals of change and transferring them into design competencies for creating tools, processes, and products to address them. During this work, we did not delve into the effects of the pandemic on corporate data systems because it was not possible to contact the sector at that time. However, we conducted an analysis of future scenarios using the three horizons method in the study: *Future scenarios. The new life of the fashion industry in the post-pandemic era I* (Marino & Remondino, 2021).

5.3.1 Involvement of Companies

Despite all efforts to engage fashion companies within the timeframe established by the initial research planning, the availability of companies to collaborate in the study was low. Among the expressed reasons, the pandemic situation was significant, as it caused companies' priorities during the first two years of research to shift from investing in research and development projects to addressing the emergency and restrictions caused by the pandemic. Specifically, the initial research plan included building a single company case study by mapping behaviors, information flows, data culture, and sustainability culture within one company context from the early stages of the research. When it became apparent that the pandemic would last longer than expected, research methods shifted towards a multidisciplinary approach with an exploratory nature rather than a descriptive or emancipatory one. Another reason for the lack of company involvement was the subject matter of the investigation: some companies involved in the study expressed concerns about engaging in research on data, citing *confidentiality* of information not only as an added value but also as a strong competitive element. Others stated

that «quantitative information, methods, processes, and innovation represent our way of doing business and were not inclined to provide this type of content and support for the research». However, over 20 industry professionals were involved during the study, enthusiastically participating in interviews and evaluating the activities conducted during the AI for Fashion Sustainability challenge.

5.3.2 Awareness of the Corporate Context

During interviews and the scoping study, it became evident that fashion companies face sustainability challenges: although interested in systemic innovations, their perspectives remain tied to corporate needs. Regarding solutions proposed in the challenge, companies preferred data collection methods that remained under their specific control, such as data from fitting rooms, rather than a more holistic or historically similarity-centered trend research. Companies also reiterated their reliance on sales data, stating it is something they are accustomed to and are unlikely to change. However, pursuing sustainability goals, we believe that relying on previous production volumes only incentivizes the growth paradigm, which the system does not need and should stop investing resources in. Instead, recycling programs, recovery, second-hand initiatives, repairability, and circularity programs are solutions that, supported by data, can be fundamental in the overall balance of a company aiming to embrace sustainability. As found during the research, companies potentially possess a large amount of data that often cannot circulate freely or is inaccessible, limiting its cross-functional value.

5.3.3 Systemic Approach to Information Flows

To achieve results consistent with the systemic approach to data, not only the product supply chain but also all collateral sectors must be integrated into the sustainable fashion system, including the end consumer who must be informed, educated, and made aware. The systemic approach to promoting sustainable design involves constantly evaluating the project's impact within its application context, which in the case of fashion, includes the end user who should be viewed not only as a consumer in a linear economy but as a component of a circular system (Bistagnino, 2010). This objective can

only be achieved through a collaborative approach where all involved designers cooperate. However, maintaining control and understanding systemic connections and dependencies is a challenge. This research transcends the limitations of many disciplines to provide an answer to the main question and collectively cover most design perspectives. However, it is an ambitious goal for one person with a single perspective.

5.3.4 Contextual Literature

Although using these data is still in its early stages in the design process, the design research community shows growing interest in understanding how product, service, and interaction designers can design with data as a creative «design material» (e.g., Dove & Jones, 2014; Bogers *et al*., 2016; Speed & Oberlander, 2016; Bourgeois & Kortuem, 2019). However, there is limited information on how designers, outside these key publications, leverage data in their process. Even fewer evidences were found.

5.3.5 Future Developments

Based on the results obtained during the research, validation phases with experts, and in-depth dialogue with companies, an outlined list of points to consider in future phases is provided below.

It is believed that starting from the theoretical-methodological framework, a series of analog or digital tools can be developed and tested to further enable collaboration among parties involved in data-driven sustainability strategies. It is anticipated that the initial part of these tests may involve beta students, but the scope of the tools can be expanded to include, as was done with the interviews, actors involved in the value chain. It is believed that to better understand the feasibility and improvement of tools from an industrial perspective, there are still too many limitations, but these can be overcome by integrating systemic design approaches already during the training phases of future fashion professionals.

The framework, intended as a tool for strategic orientation, and the various kits that may derive from it, can be used during intensive workshop sessions to stimulate designers during their ideation process and in dialogue to make decisions in broader corporate contexts.

Although the framework has been validated with multidisciplinary experts and the involvement of five experts for its usability and comprehension is justified, further detailed validation phases with individual figures and their respective fields are planned. Further structured research through partnerships with the corporate context would be necessary to measure its effectiveness in developing iterative solutions capable of embracing the complexity of the fashion system.

This volume has emphasized the perspectives of data-driven design within the fashion sector context. However, it focused only on the development of products, services, and systems while considering the product life cycle and environmental sustainability. It is believed that for a holistic view, it is worth extending the same approach to the other two systems, the socio-technical and the spatial, to have a comprehensive view of all systems and how they influence each other. This could show marginal changes even in how designers at the PSS and product levels make decisions.

Research should be guided by different design perspectives to be truly defined as *multi-design perspectives*. A suggestion for future research is to establish a design research group that can analyze how different designers approach product and system design and how they can collaborate harmoniously.

5.3.6 Extensibility of the Research

According to Flick (2006), qualitative research must deal with the theoretical generalizations of results and only later with numerical or statistical ones. Zimmerman *et al*. (2007) define extensibility as the ability to build on research findings to apply the process to further research problems or understand and leverage the knowledge generated from the research results. To ensure the extensibility of this research, data collection methods and conclusions drawn are reported to make them useful to readers who may want to apply them in another related context. The methodological framework's construction logic is open, and as tested with expert validation, the framework represents an evolving tool extensible to various areas of sustainability and different corporate application contexts.

Furthermore, beyond the contextual results derived from the involvement of multiple figures, the implications for sustainability

design in fashion can be expanded by more exhaustively defining whether fashion designers are aware of addressing sustainability at a systemic level. The research, therefore, has led to results that require further phases of experimentation and analysis through active involvement of the actors involved and observations within the corporate context.

Future developments foresee participation in international and European research projects to develop and validate the findings of this research, building not only a more solid network of partners but also one aligned with the developments of the European scenario described in the initial paragraph on the applicability of the research.

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Cristina Marino is an Italian researcher and designer specializing in sustainable fashion and systemic innovation design. She earned her degree in Industrial Design from the University of Palermo in 2014 and her Master's degree in Ecodesign from the Polytechnic of Turin in 2017. During her PhD in Management, Production and Design she focuses on integrating data into design processes to create a positive and sustainable impact in fashion. Throughout her career, Cristina has collaborated with notable academic institutions and companies, including the Creative Informatics Department at the University of Edinburgh and Lusófona University in Lisbon. These collaborations have allowed her to deepen her understanding of using data to enhance sustainability in fashion. She has published articles in prominent scientific journals and participated in international conferences, contributing significantly to the discourse on sustainable fashion.

The *data revolution* has reshaped our understanding of design, merging tradition and innovation in a world increasingly driven by complex data systems. This book explores the intersection of data science, design, and sustainability, with a particular focus on the fashion industry. It delves into how designers, historically skilled in tackling challenges posed by new technologies, are now navigating the data-rich environment. Through a systemic approach, the research proposes a framework for integrating data into design processes, promoting sustainable fashion practices. Designers are tasked with crafting systems that respond to both environmental needs and human values, bridging the gaps between diverse fields – from fashion to cutting-edge digital technologies. The book highlights the importance of data literacy for designers, emphasizing the potential of data to transform not just products, but entire systems. With insights from various case studies, it offers a comprehensive overview of strategies that integrate Data with design, showcasing how this can lead to a more sustainable and adaptive future for the fashion industry.

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La passione per le conoscenze