Article

Contextual Impacts on Industrial Processes Brought by the Digital Transformation of Manufacturing: A Systematic Review

Marco Savastano * , **Carlo Amendola, Francesco Bellini and Fabrizio D'Ascenzo**

Management Department, Sapienza University of Rome, Via del Castro Laurenziano 9, 00161 Rome, Italy; carlo.amendola@uniroma1.it (C.A.); francesco.bellini@uniroma1.it (F.B.); fabrizio.dascenzo@uniroma1.it (F.D.)
* Correspondence: marco.savastano@uniroma1.it; Tel.: +393334651337

Abstract: The digital transformation of manufacturing (a phenomenon also known as "Industry 4.0" or "Smart Manufacturing") is finding a growing interest both at practitioner and academic levels, but is still in its infancy and needs deeper investigation. Even though current and potential advantages of digital manufacturing are remarkable, in terms of improved efficiency, sustainability, customization, and flexibility, only a limited number of companies has already developed ad hoc strategies necessary to achieve a superior performance. Through a systematic review, this study aims at assessing the current state of the art of the academic literature regarding the paradigm shift occurring in the manufacturing settings, in order to provide definitions as well as point out recurring patterns and gaps to be addressed by future research. For the literature search, the most representative keywords, strict criteria, and classification schemes based on authoritative reference studies were used. The final sample of 156 primary publications was analyzed through a systematic coding process to identify theoretical and methodological approaches, together with other significant elements. This analysis allowed a mapping of the literature based on clusters of critical themes to synthesize the developments of different research streams and provide the most representative picture of its current state. Research areas, insights, and gaps resulting from this analysis contributed to create a schematic research agenda, which clearly indicates the space for future evolutions of the state of knowledge in this field.

Keywords: digital transformation; digital manufacturing; Industry 4.0; smart manufacturing; sustainable innovation; business process innovation; business model innovation; technology and innovation management; systematic literature review; literature analysis

1. Introduction

The rapid development and adoption of the Internet and digital technologies dramatically changed business processes, leading to a disruptive digital transformation of the global industrial value chain [1]. In today's highly competitive environment, digital innovation is critical for addressing manufacturers' key business drivers and creating value. Advanced digital tools allow manufacturing companies to reduce costs, increase productivity, improve product development, achieve faster time-to-market, add value to products through dedicated services, and enhance customer focus across various elements of the value chain [2,3]. These changes provide an increasing number of new possibilities for the development of new products, processes, and services [4].

The concept of *Industry 4.0* refers to a complex evolution of the entire industrial sector that includes technological advances in production equipment (i.e., additive manufacturing), smart connected products and the use of internet of things (IoT) in factories, cloud and mobile computing, artificial

intelligence (AI), data tools, and analytics, involving activities, competences, and stakeholders at all levels. The term, Industry 4.0, derives from a project from 2011 in the high-tech strategy of the German government for promoting the digitalization of manufacturing. This initiative represents the evolution of manufacturing systems. For this reason, it is worth noting that other terms, such as smart manufacturing, industrial internet, smart factories, and smart production, can be considered synonyms since they have different geographic origins, but substantially the same meaning of Industry 4.0. [5–8]. In this new era, digital manufacturing plays a crucial role and digital manufacturing technologies are key enablers for the evolution of this sector. Among these technologies, advanced manufacturing solutions play a crucial role and refer to the set of autonomous, cooperating industrial robots and to modular manufacturing systems characterised by integrated smart sensors and standardised interfaces [9]. These advances are changing how things are designed, produced, and serviced around the globe, but also the strategic view involved in the management of businesses [10,11]. In combination, they can create value by connecting different players and machines in a new "digital thread" across the value chain, relying on the availability of an unprecedented huge amount of data to address manufacturers' key business drivers [12,13]. Porter and Heppelmann (2015) described this trend as "*the most substantial change in the manufacturing firm since the Second Industrial Revolution*" [14]. On the other hand, some authors do not think that this is a real paradigm shift, since some of these enabling technologies have existed for years [15].

With such a variety of developments influencing global manufacturing, a discussion of the likely future trajectories—including spatial, technological, and operational—is both timely and necessary and involves both the innovation of production and management models, and their sustainability [2]. The Industry 4.0 initiative has been conceived in order to face the market and social trends that are still driving industrial companies nowadays. According to Lasi et al. (2014), manufacturing companies are required to be more flexible and agile to respond to the customer requirements in the most effective way. To achieve this flexibility, faster decision-making procedures are necessary. In addition, production systems must be not only adaptive, but also self-adjusting and self-optimized [8,12].

In detail, to compete in such a dynamic environment, manufacturers have sought new fabrication techniques to provide the necessary tools to support this need for increased flexibility and enable economic low volume production [16]. Among them, digital manufacturing (DM)—sometimes referred to as additive manufacturing (AM) or 3-D printing—has been compared to disruptive innovations, such as digital books, newspapers, and music (MP3s), which enabled consumers to order their selections online as well as firms to profitably serve small market segments, configuring supply chains with no physical stores (i.e., e-business) and little or no unsold finished goods inventories. In this regard, it has long been hypothesized that digital manufacturing is doing to manufacturing what the Internet has done to information-based goods and services [17]. Indeed, the implementation of digital manufacturing in industrial supply chains would lead to significant advantages, comparing DM to the Internet in its ability to cause a paradigm shift [18].

Furthermore, Rayna and Striukova (2016) recently maintained that disruptive technologies are the "*bearer of radical changes in business models and ecosystems*". Digital technologies, in particular, have led to major shifts in the industries that have adopted them. One of the key consequences of digitization has been to turn tangible objects into intangible ones. For this reason, digitization of products is also often referred to as a dematerialization process [19].

The industrial sector plays a crucial role in Europe, serving as a key driver of economic growth (e.g., job creation) and accounting for 75% of all exports and 80% of all innovations [20]. This fourth wave of technological advancement is supposed to realize the manufacturing of individual products in a batch size of one while maintaining the economic conditions of mass production. Indeed, the core of the so-called "smart factory" or "factory of the future" is to combine the strengths of optimized industrial manufacturing processes with cutting-edge internet technologies and digital dynamic skills [21,22]. Hence, it is not surprising that Industry 4.0 is currently experiencing an increasingly amount of attention, especially in Europe.

A fundamental element of this "smart revolution" is the collaboration between man and machine in advanced cyber-physical systems and the transmission of digital data [23]. Alongside technological innovation, the organization structure has undergone several major shifts, allowing companies to become more flexible to face fast changing markets. It is not only a wave of disruptive technological innovation, but also a fundamental cultural change [12,24]. Therefore, companies need to completely redesign their business models and processes, in order to achieve the important benefits disclosed by these new settings. It was argued that this process increasingly happens in the form of inter-firm manufacturing networks, enabled by integration across value chain activities [2].

Literature and Implementation Gap

Even though actual and potential advantages are remarkable, highly reliable studies based on surveys involving companies and top managers operating in this environment found that only a limited number of companies have already made rapid advances by developing structured digital strategies as well as capabilities necessary to obtain a competitive advantage [25,26].

At the same time, despite the increasing interest in this novel topic, scholarly inquiry on the economic and managerial effects of the digital transformation of manufacturing as well as its impact on business models' innovation has transpired in the literature only recently, resulting in a limited understanding of this phenomenon [19,27–35].

The existing literature focusing on the digital manufacturing ecosystem appears to suffer from a "double disease". First, its results are dominated by consultancy reports and reviews of practitioners, which lack the methodological depth and the predictive power of serious research studies. Such publications contribute to the hype without offering much analytical substance. Second, the majority of academic literature is characterized by technical publications, which, although highly valuable, focus on the engineering aspects of the technologies involved in this process and much less on the specific ways they are expected to disrupt the existing manufacturing and innovation practices, in terms of managerial strategies [33]. In fact, the models presented in the literature mainly address technological aspects of the implementation of smart systems, while they do not consider the business transformation aspects that are necessary to achieve the challenging vision of smart factories. Academic literature concerning the business transformation towards digital manufacturing suggests that the main issues in this research area are connected not only to technological evolution, but also to people involvement and organizational aspects [8]. In addition, despite the topic of Industry 4.0 recently attracting much attention, very few systematic and extensive reviews of the literature capture the dynamic nature of this topic. All this suggests the need for more systematic studies focusing on the potential managerial opportunities associated with the emergence of a digital manufacturing ecosystem to build up theoretical foundations in this area, which still results in a nascent phase.

The purpose of this study is to assess the current state of art of the academic literature regarding the fast-growing digital manufacturing ecosystem (DME) phenomenon and identify patterns and eventual gaps in the literature to be addressed by future studies. Thus, the research focuses on the digital transformation of this dynamic environment—the extended manufacturing value chain—brought by the wide development and adoption of digital technologies and skills. Unlike the concept of "digitalization", which refers to the use of digital data and technology to automate and optimize processes, digital transformation is intended as the creation of new business opportunities through the use of digital data, technology, and mindset [36].

In order to achieve this goal, the present study provides an extensive systematic analysis and review of the extant body of literature on the aforementioned topic in the research domains of innovation management, operations management, and information systems (IS) disciplines to analyze and synthesize the development of this research stream as well as provide a representative picture of its current state. Accordingly, the keywords chosen for the literature search (i.e., Industry 4.0; digital manufacturing and additive manufacturing) indicate the main purpose of investigating and analysing the academic literature regarding the extensive topic of the ongoing digital transformation of

manufacturing (represented by the umbrella terms "Industry 4.0" and "digital manufacturing"), with a specific focus on the evolution of the production process and manufacturing operations through the broad adoption and management of AM technologies. Insights and gaps resulting from this literature analysis will contribute to the development of a research agenda for the evolution of the state of knowledge in this scientific area. The contribution of this paper relies also in its innovative framework of analysis. Indeed, it is set up on a complex analytical model based on the main research question and several connected sub-questions responding to research objectives, which allowed the authors to analyse the literature with a high level of detail compared to previously published literature analyses. This model can be further applied in further studies and different scenarios. A further contribution is represented by the specific perspective of this literature review on the evolution of the production process and operations in this dynamic context.

The remainder of the paper is structured as follows. The next section presents a brief definition of the terms used for the literature search. In the second part, it describes the methodology used to gather and analyze the final sample of publications. Next, the results of the analysis are presented and are largely discussed in accordance to the literature in Section 3. Finally, Section 4 provides the concluding remarks and the research agenda based on a summary of the results. Recommendations for future research on the digital manufacturing ecosystem phenomenon and managerial implications are also included.

2. Materials and Methods

A systematic literature review was selected as the research methodology for this study. In the current work, we follow the process and classification schemes described by Hoehle et al. (2012), taking also into account the structure described by Wareham et al. (2005) in their meta-analysis on electronic commerce, and Yli-Huumo et al. (2016) in their systematic mapping study [37–39]. The purpose of a systematic literature analysis is to provide an overview of a specific research area, to establish if research evidence exists, and to quantify the amount of evidence. Accordingly, there is an established tradition in social science research (i.e., management and IS) of examining the existing research literature to better understand the "state of play" of research in the field to discern patterns in its development [39–42]. Following that tradition, the principal aim of this study is to understand the actual state of research on the digital manufacturing ecosystem phenomenon by examining the relevant literature published to date in the management and IS disciplines. According to these research traditions, the subsequent steps were followed:

- **Identifying, reviewing, and analysing the existing literature** on the development of a digital manufacturing ecosystem through the adoption and utilization of digital and mobile tools or platforms in the manufacturing sector, which impact on the innovation of processes and business models (thus, not only focused on technical issues) in the production perspective;
- **identifying theoretical and methodological approaches** generally used to investigate the digital transformation of the extended manufacturing value chain through the adoption and utilization of such applications and tools; and
- **identifying research areas and possible gaps** within the existing literature concerning the adoption and impact of digital and mobile tools leading to a paradigm shift of the manufacturing industry to redact a complete research agenda useful for further scientific contributions.

2.1. Definition of Research Question and Research Objectives

As the first stage of the systematic literature analysis, the research questions were defined consistently with the research purpose. Thus, the primary research question that guides the present literature analysis is as follows:

What is the "state of art" of the academic literature regarding the digital manufacturing ecosystem phenomenon?

To fulfill the analysis of the literature, to structure the study, and to answer the main research question, specific research objectives were set through the following sub-questions:

- Which enabling digital manufacturing technologies have been studied?
- What is the main focus/topic of the studies?
- What are the main domains identified in the existing research?
- What industrial sectors and actors (i.e., large companies, SMEs, consumers, etc.) are involved in this research field?
- What was the research method used?
- What was the research approach (qualitative, quantitative; empirical, conceptual)?
- What was the main contribution of the paper analyzed?
- What are the regional contexts where the research was undertaken?
- What are the current gaps in this research field?

Past literature analyses and systematic review studies demonstrated that these types of research objectives enable researchers to successfully synthesize research fields and identify trends, gaps, weaknesses, and possible research paths that will guide future investigations of the phenomenon studied [37,40,43].

The following sections of the paper provide evidence and insights from the analyzed literature to answer to each one of the questions outlined above.

Research Process

To conduct the present literature analysis in a systematic way, a predetermined phase sequence was followed. Figure 1 illustrates the sequential research process steps and outcomes.
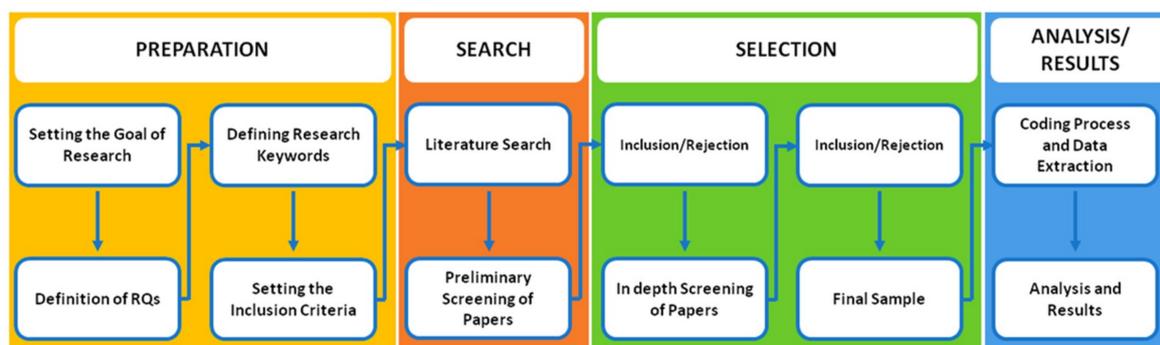

Figure 1. Research process flow.

As a subsequent stage after the definition of the research question and objectives it was necessary to set the search protocol to find all the relevant scientific papers on the research topic. Pre-defining of the methods and criteria that are used to undertake a systematic literature search is crucial to reduce the possibility of researcher bias. The primary parameters to carry out the present literature source were as follows:

- Keywords/search terms: The keywords chosen for the literature search were digital manufacturing, Industry 4.0, and additive manufacturing, which are the most common, inclusive and representative terms in the literature associated with the phenomenon under investigation. These terms include both umbrella concepts of this paradigm shift as well as a narrower focus on the innovation strategies concerning the additive technologies that are disrupting the manufacturing process.
- Research fields and sources: Coherent with the research aim, only management, organizational, and IS fields sources were selected (through databases and top journals in these research fields,

such as ProQuest, ABI/Inform, Science Direct, Emerald Insight, etc.). Therefore, we carefully filtered our search to exclude all the articles not related to these main paradigms. Many results were found to exclusively concern technical aspects of the phenomenon of interest and were related to mechanical engineering, architecture, computer science, material science, and biotechnology fields. The literature search was conducted through comprehensive bibliographic databases to cover a broad range of top journals. The explored sources are shown in Table 1.

- Relevant research: Given the tremendous breadth of research on this topic, referring to a high number of disparate disciplines, we decided to select only peer reviewed/scholarly journal articles, excluding conference proceedings not published on such journals, professional journals, industry reports, and specialized publications in magazines. This strategy also circumvented book reviews, editorials, and opinion statements as well as similar "non-scholarly" work. This choice is motivated by the requirement of seeking only high quality publications from top rated journals. The full list and frequencies of the journals included in this study are available in Table 3.

- Time period: The last 20 years. Even though the concept of digital manufacturing originated from the use of rapid prototyping and computer aided design and manufacturing (CAD/CAM and RP Technologies), which were adopted in the production process more than 20 years ago, this manuscript focuses on broader applications, extended to the production of end-products, which became a research topic more recently. Indeed, the oldest paper in our sample was published in 2001.

- **Language:** English

Table 1. Selected online databases for the literature search.

Online Research Platform	Databases
EBSCOhost	Academic Search Complete; Business Source Premier; Ebsco Discovery Service (EDS); etc.
ProQuest	ABI/INFORM Global; Emerald Insight, etc.
Science Direct	Elsevier e-journals and e-books

2.2. Sample

After designing the research protocol and choosing the abovementioned electronic databases, we conducted the literature search, with the latest update of October 2018. From the keyword search, limited to peer-reviewed scholarly journal publications, we carried out the first selection by excluding papers with subjects and titles that did not fulfill our research protocol (for instance, advanced engineering informatics, civil engineering, medical and biological engineering and computing, computer standards and interfaces, biotechnology, etc.). To do so, we refined the results using the advanced search tools offered by the databases. After this first selection, a total of 1426 articles were found.

The next stage was the screening of papers. For this purpose, we examined the title and abstract of every paper selected in the previous phase. Thus, we exported the results of our literature search to a citation management software (i.e., Mendeley) and carefully analyzed these two elements together with the keywords chosen by the author/s and the journal. Any article considered pertinent to the research topic was selected for further analysis. The general guidelines for article selection included the following:

- The central theme should be the digital transformation of manufacturing (eventually applied to different industries connected to this transition) and applications related to the definition/development of a digital manufacturing ecosystem; and
- papers should focus on the managerial aspects, economic/environmental and social impacts, and/or market implications of this phenomenon (both from the demand and supply viewpoints).

By following these criteria, we excluded all those papers not relevant to our purpose and clearly out of the scope of this study. As an additional exclusion criterion, we decided to ignore papers less than three pages in length. Furthermore, we compared the articles resulting from the three different keyword sources as well as the databases and identified any duplicates, which were excluded. In total, there were 44 articles identified more than once through the different keyword sources and databases. Putting the selected articles together, and excluding the duplicates, the final amount was 193 publications (see Table 2). Those papers were included in the next screening phase.

Table 2. Selected publications.

Keyword	Source	Time Period	Categories Excluded (Some Examples of the Excluded Subjects)	Papers (N)
1. Digital Manufacturing	ProQuest/EBSCOhost Science Direct	1998–2018	cooling; genetic algorithms; mechanical properties; neural networks; semiconductors	74
2. Industry 4.0	ProQuest/EBSCOhost Science Direct	1998–2018	agricultural policy; agricultural production; agriculture; baby boomers; mechanical engineering; computer science; cardiovascular disease	70
3. Additive Manufacturing	ProQuest/EBSCOhost Science Direct	1998–2018	alloys; aluminium; bioengineering; bond strength; ceramics; composite materials; cooling; corrosion resistance; design engineering; engineers; grain size; issue engineering; laser sintering; lasers; materials research; mechanical engineering; mechanical properties; medical equipment; metals; numerical controls; particle size; polymers; powder metallurgy; sintering; stainless steel; temperature; titanium alloys	84
Total	All databases			237
Total	Duplicates excluded			−44
Final Total				193

2.3. Analysis and Coding

The next stage consisted in reading entirely all the selected papers with a twofold objective:

1. Ensuring that all the selected publications were consistent with the selection criteria; and
2. Recognizing and analyzing the patterns contained within the paper through a coding process.

From this in-depth selection, we found 37 articles that did not respond to our search protocol and inclusion criteria for different reasons (i.e., research domain, scope, main focus, contribution). After their exclusion, the final sample was composed of 156 primary papers, which were selected for detailed analysis.

Table 3 shows the selected articles listed by journal and year of publication. The starting date of the literature search was 1998 since, from a prior pilot search we carried out, we found that the literature in this area is relatively recent and no relevant publications were retrieved before that date in accordance with our research protocol. In addition, it is noteworthy that 81% of our sample was published in the time frame 2014–2018. To this purpose, the chart below (Figure 2) shows the distribution of articles based on the publication year. It is easy to observe how the majority of the articles are concentrated mainly in the time frame of 2014–2018, indicating a high growth of contributions in this research area. As for the year of 2018, the number of publications reported is considered as not definitive since the last update of our literature search was carried out in October 2018.

Table 3. Selected articles listed by journal and year of publication.

Journal	'01	'04	'05	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	Tot.	%
A I B Insights												1				1	0.64%
African Journal of Business Management											1					1	0.64%
Business & Information Systems Engineering										1	3	1				5	3.21%
Business Horizons									1			2				3	1.92%
Business Process Management Journal													1			1	0.64%
Clean Technologies and Environmental Policy												1				1	0.64%
Computer Networks													1			1	0.64%
Computers in Industry		1				1					1	1	4	2	2	12	7.69%
Creativity and Innovation Management												1				1	0.64%
European Journal of Operational Research													1			1	0.64%
European Networks Law and Regulation Quarterly (ENLR)												1				1	0.64%
Foundations of Management													1			1	0.64%
Fashion and Textile														1		1	0.64%
IFAC-PapersOnLine														1	7	8	5.13%
Industrial Management & Data Systems													2			2	1.28%
Info											1					1	0.64%
Intereconomics												1				1	0.64%
International Entrepreneurship and Management Journal											1					1	0.64%
International Journal of Innovation Management														1		1	0.64%
International Journal of Management & Information Systems (Online)											1					1	0.64%
International Journal of Precision Engineering and Manufacturing-Green Technology															1	1	0.64%
International Journal of Operations & Production Management													2			2	1.28%
International Journal of Physical Distribution & Logistics Management													2			2	1.28%
International Journal of Production Economics											1	1		1		3	1.92%
International Journal of Production Research						1							3			4	2.56%
IUP Journal of Operations Management													1			1	0.64%
Journal of Centrum Cathedra												1				1	0.64%
Journal of Cleaner Production														4	4	8	5.13%
Journal of Engineering and Technology Management												1				1	0.64%

Table 3. *Cont.*

| Journal	'01	'04	'05	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	Tot.	%
Journal of Humanitarian Logistics and Supply Chain Management												1				1	0.64%
Journal of Industrial Engineering and Management												1				1	0.64%
Journal of Information Systems & Operations Management										1						1	0.64%
Journal of Intelligent Manufacturing					1			2								3	1.92%
Journal of International Business Studies													1			1	0.64%
Journal of Manufacturing Technology Management				1					1		2	1	4			9	5.77%
Journal of Manufacturing Technology Research										1						1	0.64%
Journal of Marketing Theory and Practice													1			1	0.64%
Knowledge Horizons - Economics													1			1	0.64%
MIT Sloan Management Review									1	1			1			3	1.92%
Mobile Networks and Applications													1			1	0.64%
Nexus Network Journal									2							2	1.28%
Northwestern Journal of Technology and Intellectual Property													1			1	0.64%
Operations Management Research													1			1	0.64%
Procedia - Social and Behavioral Sciences													1			1	0.64%
Procedia Manufacturing												2	1			3	1.92%
Proceedings in Manufacturing Systems												1				1	0.64%
Process Safety and Environmental Protection															2	2	1.28%
Production Planning & Control											1		1			2	1.28%
Rapid Prototyping Journal	2		1				1	1	1		1	2	1			10	6.41%
Research Technology Management										1	1	4				6	3.85%
Strategy & Leadership									1							1	0.64%
Studia Commercialia Bratislavensia										1						1	0.64%
Supply Chain Management											1					1	0.64%
Sustainability															5	5	3.21%
Symphonya									1							1	0.64%
Technological Forecasting and Social Change									1		1		9	1	9	21	13.46%
Technology Innovation Management Review											1	1			1	3	1.92%
Technovation													1			1	0.64%
Telecommunications Policy												1				1	0.64%
The Journal of Business Strategy									1							1	0.64%
Total	2	1	1	1	1	2	1	3	10	6	17	27	42	11	**31**	**156**	100%
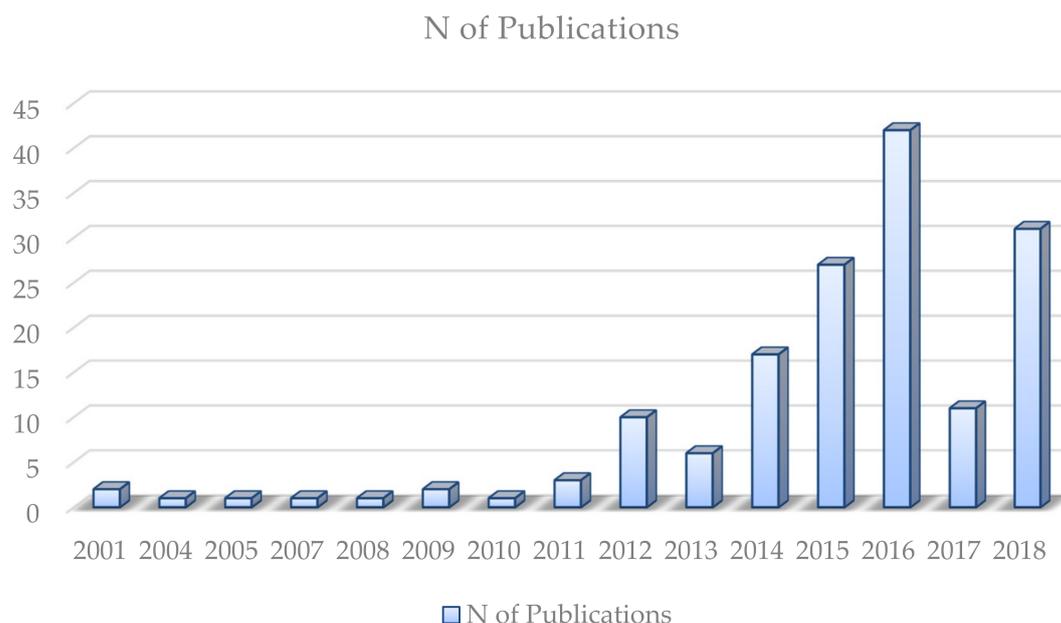
N of Publications

Figure 2. Articles by year of publications.

Moreover, Table 4 shows the distribution of publications ordered by the keyword used in the keyword search. Terms listed with a slash - for instance, DM/AM or Industry 4.0/AM—indicate that the same publication resulted in a keyword search of both terms. It is interesting to note that the term, "additive manufacturing" (AM), obtained the highest absolute score in terms of publications until 2016 (39% of the total), in comparison to "digital manufacturing" (DM, 21%) and Industry 4.0 (15%). Further - always counting the results obtained by the single terms; not combined together - it is worth noting that, according to papers published only in the last two years (2017 and 2018), the trend completely changed: Among these papers, the great majority (69%) were retrieved with the keyword, "industry 4.0", followed by "digital manufacturing" (12%) and "additive manufacturing" (7%).

Table 4. Search keywords results by the year of publication.

Keywords	'01	'04	'05	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	Tot.	%
AM	1		1					1	1	4	8	8	20	3		47	30%
DM	1	1		1	1	2		2	7		1	1	7	3	2	29	19%
DM/AM						1		2	2	5	9	6		1	26	17%
Industry 4.0											2	7	8	3	26	46	29%
Industry 4.0/AM											1	1	1			3	2%
Industry 4.0/DM												1		2	2	5	3%
Total	2	1	1	1	1	2	1	3	10	6	17	27	42	11	31	**156**	
%	1.3	0.6	0.6	0.6	0.6	1.3	0.6	1.9	6.4	3.8	10.9	17.3	26.9	7.1	19.9		

As per the remaining articles, the 10% was retrieved through the combination of I4.0/DM keywords, and the 2% through DM/AM. This evidence highlights the growing interest in the novel topic of Industry 4.0, according to our selection criteria. Considering this, it is possible to observe that publications related to the term, "Industry 4.0", have quickly grown from zero to a maximum of 26 per year in the period of 2013–2018, exceeding the values of the other terms in the same years. These dynamics can be clearly visualized in Figure 3, taking into account only each single keyword, not combined together.
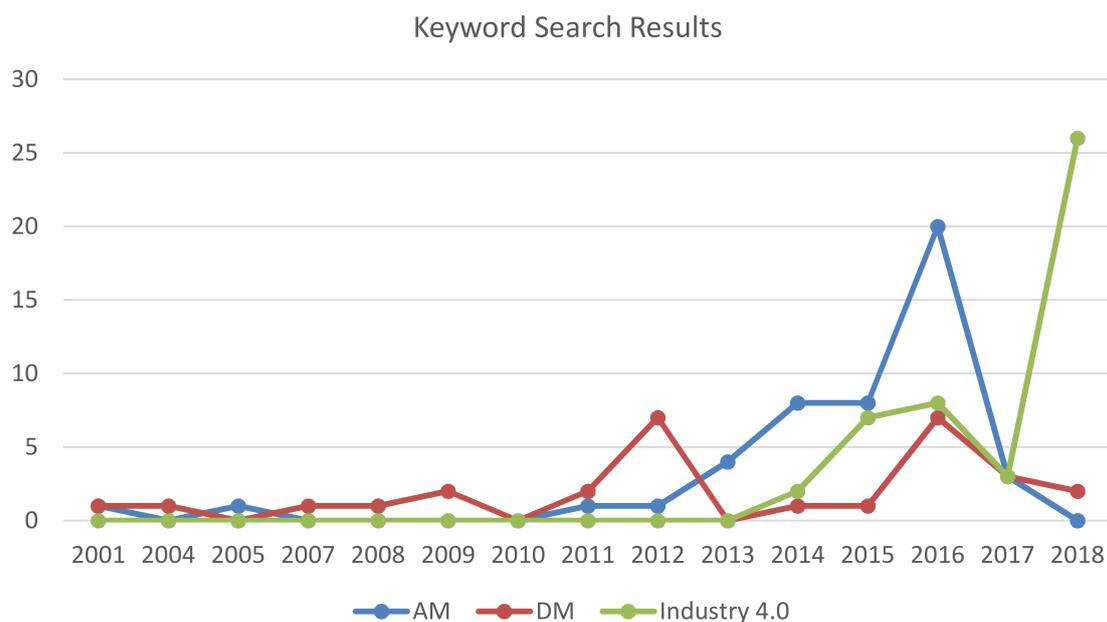
Keyword Search Results

Figure 3. Publications by single keyword search.

2.4. Coding Process

The first step undertaken for the data analysis involved a coding procedure. We followed coding techniques outlined by Alavi and Carlson (1992) as reported in Hoehle et al. (2012), investigating all the identified articles to address the above-mentioned research questions [37,40]. A data matrix was designed to collect the information needed, visualized in the form of codes, as well as to highlight similarities and differences among the various research articles. Next, as mentioned, all 156 papers were entirely read and reviewed for the association of coding patterns. In a few cases, where the paper was not univocally codifiable, an expert faculty was asked to codify, in turn, the paper until a consensus between the two reviewers was achieved. The coding process gathered basic information of the papers, including, for instance, the name(s) of the author(s), year of publication, the country based on the author's affiliation (based on the first author's affiliation when different), as well as more in depth information, such as the main focus, method, and major findings of each paper. After reading them, we also updated the categories of the data matrix or created new ones when the papers revealed something new. The extracted data items were collected to Excel, which helped us to organize and analyze them. Also, R software was used during this process to run some specific analysis. First, raw codes were created in order to collect and record all the different facets present in the sample papers. Subsequently, these codes were clustered in macro categories to obtain a clearer understanding of the state of the literature. Table 5 exemplifies the coding procedure by outlining the codes chosen for one research article as an example.

Table 5. Example of data items for the coding process.

Codes	Publication
Technology/Process Type	3D Printing
Country/Regional Context	USA
Focus/Main Topic	Business Model Innovation
Domain/Research Field	Technology and Innovation Management
Sector/Industry/Firm Size	Manufacturing
Research Design	Literature Survey
Research Approach	Qualitative
Source of Data	Secondary
Key Contribution	Insights

3. Results and Discussion

3.1. Technologies

Given the breadth of our sample and the different keywords used for the literature search, the classification of the technologies encountered in the literature gave several diverse results.

Table 6 reports the five macro categories created to label the nature of the technologies described in the papers. To do so, we referred to the definition given by authors and to the technology standards (e.g., ASTM—American Society for Testing and Materials International). However, these categories are so broad that such a categorization conveys limited information. As a consequence, we added a description as well as the single specific codes to further qualifying these high-level categories.

Table 6. Technology categories.

Clustered Codes	Description	F	%	References
AM Technologies	**Different technologies referable to additive manufacturing:** 3D Printing (3DP), 3DP/AM, 3DP/DDM, AM, AM/3DP, AM/RP, Consumer 3DP, Home fabrication, Direct Digital Manufacturing (DDM), Digital Fabrication (DF), Digital Manufacturing Technologies, DM, Rapid Manufacturing (RM), Rapid Prototyping (RP)	71	46%	[2,10,16,18,19, 30–34,44–104]
Advanced Manufacturing Systems (Industry 4.0/IIoT)	**Technological tools and advanced systems employed in the manufacturing sector, often related to the Industry 4.0 framework and IoT concept:** Robotic Process Automation, Advanced Manufacturing Technologies (AMTs), Advanced Materials Technologies, Advanced Production Systems (CPPS), Advanced systems of additive technologies, Cloud-integrated Cyber-Physical Systems (CCPS), Cyber-Physical Manufacturing Systems (CPMSs), Smart Factories, Cyber-Physical Systems (CPS), Smart Factories, Digital systems, Open-source collaboration platform, smart sensors, digital enterprises, Smart Factories, Industry 4.0, IoT, Industrial Internet of things (IIoT), Smart Factories/Industry 4.0, Online 3DP Platforms, Smart Factories/Industry 4.0, Web-based RP & Manufacturing systems, Automated Guided Vehicles (AGVs), Digital Supply Chain (DSC), Smart Manufacturing, Distributed Manufacturing	45	29%	[8,9,12,17,29, 105–144]
ICT	**Information and communication technologies for the DME:** 3D sensors, AR and Web technologies; Big Data Analytics; Cloud computing; Digital Technologies; Digitally driven technologies (ICT); ICT; Industry 4.0 enabling technologies (ICT); Information Systems, Enterprise resource planning software (ERP)	21	13%	[25,35,145–163]
Innovation Process	**Focus on the innovation process:** Manufacturing process innovation; Innovation; Technological Innovation Activities; Assessment of the digital maturity of companies; Transition to I 4.0; Evolution of Chinese Manufacturing through China 2025; Technological ECO-Innovation	16	10%	[4,20,28,36,164–175]
Digital Design Tools	**Digital tools employed in the design phase of products and spare parts:** CAD/CAM tools; Digital Design Tools/RP; Prototyping Technologies	3	2%	[176–178]
TOT		156	100%	

Looking at their distribution, it is possible to identify that almost half of the sample (46%) was focused on additive manufacturing technologies, also identified as 3D Printing (e.g., [44–49]; etc.), DDM, digital or home fabrication (e.g., [50,51]; etc.), and rapid manufacturing technologies (e.g., [52,53]; etc.). All these technologies can be included in the additive manufacturing category. Digital and home

fabrication are often associated to studies focused on the user-producer perspective (also known as "prosumer") and related to the consumer products/services sector.

Secondly, 45 publications (29% of the sample) were found to be focused on digital technological tools developed and applied for the creation of advanced manufacturing systems. For instance, cyber-physical manufacturing systems (CPMSs), smart factories, open-source collaboration platforms, industrial internet of things (IIoT), 3DP platforms, and web-based rapid prototyping and manufacturing systems are the basic elements of the Industry 4.0 framework (e.g., [17,105–108,145]).

The third category (13%) includes information and communication technologies (ICT), which are fundamental for the creation of a digital-enhanced ecosystem, such as information systems, smart sensors and products, web technologies, cloud computing, and big data analytics (e.g., [109,146–148]; etc.). It must be noted that the categories of advanced manufacturing systems and ICT sometimes referred to similar or identical technologies, but the characterization is based on their main/final application in a more complex and advanced system connected to the concept of Industry 4.0 or a smart factory.

The last two categories include Innovation process/activities (accounting for 10% of the sample), such as, for instance, the assessment of the digital maturity of businesses [4,164–167]; and papers focused only on digital design tools (2%), such as rapid prototyping and CAD/CAM tools [176–178].

3.2. Main Focus

The next step was to identify the main focus of the primary papers. Thus, each article was classified primarily according to the definitions given by the authors. The codes were than grouped in macro-themes to facilitate the analysis of the results.

From the coding process, 14 main categories of different topics were identified. Table 7 shows that these categories were highly fragmented. Considering their frequency values, it is possible to highlight that only two of them have a value greater than 10%, which was analysed above in detail:

- **Manufacturing supply chain reconfiguration** (32.7%): This category concerns papers focused on the radical paradigm-shift occurring in manufacturing settings and operations' configurations due to innovative technologies' development and adoption (e.g., the evolution of manufacturing through mass production, mass customization, and 3DP/digital manufacturing processes, CPPS and smart digital factories characterizing Industry 4.0, etc.). This technological radical change comes in response to the need of reducing costs, lead times, and the time to the market of standard manufacturing processes while at the same time making the system adaptable to the changing needs of customers [106].

The impact of technology was investigated both at the firm level, in terms of shifts in value propositions and the creation of additional value streams [54–56], as well as on global manufacturing industry processes and competitive dynamics [57].

In detail, some studies analyzed the extent to which disruptive digital manufacturing technologies drive structural shifts in supply chain management and configurations by revolutionizing the production process as well as rethinking many traditional operations' management practices (i.e., inventory management, job shop scheduling, and batch sizing), leading to value-added achievement through distributed manufacturing strategies [18,58–60]. For instance, in their explorative study, Laplume et al. (2016) investigated the potential implications of open-source AM and 3D printing technologies for the configuration of new global value chains (GVCs) or the modification of existing ones. The study suggests that the diffusion of 3D printing technologies in an industry is associated with a development toward shorter and more dispersed global value chains. Therefore, in some industries, the new manufacturing technology is likely to pull manufacturing value chains in the direction of becoming more local and closer to the end-users [61]. A further significant example comes from the study of Büyüközkana and Göçer (2018), who proposed a conceptual framework based on their review of the literature, which was centered on the concept of the digital supply chain (DSC) and aimed to deploy smart, value-driven, and efficient integration among digitalization, technology implementation, and supply chain management [110].

Table 7. Main focus of the papers ordered by frequency.

Focus (Clustered Codes)	Characterization	F	%
Manufacturing Supply Chain Reconfiguration	Digitally-Enabled Collaborative Manufacturing Networks; Digitally-Enabled Project Manufacturing; E-commerce channels for AM; Reconfiguration of Manufacturing (Advanced Manufacturing); Supply Chain Planning Optimization Models; Value Chain/Supply Chain Reconfiguration; Supply Chain reconfiguration and Sustainable Development; Digital Transformation of Supply Chains; Smart Manufacturing Revolution; The impact of DDM on the Fashion Industry	51	32.7%
Democratization of Manufacturing	Democratization and Disintermediation of Manufacturing; Open-source Innovation; Makers and FabLab Movements; Peer-to Peer Exchanges; Prosumption; Technology-User/Consumer Interaction; Users' Technology Acceptance; Value co-creation and Social Innovation; Social Manufacturing	18	11.5%
Policy-driven Economic/Competitive Impact of Digital Transformation	Back-shoring of Value Chain activities; Digital Competitiveness; Economic impact of AM; Macro-Economic Impact of Community Innovation; Reindustrialization; Technological discontinuity and New Ecosystems; Dynamics of the evolution of manufacturing industry due to digital transformation on a country-level (e.g., China, Korea, etc.); Green Servitization impact; Policy-driven innovation for Industry 4.0	14	9.0%
AM Features/Applications	AM/3DP Features and Applications; AM/DM Implementation;	12	7.7%
Business Model Innovation	Business Model Innovation; Digital Transformation of Companies; How SMEs change due to Industry 4.0	12	7.7%
Sustainability	Humanitarian 3DP; Sustainable Product Design, Development and Manufacturing, Eco-Innovation; Environmentally-sustainable manufacturing; Sustainability with advanced manufacturing; Sustainable value creation	12	7.7%
Technological Development Dynamics	Contribution of Standards to innovation; Enterprise 3D Printing Adoption; Technological Development Alignment; Technological Forecasting and Fiction; Technological Process Innovation; Technological paradigm shift; Digital Transformation of Business Processes; Technology Assessment and Evolution; Innovative (not redundant) solutions for the transition to I 4.0	12	7.7%
Digital Transformation of Products/Services	Dematerialization due to Increased Digital Consumption; Digital Service Management; Digitalized Product-service systems (PSS); Digitally Enhanced New product development (NPD); Smart-Connected Products; Servitization/App-izzation;	8	5.1%
Technology Assessment and Comparison	Cost-Benefit Analysis/Estimation; Technology Assessment and Evolution; Industry 4.0 technologies classification	7	4.5%
Digital Knowledge Dissemination	AM Users Education and Engagement; Digital Knowledge creation/dissemination and Value Creation	4	2.6%
Impact on Value Proposition	Customer Satisfaction; Impact of Disruptive Technology on Value Proposition	2	1.3%
Intellectual Property Law	Anti-Piracy Strategies; Intellectual Property Protection	2	1.3%
Multiple	Intellectual Property Law and Democratization of Manufacturing	1	0.6%
Job Sustainability and Insecurity	Relationships among perceived job insecurity, technology usage, and long-term projection in the transition toward Industry 4.0	1	0.6%
Total		**156**	**100%**

The abovementioned studies mainly present either insights or propositions and conceptual frameworks/scenarios that may serve as a starting point for further research, as well as a fewer number of conceptual models to be tested (see Table 15). The impact of this new ecosystem on the personalized products market, namely the potential of digital manufacturing to increase the level to which customers are virtually integrated in a manufacturer's supply chain [62] and the modification of the value chain activities, has received very limited investigation in existing research [63].

A further stream of research included in this category investigates the phenomenon of digitally-enabled collaborative manufacturing networks, indicating industrial networked structures

where collaboration among different players comes through the intense cooperation and knowledge sharing between loosely connected entities (i.e., large companies and SMEs – Small and Medium Enterprises, users, consumers), improving innovation processes and creating value. For instance, Beckmann et al. (2016) studied the digitization of design and manufacturing through a web platform (DMC platform—digital manufacturing commons), which supports the democratization of design and manufacturing model development and has the ability to bring together SMEs, large enterprises, software vendors, researchers, and intermediaries into an ecosystem in which participation is mutually beneficial, in order to promote the manufacturing competitiveness of SMEs. These collaborative networks and platforms represent the foundations of Industry 4.0 regardless of firm size [111].

Finally, another important topic is connected to the multiplication of channels necessary for the full exploitation of AM technologies. The implementation of e-commerce channels is to transfer design files for additive manufacturing implications for supply chain management and business value chain activities [64]. Although this topic seems to be based on the research field under investigation, it has not received much attention in the existing research.

- **Democratization of manufacturing** (11.5%): This category also includes different research streams and topics. It describes radical changes in the entire value chain around how products are designed, funded, sourced, manufactured, and distributed [65]. Digital manufacturing and home fabrication revolutions are expected to substantially contribute toward the democratization and disintermediation of inventions, the economy, market, and society (enabling more people not only to receive, but also to conceive new knowledge). The increasingly widespread availability of the Internet and these digitally enabled tools have made production processes more accessible to private individuals, introducing new opportunities for personal fabrication and social manufacturing [148]. 3D printing has the potential to bring personal digital fabrication to everyone and to boost the creation of new products and businesses, thanks to the open source innovation and the emergence of collaborative design among communities of connected users, turning consumers into creators and, as a result, into competitors of incumbent companies.

Some studies focused on maker and FabLab movements, seeking to identify how digital fabrication technologies combined with new services (through "fab–spaces", that is fabrication spaces) can help transfer familiar principles from the digital to the physical world, by empowering user-entrepreneurs to turn their ideas into real prototypes or products to start a business in a comparatively easy way [50,179]. Mortara and Parisot (2016), in their work, map the current fab—spaces landscape and provide a detailed hierarchical classification of these emerging organizations by taking the particular perspective of those who use the Fab–spaces to launch entrepreneurial ventures [66]. From these settings, a research stream investigating the concept of the prosumer emerged. It refers to the important social change of individuals directly involved in the design and production of the goods they consume. Innovations enable end-users to have authority over the design and production of their own original one-off goods, reshaping the traditional role of passive consumers in the production process by providing them with the highest level of involvement [112,113,149].

Another stream representing a sub-level of this category is the body of research concerning peer-to peer exchanges. It is focused on the trade or exchange of 3D designs/models over the web, similar to the sharing of music and movie files in online peer-to-peer exchanges [67].

The category of democratization of manufacturing is strictly connected to the topics covered by the digital transformation of products/services category (5.1%), but while the latter adopts a business strategy perspective (see, for instance, [114,150]), the former is focused on the user/consumer perspective.

The category of **policy-driven economic/competitive impact of digital transformation** (9%) includes articles with a macro-level (i.e., national, international, worldwide) and long-term perspective on industrial evolution dynamics, as dependent on public policies, legal frameworks, societal reactions, and homogeneous/heterogeneous dissemination of digital infrastructure and knowledge. Industry

4.0 is viewed as a policy-driven innovation discourse in manufacturing industries, which aims to institutionalize innovation systems that encompass business, academia, and politics [173]. In addition, while for "policy-driven economic/competitive impact of digital transformation", the level of analysis is often the entire industry or country, for "digital transformation of products/services", the focus is on firms and their customers.

The category of **AM features/applications** (7.7%) presents publications concerning the state of the art, evolution, and trends of additive manufacturing and 3D printing technologies. Technological characteristics, phases of the production process as well as main advantages and disadvantages of AM applications in comparison to conventional techniques in terms of efficiency, times, and costs are presented [45,68]. Recent applications in different industries are considered and possible future scenarios are outlined to assess any disruptions and consequences of the technology that might impact the firms and consumers [69]. Data from our sample show that this category of publications is quite well covered, and provides insights (see Table 16) based mainly on research commentary studies (10 papers out of a total of 14, the 71%).

Also, research on business model innovation was found in 12 papers (7.7% of the sample). Publications in this category focused on how digital manufacturing technologies modify business model components and key processes, allowing large companies and SMEs to create and capture value as well as satisfy customers' needs (e.g., [28,115]). The low amount of publications is further confirmed by the limited attention received by the connected category of impact on value proposition (1.3%). Bogers et al. (2016) explored how AM technologies may influence viable business models within the consumer goods manufacturing industry, with the aim of answering the question of how emerging AM technologies affect business model development and operations in this context [10]. Business model innovation is not only about implementing more and better technologies. It also involves digital congruence, the process of aligning a company's culture, people, structure, and tasks. Indeed, history has shown that technological revolution without adequate business model evolution is a pitfall for many businesses [19].

Research on the topic of sustainability (7.7%) concerns the implications of the digital transformation in terms of economic, ecological, and social aspects, referring to the triple bottom line (TBL) dimensions of sustainable development and value creation. The ongoing evolution of the production and industrial process along the fourth industrial revolution, and its related technologies, was studied to understand the potential impact on both the environment and society. Benefits, risks, and challenges connected to the implementation of Industry 4.0 in this perspective were considered. For instance, Bonilla et al. (2018) outlined four different scenarios to evaluate the impacts of the Industry 4.0 production context and its underpinning technologies on environmental sustainability aspects: Industry 4.0 deployment, operation, and technologies, integration, and compliance with the sustainable development goals, and long-term scenarios. By analysing these scenarios, the authors identified positive and negative impacts related to the basic production inputs and outputs flows, respectively: Raw material, energy, and information consumption; products, waste, and end-life products disposal [138]. Moreover, the topic of productive synergy between Industry 4.0 and environmentally-sustainable manufacturing, which organisations should consider carefully when implementing their industrial strategies through the analysis of the integration of economic and environmental issues into sustainable operations management, requires investigation into identifying the critical success factors capable of unlocking this process. Despite the importance of this research domain and perspective in connection to the topic under consideration, the issue of sustainability has received limited attention until now in the Industry 4.0 literature [139].

The subsequent two categories listed in Table 7—digital transformation of products/services and technology assessment and comparison—present a similar frequency value in terms of the number of publications, with low results probably due to the strong connections of these topics to the main categories already presented above, of which they represent important aspects.

Finally, only one paper of our final sample was identified that focused on the meaningful and critical relationships among perceived job insecurity, technology usage, and long-term projection in the transition toward the fourth industrial revolution [168].

3.3. Research Domain

As per the previous focus category, there are a few domains that were clearly dominant in our sample. Domains were classified primarily according to the definitions given by the authors, their research field, and our interpretation of each paper. Indeed, a broad look at the top-level codes indicates a concentration of the research principally in four main categories (with a relative frequency value of at least 10%): Technology and innovation management; supply chain management/operations management (SCM/OM); research that interest multiple domains, and innovation. The "multiple" category includes studies referring to several academic disciplines in a single paper, such as strategic management and decision making, marketing, and manufacturing research. The innovation category concerns papers that study through theoretical frameworks and empirical methods, the dynamics of the innovation process applied to several aspects concerning this environment. Production economics, more specifically, concerns the design and development of advanced manufacturing information systems and platforms as well as studies focused on the growing phenomenon of Industry 4.0. Table 8 represents the distribution of the different domains within the analyzed sample.

Table 8. Domain codes.

Category	N	%
Technology and Innovation Management	25	16%
SCM/OM	23	14.7%
Multiple	15	9.6%
Innovation (Process)	15	9.6%
Production Economics	11	7.1%
Decision Making (for Innovation)	8	5.1%
MIS	7	4.5%
Sustainable Development/Innovation	7	4.5%
Industrial Economics	6	3.8%
Education	5	3.2%
Entrepreneurship and Business Research	5	3.2%
Service Science	5	3.2%
IP Law	4	2.6%
Sharing Economy	4	2.6%
Strategic Management	4	2.6%
Consumer Research	3	1.9%
Organization Science	3	1.9%
Manufacturing Economics	2	1.3%
Circular Economy	1	0.6%
International Business Research	1	0.6%
Multichannel Management	1	0.6%
Product/Service Innovation	1	0.6%
Total	156	100%

As a confirmation of the evidence from the previous focus categories, domains, such as entrepreneurship and business research (3.2%) and strategic management (2.6%), did not receive enough interest in connection to the topics under investigation. Moreover, as already observed in the previous section, the domain of multichannel management, which represents one of the trending research streams of the last decade in marketing and IS, which resulted in only one publication within our sample concerning the implementation of e-commerce channels for AM.

3.4. Industrial Sector/Industry

The analysis of the sector/industries that are interesting to digital transformation shows results that can be clustered in four main categories (see Table 9, sorted in alphabetical order due to the high heterogeneity of the results). Indeed, 33.78% of the overall sample (50 publications) presented studies concerning the broad manufacturing sector, in some cases, focusing on a specific firm category, such as: Large enterprises [166], SMEs [35,55,106,151], or multinational enterprises [61]. Moreover, 42 publications did not focus on a specific sector or industry, but provided applications and cases from multiple sectors among which healthcare and medical industry, jewelry, dental implants, orthopedics, education, automotive, aerospace, etc. were included in the DME [2,48,70,71,148,152,169].

Table 9. Sectors listed in alphabetic order.

Category	Characterization	F	Tot	%
3D Printing Industry	3D Printing	1	3	1.9%
	3D Printing (Startups)	2		
Aerospace Industry	Aerospace Industry	3	5	3.2%
	Aerospace Industry (SMEs)	2		
Automotive Industry		2	2	1.3%
Ceramic Industry		1	1	0.6%
Construction Industry		1	1	0.6%
Consumer Goods/Services		12	12	7.7%
Digital Trade		4	4	2.6%
Education Industry		2	2	1.3%
FabLabs		4	4	2.6%
Fashion		1	1	0.6%
Food Industry		2	2	1.3%
Footwear Industry		1	1	0.6%
Handicraft Industry		1	1	0.6%
Hearing Aid Industry		1	1	0.6%
Industrial Service Industry		2	2	1.3%
Lamp Industry		1	1	0.6%
Manufacturing Sector	Manufacturing Sector	42	52	33.3%
	Manufacturing Sector (Large Enterprises)	1		
	Manufacturing Sector (Multinational Enterprises)	1		
	Manufacturing Sector (SMEs)	8		
Multiple	Multiple	44	47	30.1%
	Multiple (SMEs)	3		
NGO		1	1	0.6%
No Industry Specified (theoretical)		11	11	7.1%
Plastics Industry		1	1	0.6%
Public Sector		1	1	0.6%
Total		156	156	100%

In addition, 7.7% of the publications studied the effects of disruptive digital manufacturing technologies on the consumer goods and services sector. For instance, Steenhuis and Pretorius (2016) explored the adoption of consumer-level 3D printing and its potential disruptive impact on the existing

manufacturing industry by investigating how competitive consumer printed products are compared to industrially manufactured ones [51].

From the previous evidence, it is clear that some important areas, such as the public sector (0.6%), education and industrial service industries (1.3%), and the FabLab network phenomenon (2.6%), received only limited investigation in the existing literature. The 3D printing industry can be added to the latter, which is related to the development and commercialization of different types of 3D printers (desktop, industrial, etc.), materials, and connected services.

3.5. Research Method

Primarily based on the research method stated in each article, the classification presented below was developed according to the authors of the papers considered in the final sample. In the cases where this indication was missing, a classification was made by interpreting the author's design. Indeed, to investigate whether the literature concerning the digital transformation of manufacturing is dominated by intuition-based reasoning and conceptual analysis (conceptual research category) rather than empirical research, a categorization was needed to classify the selected articles [39,43]. In this analysis, all the studies originating from or based on direct observation or experience were considered "empirical research", including, in some cases, articles in which the researcher gathered data through secondary sources (e.g., case studies based on information collected from secondary data collection sources, such as websites, databases, etc.). Mixed methods studies include publications based on two or more different research methods, among them, at least one is always empirical, which employs either qualitative or quantitative research or both [180].

Articles characterized by intuition-based reasoning and academic literature reviews were classified as "conceptual research".

Looking at the aggregated frequency values, the sample appears split into two main groups characterized by almost equal amounts of studies, with a slightly higher percentage of empirical studies (80 papers, in comparison to 76 conceptual papers). Table 10 presents the distribution found in the sample. Conceptual research (48.7%) included articles based either on authors' subjective opinions and/or literature reviews, literature surveys, and research commentary. One paper classified as conceptual research in the category of "technology assessment" [72] was found to be based on a primary data collection. However, the majority of the publications included in this macro-category were "research commentary" (34.5% of the entire sample), which is the main research method of our sample.

The frequency of methods in our sample indicates that empirical articles are the most prevalent type of research (51.3%). Empirical articles were classified as those publications mainly relying on direct or field observations, usually captured through several methodological research techniques, such as case studies, field surveys, field studies/interviews, as well as laboratory and field experiments. By far, the most frequent research method in this category was "multiple-case study research" (12.8% of the sample); at the same time, the category of "case study" represents the third cluster in terms of the number of papers in the empirical group (7.7%). This evidence can be explained by the fact that the phenomena and technologies under investigation are relatively young and present limited empirical evidence [28,71], thus the research is exploratory in nature. For this reason, an inductive approach based on exploratory case studies, frequently through in-depth interviews or expert evaluations (e.g., the Delphi method), was often adopted [113]. This kind of theory building research is not oriented towards general laws or correlations between dependent and independent variables, but instead aims to uncover the social dynamics and mechanisms that underlie certain processes. When based on multiple data-sources, this method allows for triangulation to enrich and corroborate the findings [46,181]. Furthermore, the research questions identified are mainly "how" questions. Yin (1994) suggests the case study methodology is well suited to meet the requirements of answering "how" questions, such as the ones raised to examine a contemporary phenomenon in a context, like the digital transformation of manufacturing. A case study is an objective, in-depth examination of a contemporary phenomenon where the investigator has little control over events [55,182]. Scholars have used case

studies to develop theories about topics as diverse as group processes [183], internal organizations [184], and strategies [185]. Building theories from case studies is a research strategy that involves using one or more cases to create theoretical constructs, propositions, and/or midrange theories from case-based, empirical evidence [30,186]. For instance, Milewski et al. (2015) adopted an exploratory case-based research design and conducted a multiple-case study of five large successful manufacturing companies operating in different industries in Germany to investigate the management of technological change, organizational change, and systemic impact at different stages of the innovation lifecycle (ILC) in large manufacturing companies [166].

Table 10. Categorization of research methods.

Category	Sub-category	N	%
Conceptual Research	Market Assessment	3	2.03%
	Literature Survey	5	2.70%
	Technology Assessment	4	2.70%
	Literature Review	13	7.43%
	Research Commentary	51	34.46%
Sub-Total		**76**	**48.7%**
Empirical Research	Grounded Theory	1	0.68%
	Action Research	1	0.68%
	Focus Group	1	0.68%
	Empirical Study	2	1.35%
	Interviews	3	2.03%
	Experiment	4	2.70%
	Survey	8	4.05%
	Simulation	10	6.76%
	Case Study	12	8.11%
	Mixed Methods	18	10.81%
	Multiple-Case Study	20	12.84%
Sub-Total		**80**	**51.3%**
Total		**156**	**100%**

The second largest category is "mixed methods" (11.5%), which includes studies developed through different phases and research methods, where one of them is always based on empirical research (e.g., [4,153,175]).

Furthermore, the low relative frequency values of "survey" (5.1%) and "experiment" (2.6%) categories—typically characterized by a quantitative approach to research—highlight the lack of publications based on these methods in this field. This datum will be further analyzed in the research approach section.

In addition, it is worth noting that only one paper of the sample was based on grounded theory.

Table 10 shows the evidence presented in this section.

The above chart (Figure 4) represents the publications divided into the two main research method categories (i.e., conceptual and empirical research), ordered by year. It is useful to examine the evolution of the publications in this field through the considered period. In particular, it is possible to observe an overall increase in the number of empirical publications starting from 2014. This trend was not confirmed for 2017; in addition, the datum from 2018, which contains a majority of empirical studies (16 in comparison to 15 conceptual), was not considered definitive since the literature search was completed in October of the same year.
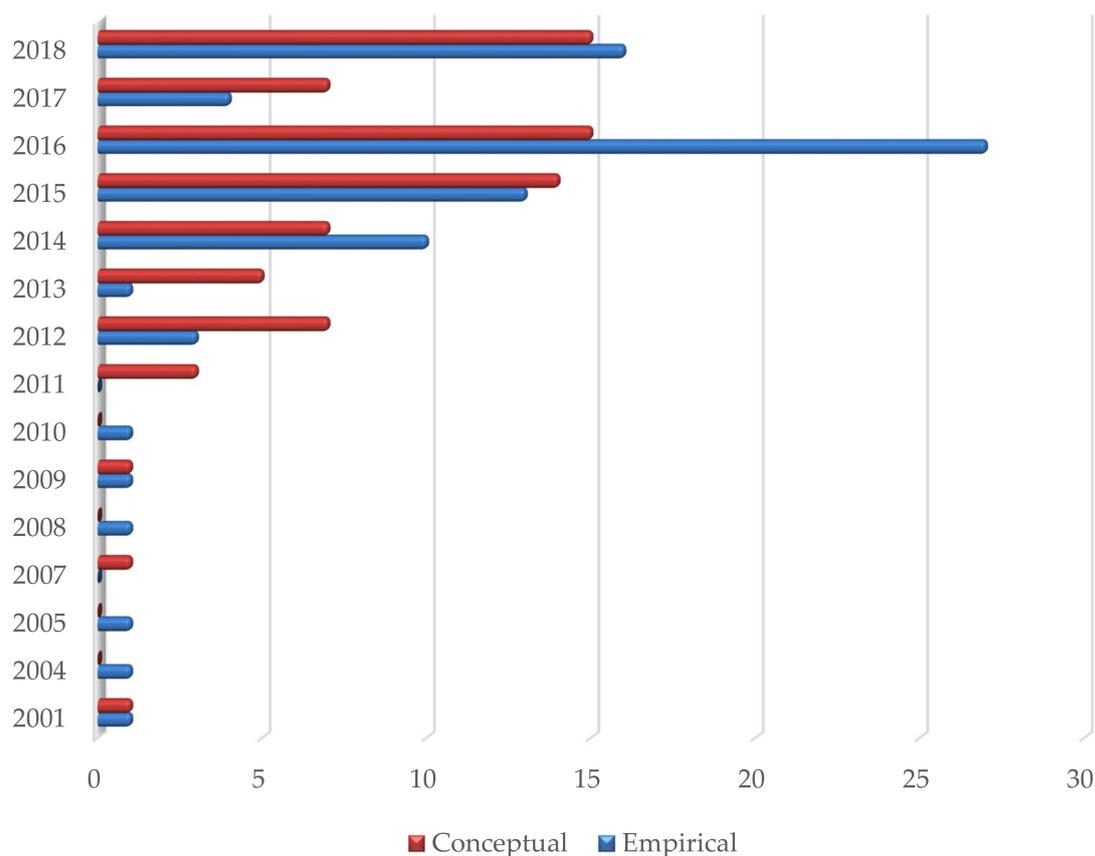
Figure 4. Research method distribution per publication year.

At the same time, in Figure 7, a similar increasing trend is recorded concerning the number of publications based on secondary data.

3.6. Research Approach

Following Alavi and Carlson (1992), our primary papers were classified as qualitative research if they had an emphasis on both the description and understanding of the context and the environment of the research phenomenon [40]. On the other hand, studies based on the use of numerical analysis to illustrate the relationship among factors concerning the phenomenon studied were classified as quantitative research. Papers that used both quantitative and qualitative methods were categorized as "mix". Steenhuis and Pretorius (2016), in their exploratory study on the adoption of consumer-level 3D printing and its potential impact, followed a two-methods research approach. The authors initially used a qualitative research method similar to an in-depth exploratory case study to determine user friendliness and the role of technological characteristics of a consumer-level 3D printer. In the follow-up research, they used a questionnaire-based survey as well as a bibliometric analysis as part of a triangulation strategy to explore the adoption of 3D printer technology by consumers more broadly and confirm their previous conceptualizations through quantitative research [51].

Table 11 and Figure 5 present the distribution found in the sample. Clearly, the most common research approach was qualitative (66.7%), which presents a value more than four times higher than the quantitative approach. These datum results are coherent with the high frequency recorded by the "conceptual research" category, typically characterized by a qualitative approach, as well as the overall case study research (counting together the case study and multiple-case study), whose results were based on a qualitative approach for 78% of its total results (see Table 13). In addition, 29 papers of the sample (18.6%) were based on a mix of both a qualitative and quantitative approach (i.e., "mix" category in the table above).

Table 11. Research approach categories.

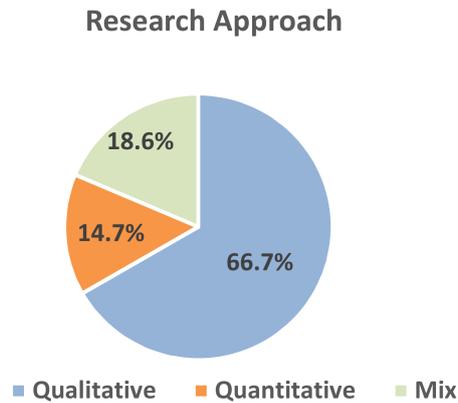| Category	N	%
Qualitative	104	66.7%
Quantitative	23	14.7%
Mix	29	18.6%
Total	156	100%

Research Approach

Figure 5. Distribution of research approach categories.

Table 12 shows a cross-analysis between the domain and approach categories, ordered alphabetically. The most significant evidence is represented by the relatively high frequency values (respectively, 18 and 14 publications) of the technology and innovation management and supply chain management-operations management (SCM-OM) domains in connection to qualitative research. Moreover, the latter presents the highest frequency in terms of quantitative research (seven publications).

Table 12. Research domain vs. approach.

Domain/approach	Qual.	Quant.	Mix
Circular economy	1	0	0
Consumer research	2	0	1
Decision making for innovation	5	2	1
Education	3	0	2
Entrepreneurship and business research	2	0	3
Industrial economics	2	0	4
Innovation (process)	9	1	5
International business research	1	0	0
IP law	4	0	0
MIS	4	2	1
Manufacturing economics	2	0	0
Multichannel management	1	0	0
Multiple	12	3	0
Organization science	2	1	0
Product/service innovation	1	0	0
Production economics	6	3	2
SCM-OM	14	7	2
Service science	4	0	1
Sharing economy	3	0	1
Strategic management	4	0	0
Sustainable Development/Innovation	4	2	1
Technology and innovation management	18	2	5

Furthermore, from Table 13, it is possible to observe that research commentary and multiple case study research present the highest values in terms of qualitative studies, with almost their entirety composed of qualitative studies. In addition, the research method characterized by the highest frequency value of quantitative studies was found to be simulation.

Table 13. Research design vs. approach.

Design/approach	Qual.	Quant.	Mix
Action research	1	0	0
Case study	9	2	1
Empirical study	0	1	1
Experiment	1	1	2
Focus group	1	0	0
Grounded theory	1	0	0
Interviews	3	0	0
Literature review	11	1	1
Literature survey	5	0	0
Market assessment	1	1	1
Mixed methods	5	3	10
Multiple case study	16	0	4
Research commentary	47	0	4
Simulation	2	7	1
Survey	0	5	3
Technology assessment	1	2	1

3.7. Nature of Data Collection

The present section concerns the distribution of data sources in our sample. We categorized data based on the main collection approach used in each study. It should be noted that 66% of the publications are based on secondary data collection, that is, data that were already collected and were readily available from other sources, such as public datasets, websites, industrial reports, etc. (see Table 14 and Figure 6). Interestingly, this frequency has an almost identical value to the frequency of publications based on a qualitative approach. For instance, Chiarello et al. (2018) generated an enriched dictionary of Industry 4.0 enabling technologies by using technical documents and the Wikipedia free online encyclopedia through automatic text extraction, field delineation, and clustering, aiming to create a shared semantic for Industry 4.0 [105]. Moreover, Kim (2018), in his study concerning Korea's preparedness for Industry 4.0, used the Bank of Korea's statistical database for private sector analysis, and cost benefit analysis results from the government's major research projects for public sector analysis [171]. On the contrary, primary data relies on original data sources, in which the data are collected firsthand by the researcher for a specific research purpose or project. The most common techniques of primary data collection are self-administered surveys, interviews, field observation, case-study research, and experiments. Primary data collection is quite expensive and time consuming compared to secondary data collection [187]. For these reasons, our sample shows that only the 31% of publications present this type of data collection.

Table 14. Nature of data collection categories.

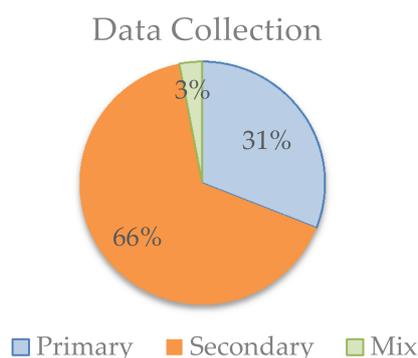| Category	F	%
Primary	48	31%
Secondary	103	66%
Mix	5	3%
Total	156	100%

Figure 6. Distribution of nature of data collection categories.

The chart above (Figure 7) represents the publications sorted by the nature of the data collection categories (i.e., primary, secondary, mix) and ordered per year. The figure further confirms an overall increasing trend in the number of publications based on secondary data collection (which represents the main category of the sample).
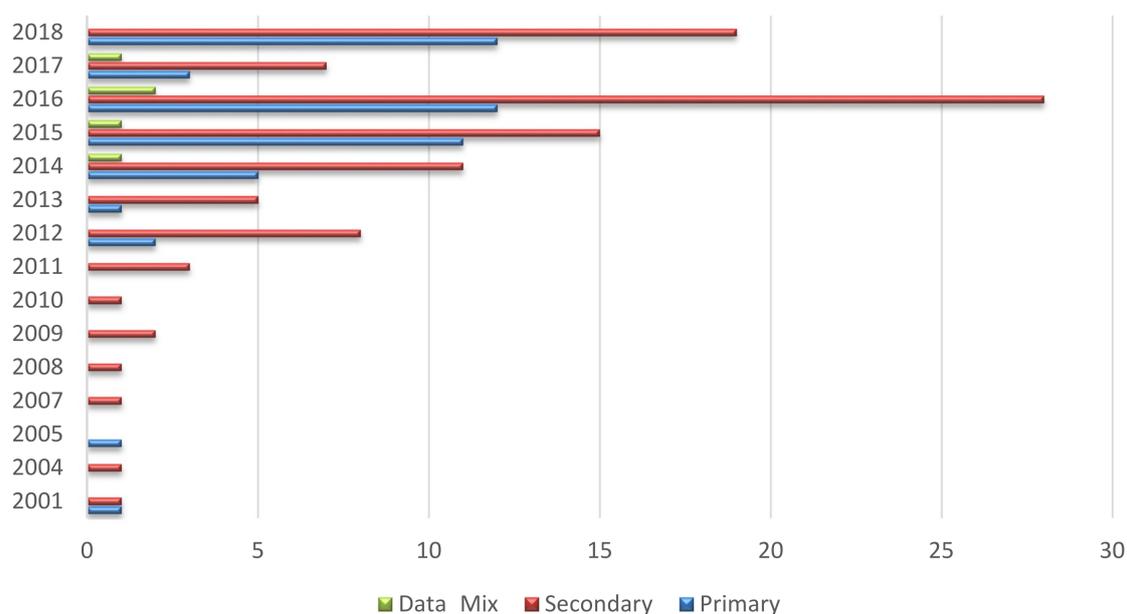

Figure 7. Nature of data collection per publication year.

3.8. Main Contribution

An analysis of the main contribution of each article was also conducted. Many authors clearly highlighted the main contributions of their papers. However, as per other classifications, due to the lack of information given by the authors in some cases, the present classification required a reviewer's judgment. Table 15 shows the findings. The fact that research commentary was the most common research method undoubtedly resulted in insights/overview (39.7%) and, to a lesser extent, in conceptual frameworks (26.9%) emerging as the most common type of contribution of the articles reviewed.

Table 15. Main contribution of the sample publications.

Main Contribution	F	%
Theory Building	4	2.56%
Multiple	10	6.41%
Research Agenda	13	8.33%
Conceptual Model	25	16.03%
Conceptual Framework	42	26.92%
Insights/Overview	62	39.74%
Total	156	100%

Only four papers resulted in building a new theory as the main contribution (see theory building). Moreover, 10 papers showed a combination of more than one main contribution; for instance, [70,73,74,116] present both "insights" and "research agenda" as main contributions. Therefore, these articles were classified as "multiple".

Table 16 presents a cross-analysis between the "focus" and "main contribution" categories.

Table 16. Focus/main contribution cross analysis.

Focus/Main Contribution	Conceptual Model	Conceptual Framework	Insights	Research Agenda	Theory Building
AM Features/Applications	0	1	10	3	0
Business Mode Innovation	3	5	2	3	0
Democratization of Manufacturing	1	5	11	4	1
Digital Knowledge Dissemination	1	2	1	0	0
Digital Transformation of Products/Services	3	0	4	1	0
Policy-driven Economic/Competitive Impact of Digital Transformation	2	1	10	1	0
Grounded Theory	0	0	0	0	1
Impact on Value Proposition	0	1	1	0	0
Intellectual Property Law	0	0	2	0	0
Job Sustainability and Insecurity			1		
Manufacturing Supply Chain Reconfiguration	9	20	14	6	3
Multiple	0	0	1	0	0
Sustainability	1	4	6	1	0
Technological Development Dynamics	3	4	2	3	0
Technology Assessment and Comparison	2	1	3	1	0

From this inter-dependence test, the following results were identified:

- The stream category of "manufacturing supply chain reconfiguration" shows the highest number of contributions in terms of all the different contribution categories indicated in the table, including a very high score in terms of conceptual frameworks;
- "manufacturing supply chain reconfiguration" shows also the highest score in terms of theory building contributions over the entire sample, although the absolute value results are very low; and
- papers in the categories of "economic/competitive impact of digital transformation", "AM features/applications", and "democratization of manufacturing" contributed mainly with insights into the current research in this field.

In addition, we crossed the results concerning the method and contribution categories. Among the information derivable from Table 17, the most meaningful results are:

- Research commentary publications show the highest values in terms of "insights" (34) and "research agenda" (12) contributions. This evidence confirms the exploratory nature of this type of study; and
- simulation and survey are the categories with the highest score in terms of the conceptual model as the main contribution (5). Together with the relatively high frequency value for the conceptual framework type of contribution, this result indicates that this category of publications tends to contribute to the literature by offering structured models or frameworks that can be useful for the development of future studies as well as for theory building in this research field.

Table 17. Method/contribution cross analysis.

Method/Contribution	Conceptual Model	Conceptual Framework	Insights/Overview	Research Agenda	Theory Building
Action Research	0	1	0	0	0
Case Study	1	5	6	0	0
Empirical Study	0	1	1	0	0
Experiment	2	1	1	0	0
Focus Group	0	0	1	0	0
Grounded Theory	0	0	0	0	1
Interviews	1	1	1	0	0
Literature Review	1	3	5	3	1
Literature Survey	1	3	0	1	0
Market Assessment	0	2	1	0	0
Mixed Methods	4	5	7	2	0
Multiple-Case Study	1	8	10	2	0
Research Commentary	3	8	34	12	2
Simulation	5	4	0	1	0
Survey	5	0	2	1	0
Technology Assessment	1	2	0	1	0

The totals of the last two tables are higher than 156 since publications with more than one main contribution were counted twice.

3.9. Geographical Distribution

Finally, our sample was analysed in terms of the regional context of the publications. As mentioned, the nationality of the research was assigned to a country based on the first author's affiliation. Figure 8 shows the distribution of papers per country.

By observing the graphical representation provided in Figure 8, it is clear that the largest number of papers (21, corresponding to 13.5% of the sample) were written by researchers or academics working in the USA. It is worth noting that one of these papers concerns the evolution of Chinese manufacturing by comparing Germany's Industry 4.0 and China's "Made-in-China 2025", the Chinese governmental project aimed at enhancing its industrial capability through innovation-driven manufacturing, optimization of the structure of the Chinese industry, emphasis of quality over quantity, the training and attracting of talent, and achievement of green manufacturing and environmental sustainability [170]. The manufacturing sector is at the core of the American economy. With American leadership in advanced manufacturing at risk due to changes in the global economy and new competitors rising across the globe, in March 2012, the U.S. President Barack Obama announced an investment of $1 billion in the National Network for Manufacturing Innovation (NNMI) to support U.S. manufacturing innovation and encourage insourcing (or re-shoring) of these activities. The key focus is on new technology paradigms that can improve the competitiveness of American manufacturing—with particular attention to small and medium enterprises (SMEs)—through the digitalization of design and manufacturing, democratization of technology, and collaborative design and analytics to sustain leadership across the U.S. manufacturing ecosystem [111]. These settings have pushed American universities, companies, and institutions in orienting scientific and professional research to these subjects. We can further argue that in general, also including other countries (e.g., Germany and the UK), the strong presence of universities, scientific journals, and multinational companies represents an important driver for research on these specific topics.
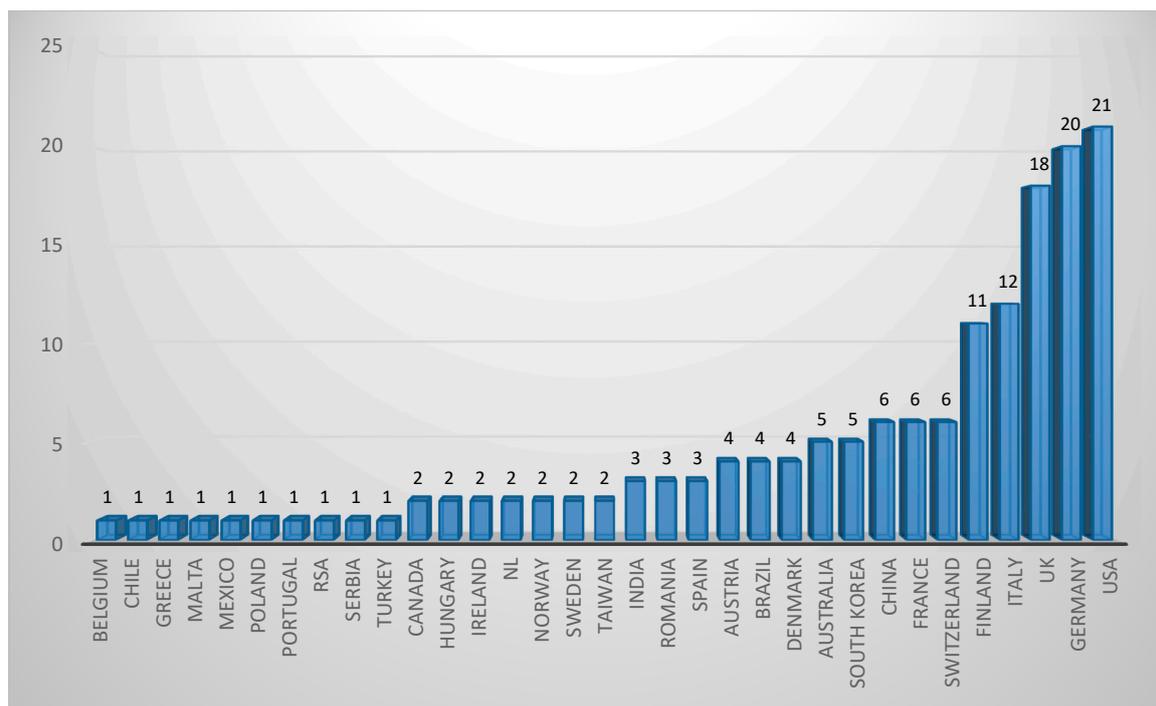
Figure 8. Chart of the regional distribution of publications.

A similar background makes Germany the second country for the number of publications within the analyzed sample, with a frequency value of 20. Germany relies heavily on manufacturing to fuel its economy as well as Europe. Twenty-two of its top 100 small and medium-sized enterprises are machinery and plant manufacturers, with three of them among the world's top 10. "Industrie 4.0", Germany's response to the so-called "fourth industrial revolution", is a cornerstone of the German government's industrial 2020 high-tech strategy initiated by Industry Science Research Alliance. Investment in research is essential to realize all the initiatives needed for the industrial digital transformation, and plenty of funding will be needed. The idea has already spurred collaboration in Germany's research community. Electronics and engineering giant, Siemens, has formed an industrial automation and digitization research alliance with the state funded Technical University Munich (TUM), the Ludwig-Maximilians University (LMU), the German Research Center for Artificial Intelligence (DFKI), and the Fraunhofer Institute for Applied and Integrated Security (AISEC). Doctoral and postdoctoral programs offered by the technical universities will enable up to 100 doctoral candidates to pursue their studies while collaborating on automation and digitalization research [188]. These growth strategies have certainly strongly influenced scientific production in this field. A similar strategy was implemented by the Italian government (Ministry of Economic Development), concerning objectives and incentives for the period of 2017—2020, under the name of "Piano Nazionale Industria 4.0". The latter was renovated this year as " Piano Nazionale Impresa 4.0" to emphasize the opportunity offered to firms (especially SMEs, which represent almost an entirety of the Italian industrial sector) to seize the chances related to digital transformation and the fourth industrial revolution [189]. The importance given by the Italian government to the ongoing industrial revolution is also reflected by the number of Italian studies found in the sample (12).

3.10. Defining the Digital Manufacturing Ecosystem

Based on the results presented as well as the key terms and definitions encountered in the analyzed literature, it is possible to provide our comprehensive definition of a digital manufacturing ecosystem (DME), which is understood as:

The transformation of the manufacturing sector driven by an extended set of enabling digital tools and internet technologies, but also renovated strategies, capabilities, and business processes. These settings provide an increased level of flexibility, reconfigurability, and intelligence. Such a smart, value-driven, and efficient context reshapes the way goods are designed, produced, delivered, and updated; creates new business opportunities and models; and modifies the relationships among all the different actors of the supply chain.

Consequently, deriving from the above definition of digital manufacturing as an extensive ecosystem that includes different value activities and business functions, specific technologies (e.g., 3D printing, cyber-physical systems, IoT, smart products, digital platforms, advanced robotics, cloud computing and data analytics, etc.) and definitions (e.g., additive manufacturing, digital fabrication, home fabrication, prosumption, Industry 4.0, industrial internet, smart manufacturing, etc.) are here considered as constitutive elements of this context.

4. Concluding Remarks and Research Agenda

This paper presents an extensive systematic review of the most relevant existing literature on the deep changes brought by the digital transformation of the manufacturing process, operations, and value chain. The aim was to provide researchers and practitioners with a clear overview on this topic. Published between 2001 and 2018, 156 peer-reviewed papers made up the sample of this study and were deeply analyzed in the review. Several research objectives guided the analysis of these papers and allowed identification of the main research streams and gaps in this field. Particularly, in this paper, we shed light on past and current research concerning digital transformation of manufacturing to provide a detailed picture of this field through a categorization and statistical analysis of scholarly journal publications. This paper contributes to a deeper comprehension of this topic of interest from the specific perspective of the evolution of the production process and operations in this dynamic context, as well as the different parties involved in this transition. The evolution of the research outcomes in the last 10 years demonstrates a progressive, but rapid shift (especially in the last two to three years) of the focus from the analysis of single technological trends to a comprehensive, holistic analysis of their integrated adoption in advanced manufacturing systems through industrial value networks and supply chains. Indeed, the findings presented above provide evidence that there is an increasing interest of scholars from several research domains as well as a rapid growth of the body of literature connected to the parallel technological evolution of the sector mainly due to the huge investments made in the USA, Europe, and many other industrialized countries of the world (e.g., South Korea, China, etc.). However, the literature analysis shows that although some research streams have received much attention from the academic community, others require further research efforts.

Based on our evidence, the applicability of digital manufacturing technologies varies considerably across the different industries in the manufacturing sector and presents a growing number of technical tools, industrial and managerial strategies as well as end-users' applications. In some industries—or industry segments—digital manufacturing is technologically, but not economically feasible. Overall, the analyzed literature shows that the diffusion of digital manufacturing in industries is often associated with a development toward shorter and more dispersed global value chains. Hence, in some industries, this new ecosystem is likely to pull manufacturing value chains in the direction of becoming more local and closer to the end-users [61]. At the same time, in this way, digitalized industrial supply chains become smart and value-driven, and create efficient processes that are able to generate new forms of revenue and business value for organizations [110]. Regardless, these assumptions require extensive research to confirm and determine the dimensions of this trend.

From our systematic literature review, the following patterns and gaps were highlighted:

- Within our sample, we found a high concentration of articles focused on digital and AM technologies employed in the reconfiguration of operations in the manufacturing supply chain;
- some specific topics have received limited investigation, including the consequent innovation of business models and value chain activities, multi-dimensional evaluation (i.e., from an economic,

social, and environmental viewpoint) of the sustainability of digital transformation, as well as the digitalization of customized one-off products, leading to an integration of customers/end users in the manufacturer's supply chain;

- the sample was well-balanced regarding empirical and conceptual research;
- within this last broad category, a high number of papers were found to be "research commentary", which represents the larger category of the whole sample. Moreover, the very limited number of systematic literature analyses/surveys as well as the absence of grounded theory studies must be mentioned [139]. In light of this result, the present systematic and extensive analysis of the literature appears to be necessary;
- publications were characterized mainly by exploratory qualitative research based, in the large majority of cases, on secondary data collection;
- empirical studies were strongly dominated by exploratory case-study research. The analysis of the distribution highlighted an important lack of quantitative research based, for instance, on surveys and experimental studies; and
- from the analysis of the main contributions, a high frequency of "insights" and, at the same time, a lack of "theory building" contributions were observed.

As the body of research into the digital transformation of manufacturing grows, this field is likely to develop and mature as a research tradition of its own. However, our analysis suggests that for this outcome to happen, researchers in this field should begin to focus their efforts more carefully. In particular, according to the gaps found in the literature, hereby, we propose the following research agenda of areas representing promising candidates for future research:

- Research focused on the impact of AM on value chain activities, with possible important implications on the re-organization of internal business functional units. This topic is connected to the involvement of customers and end-users in the creation of customized products through a multichannel strategy (value co-creation);
- in connection to the previous point, more relevant research is needed in the area of business model innovation and value creation/capturing. These topics are closely linked since a company's business model describes its logic of creating and capturing value [190–192]. There is a growing consensus that DM technologies are going to be one of the next major technological revolutions. While a lot of work has already been carried out on what these technologies will bring in terms of product and process innovation, little has been said on their impact on business models and business model innovation [19]. While much more value can be created, capturing value can become extremely challenging. Hence, research should focus on developing a suitable business model to capture this value;
- quantitative research based on primary data collection: The existing body of literature involves a disproportionately large amount of research characterized by qualitative studies based on secondary data collection. More research based on quantitative studies (e.g., surveys and statistical model testing) needs to be carried out to address this gap;
- specific research areas and topics: Some important research domains and perspectives are represented by a limited number of studies in connection with the main topic. For instance, the comprehensive and multi-dimensional concept of sustainability (concerning economic, ecological, and social aspects) in the context of this new production paradigm has received limited attention in terms of academic studies [139]. Furthermore, Piccarozzi et al. (2018) recently suggested that sustainability issues should be considered as core drivers of the Industry 4.0 strategy, together with other related aspects, such as social innovation and democratization of manufacturing [144]. Moreover, other important topics, such as intellectual property law issues connected to the online trade of digital projects/models, job sustainability and insecurity due to the disruptive technological transition, as well as the educational perspective about the digital knowledge

dissemination, represent interesting, but understudied fields, which require more attention from researchers;

- impact on performance/competitive advantage: We found very few studies concerning the impact of this new ecosystem on business and organizational performance intended as a sustainable competitive advantage (SCA), enhanced value proposition, customer satisfaction, market share, etc. To understand and measure this impact, it is necessary to investigate how this disruptive change can confer or drive organizations to build essential dynamic capabilities and core competence to allow them to successfully compete in highly competitive and turbulent business environments; and

- theory development: To gain a solid theoretical foundation, this field needs contributions aimed at creating specific theories, in addition to the application of existing reference theories.

Through consideration of future avenues and managerial implications suggested by the results obtained through this research, it is clear that digitally-enabled technologies lead to a disruptive paradigm shift of industrial production. Business process digitalization reconfigures every aspect of organizational and operating activities along the entire value chain. Manufacturing companies need to adopt a systematic approach by drawing a digital roadmap to address business opportunities across their value chain: (i) First, they should clearly outline the strategic business objectives to be achieved. Objectives need to be explicitly defined and committed to by all functions before starting the project. (ii) Secondly, manufacturers should identify and select potential innovations that can be applied and further developed, and that are able to improve manufacturing processes and provide business value. To do so, companies need to achieve a good understanding of the latest digital platforms and applications across the manufacturing value chain through market analysis and running specific simulations to verify the real achievable benefits. (iii) Finally, they must prioritize initiatives based on the perceived business benefits (e.g., social-environmental-financial, internal, and for customers) and ease of implementation, according to the specific market and long term objectives. Innovation projects are often technology driven. While, in the majority of cases, technology is mature for almost any industrial application, greater commitment must be given to redesigning business models to be aligned with the technological paradigm shift to achieve a real, sustainable competitive advantage on the market.

Finally, some limitations also characterize the present study. While our sample was extensive and systematically updated, it was fully comprehensive. Indeed, as mentioned we only included peer-reviewed publications from scholarly journals in our sample, excluding many other potentially excellent papers out of this category (e.g., conference proceedings not published in scholarly journals, working papers, etc.). Moreover, our search criteria may have excluded those papers that did not respond to the terms used for the keyword search, but that were potentially interesting in terms of content and analyses in connection to the topic of interest. Also, the choice of the databases used for the literature search (listed in Table 1) could have excluded some interesting papers not present in those platforms. In addition, sometimes it was necessary to interpret the articles during the coding process to classify them according to our coding scheme. This process, although it was carried out in the most rigorous way possible and only in cases where the authors had not explicitly stated the nature of their research, this may have resulted in a source of biases in the evaluation of the articles.

In conclusion, our intention was to take stock of the existing literature and extend research on the digital manufacturing ecosystem by drawing on its foundations. In doing so, this study seeks to propel more focused theory building and discussion concerning effective and sustainable performance and implications of this phenomenon for businesses and society.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Li, J.; Merenda, M.; Venkatachalam, A.R. Business Process Digitalization and New Product Development: An Empirical Study of Small and Medium-Sized Manufacturers. *Int. J. E-Bus. Res.* **2009**, *5*, 49–64. [CrossRef]
2. Brennan, L.; Ferdows, K.; Godsell, J.; Golini, R.; Keegan, R.; Kinkel, S.; Srai, J.S.; Taylor, M. Manufacturing in the world: Where next? *Int. J. Oper. Prod. Manag.* **2015**, *35*, 1253–1274. [CrossRef]
3. Capgemini Consulting. *Are Manufacturing Companies Ready to go Digital?* Capgemini: Paris, France, 2012.
4. Colli, M.; Madsen, O.; Berger, U.; Møller, C.; Wæhrens, B.V.; Bockholt, M. Contextualizing the outcome of a maturity assessment for Industry 4.0. *IFAC-PapersOnLine* **2018**, *51*, 1347–1352. [CrossRef]
5. Chand, S.; Davis, J.F. What is smart manufacturing. *Time Magazine Wrapper*, July 2010; 28–33.
6. Lohr, S. The internet gets physical. *The New York Times*, 17 December 2011; 1–4.
7. Fox, S. Relevance: A framework to address preconceptions that limit perceptions of what is relevant. *Int. J. Manag. Proj. Bus.* **2015**, *8*, 804–812. [CrossRef]
8. Cimini, C.; Pinto, R.; Cavalieri, S. The business transformation towards smart manufacturing: A literature overview about reference models and research agenda. *IFAC-PapersOnLine* **2017**, *50*, 14952–14957. [CrossRef]
9. Bortolini, M.; Galizia, F.G.; Mora, C. Reconfigurable manufacturing systems: Literature review and research trend. *J. Manuf. Syst.* **2018**, *49*, 93–106. [CrossRef]
10. Bogers, M.; Hadar, R.; Bilberg, A. Additive manufacturing for consumer-centric business models: Implications for supply chains in consumer goods manufacturing. *Technol. Forecast. Soc. Chang.* **2016**, *102*, 225–239. [CrossRef]
11. Magnani, A. Perché si parla tanto di industria 4.0: Che cos'è e quanti lavori può creare. *Sole 24 Ore*, 13 October 2017.
12. Lasi, H.; Fettke, P.; Kemper, H.G.; Feld, T.; Hoffmann, M. Industry 4.0. *Bus. Inf. Syst. Eng.* **2014**, *6*, 239–242. [CrossRef]
13. Nanry, J.; Narayanan, S.; Rassey, L. Digitizing the Value Chain. *McKinsey Quarterly*. March 2015. Available online: https://www.mckinsey.com/business-functions/operations/our-insights/digitizing-the-value-chain (accessed on 2 February 2019).
14. Porter, M.; Heppelmann, J. How smart, connected products are transforming industry. *Harv. Bus. Rev.* **2015**, *93*, 96–114.
15. Kliewe, D.; Kühn, A.; Dumitrescu, R.; Gausemeier, J. Challenges in Anti-Counterfeiting of Cyber-Physical Systems. *Int. J. Soc. Behav. Educ. Econ. Manag. Eng.* **2015**, *9*, 1732–1739.
16. Mellor, S.; Hao, L.; Zhang, D. Additive manufacturing: A framework for implementation. *Int. J. Prod. Econ.* **2014**, *149*, 194–201. [CrossRef]
17. Denning, S. A tipping point for foreign outsourcing economics. *Strateg. Leadersh.* **2012**, *40*, 8–15. [CrossRef]
18. Holmström, J.; Partanen, J. Digital manufacturing-driven transformations of service supply chains for complex products. *Supply Chain Manag.* **2014**, *19*, 421–430. [CrossRef]
19. Rayna, T.; Striukova, L. From rapid prototyping to home fabrication: How 3D printing is changing business model innovation. *Technol. Forecast. Soc. Chang.* **2016**, *102*, 214–224. [CrossRef]
20. Hofmann, E.; Rüsch, M. Industry 4.0 and the current status as well as future prospects on logistics. *Comput. Ind.* **2017**, *89*, 23–34. [CrossRef]
21. Blanchet, M.; Rinn, T.; Von Thaden, G.; Georges, D.T. *Industry 4.0. The New Industrial Revolution. How Europe Will Succeed*; Roland Berger Strategy Consultants: Munich, Germany, 2014.
22. IEC. *Factory of the Future—White Paper*; IEC: Geneva, Switzerland, 2015.
23. Lee, J.; Kao, H.A.; Yang, S. Service innovation and smart analytics for Industry 4.0 and big data environment. *Procedia CIRP* **2014**, *16*, 3–8. [CrossRef]
24. Brettel, M.; Friederichsen, N.; Keller, M.; Rosenberg, M. How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective. *Int. J. Mech. Aerosp. Ind. Mechatron. Eng.* **2014**, *8*, 37–44.
25. Kiron, D.; Kane, G.C.; Palmer, D.; Phillips, A.N.; Buckley, N. *Aligning the Organization for its Digital Future*; MIT Sloan Management Review: Cambridge, MA, USA, 2016; Volume 58.

26. Puthiyamadam, T. How The Meaning of Digital Tranformation Has Evolved. *Harvard Business Review*. 29 May 2017. Available online: https://hbr.org/2017/05/how-the-meaning-of-digital-transformation-has-evolved (accessed on 2 February 2019).

27. Arnold, C.; Kiel, D.; Voigt, K.-I. How the industrial internet of things changes business models in different manufacturing industries. *Int. J. Innov. Manag.* **2016**, *20*, 1640015. [CrossRef]

28. Müller, J.M.; Buliga, O.; Voigt, K.I. Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technol. Forecast. Soc. Chang.* **2018**, *132*, 2–17. [CrossRef]

29. De Felice, F.; Petrillo, A.; Zomparelli, F. A Bibliometric Multicriteria Model on Smart Manufacturing from 2011 to 2018. *IFAC-PapersOnLine* **2018**, *51*, 1643–1648. [CrossRef]

30. Cautela, C.; Pisano, P.; Pironti, M. The emergence of new networked business models from technology innovation: An analysis of 3-D printing design enterprises. *Int. Entrep. Manag. J.* **2014**, *10*, 487–501. [CrossRef]

31. Despeisse, M.; Baumers, M.; Brown, P.; Charnley, F.; Ford, S.J.; Garmulewicz, A.; Knowles, S.; Minshall, T.H.W.; Mortara, L.; Reed-Tsochas, F.P.; et al. Unlocking value for a circular economy through 3D printing: A research agenda. *Technol. Forecast. Soc. Chang.* **2017**, *115*, 75–84. [CrossRef]

32. Ford, S.; Mortara, L.; Minshall, T. The Emergence of Additive Manufacturing: Introduction to the Special Issue. *Technol. Forecast. Soc. Chang.* **2016**, *102*, 156–159. [CrossRef]

33. Hahn, F.; Jensen, S.; Tanev, S. Disruptive Innovation vs Disruptive Technology: The Disruptive Potential of the Value Propositions of 3D Printing Technology Startups. *Technol. Innov. Manag. Rev.* **2014**, *4*, 27–36. [CrossRef]

34. Schniederjans, D.G. Adoption of 3D-printing technologies in manufacturing: A survey analysis. *Int. J. Prod. Econ.* **2017**, *183*, 287–298. [CrossRef]

35. Sommer, L. Industrial revolution—Industry 4.0: Are German manufacturing SMEs the first victims of this revolution? *J. Ind. Eng. Manag.* **2015**, *8*, 1512–1532. [CrossRef]

36. Buer, S.-V.; Fragapane, G.I.; Strandhagen, J.O. The Data-Driven Process Improvement Cycle: Using Digitalization for Continuous Improvement. *IFAC-PapersOnLine* **2018**, *51*, 1035–1040. [CrossRef]

37. Hoehle, H.; Scornavacca, E.; Huff, S. Three decades of research on consumer adoption and utilization of electronic banking channels: A literature analysis. *Decis. Support Syst.* **2012**, *54*, 122–132. [CrossRef]

38. Yli-Huumo, J.; Ko, D.; Choi, S.; Park, S.; Smolander, K. Where Is Current Research on Blockchain Technology?—A Systematic Review. *PLoS ONE* **2016**, *11*, e0163477. [CrossRef] [PubMed]

39. Wareham, J.; Zheng, J.; Straub, D. Critical themes in electronic commerce research: A meta-analysis. *J. Inf. Technol* **2005**, *20*, 1–19. [CrossRef]

40. Alavi, M.; Carlson, P. A Review of MIS Research and Disciplinary Development. *J. Manag. Inf. Syst.* **1992**, *8*, 45–62. [CrossRef]

41. Banker, R.D.; Kauffman, R.J. The Evolution of Research on Information Systems A Fiftieth-Year Survey of the Literature in Management Science. *Manag. Sci.* **2004**, *50*, 281–298. [CrossRef]

42. Culnan, M.J.; Swanson, E.B. Research in Management Information Systems, 1980–1984: Points of Work and Reference. *MISQ* **1986**, *10*, 289–302. [CrossRef]

43. Scornavacca, E.; Barnes, S.J.; Huff, S.L. Mobile Business Research Published in 2000–2004: Emergence, Current Status, and Future Opportunities. *Commun. Assoc. Inf. Syst.* **2006**, *17*, 635–646. [CrossRef]

44. Adams, R.; Downey, C. Edited platforms: Anticipating future consumption. *J. Mark. Theory Pract.* **2016**, *24*, 224–235. [CrossRef]

45. Berman, B. 3-D printing: The new industrial revolution. *Bus. Horiz.* **2012**, *55*, 155–162. [CrossRef]

46. Birtchnell, T.; Böhme, T.; Gorkin, R. 3D printing and the third mission: The university in the materialization of intellectual capital. *Technol. Forecast. Soc. Chang.* **2017**, *123*, 240–249. [CrossRef]

47. Jia, F.; Wang, X.; Mustafee, N.; Hao, L. Investigating the feasibility of supply chain-centric business models in 3D chocolate printing: A simulation study. *Technol. Forecast. Soc. Chang.* **2016**, *102*, 202–213. [CrossRef]

48. Öberg, C.; Shams, T.; Asnafi, N. Additive Manufacturing and Business Models: Current Knowledge and Missing Perspectives. *Technol. Innov. Manag. Rev.* **2018**, *8*, 15–33. [CrossRef]

49. Park, S.; Kim, J.; Lee, H.; Jang, D.; Jun, S. Methodology of technological evolution for three-dimensional printing. *Ind. Manag. Data Syst.* **2016**, *116*, 122–146. [CrossRef]

50. Buxmann, P.; Hinz, O. Makers. *Bus. Inf. Syst. Eng.* **2013**, *5*, 357–360. [CrossRef]

51. Steenhuis, H.-J.; Pretorius, L. Consumer additive manufacturing or 3D printing adoption: An exploratory study. *J. Manuf. Technol. Manag.* **2016**, *27*, 990–1012. [CrossRef]

52. Atzeni, E.; Iuliano, L.; Minetola, P.; Salmi, A. Redesign and cost estimation of rapid manufactured plastic parts. *Rapid Prototyp. J.* **2010**, *16*, 308–317. [CrossRef]

53. Hopkinson, N.; Dickens, P. Rapid prototyping for direct manufacture. *Rapid Prototyp. J.* **2001**, *7*, 197–202. [CrossRef]

54. Holmstrom, J.; Liotta, G.; Chaudhuri, A. Sustainability outcomes through direct digital manufacturing-based operational practices: A design theory approach. *J. Clean. Prod.* **2017**, *167*, 951–961. [CrossRef]

55. Rylands, B.; Böhme, T.; Gorkin, R., III; Fan, J.; Birtchnell, T. The adoption process and impact of additive manufacturing on manufacturing systems. *J. Manuf. Technol. Manag.* **2016**, *27*, 969–989. [CrossRef]

56. Sun, L.; Zhao, L. Envisioning the era of 3D printing: A conceptual model for the fashion industry. *Fash. Text.* **2017**, *4*, 25. [CrossRef]

57. Weller, C.; Kleer, R.; Piller, F.T. Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited. *Int. J. Prod. Econ.* **2015**, *164*, 43–56. [CrossRef]

58. Holmström, J.; Holweg, M.; Khajavi, S.H.; Partanen, J. The direct digital manufacturing (r)evolution: Definition of a research agenda. *Oper. Manag. Res.* **2016**, *9*, 1–10. [CrossRef]

59. Khajavi, S.H.; Partanen, J.; Holmström, J. Additive manufacturing in the spare parts supply chain. *Comput. Ind.* **2014**, *65*, 50–63. [CrossRef]

60. Liu, P.; Huang, S.H.; Mokasdar, A.; Zhou, H.; Hou, L. The impact of additive manufacturing in the aircraft spare parts supply chain: Supply chain operation reference (scor) model based analysis. *Prod. Plan. Control* **2014**, *25*, 1169–1181. [CrossRef]

61. Laplume, A.O.; Petersen, B.; Pearce, J.M. Global value chains from a 3D printing perspective. *J. Int. Bus. Stud.* **2016**, *47*, 595–609. [CrossRef]

62. Oettmeier, K.; Hofmann, E. Impact of additive manufacturing technology adoption on supply chain management processes and components. *J. Manuf. Technol. Manag.* **2016**, *27*, 944–968. [CrossRef]

63. Chiu, M.-C.; Lin, Y.-H. Simulation based method considering design for additive manufacturing and supply chain. *Ind. Manag. Data Syst.* **2016**, *116*, 322–348. [CrossRef]

64. Eyers, D.R.; Potter, A.T. E-commerce channels for additive manufacturing: An exploratory study. *J. Manuf. Technol. Manag.* **2015**, *26*, 390–411. [CrossRef]

65. Hoover, S.; Lee, L. Democratization and Disintermediation: Disruptive Technologies and the Future of Making Things. *Res. Technol. Manag.* **2015**, *58*, 31–36.

66. Mortara, L.; Parisot, N.G. Through entrepreneurs' eyes: The Fab-spaces constellation. *Int. J. Prod. Res.* **2016**, *54*, 7158–7180. [CrossRef]

67. Burns, M.; Howison, J. Digital manufacturing—Napster fabbing: Internet delivery of physical products. *Rapid Prototyp. J.* **2001**, *7*, 194–196. [CrossRef]

68. Pîrjan, A.; Petrosanu, D.-M. The Impact of 3D Printing Technology on the Society and Economy. *J. Inf. Syst. Oper. Manag.* **2013**, *7*, 360–370.

69. Kietzmann, J.; Pitt, L.; Berthon, P. Disruptions, decisions, and destinations: Enter the age of 3-D printing and additive manufacturing. *Bus. Horiz.* **2015**, *58*, 209–215. [CrossRef]

70. Campbell, I.; Bourell, D.; Gibson, I. Additive manufacturing: Rapid prototyping comes of age. *Rapid Prototyp. J.* **2012**, *18*, 255–258. [CrossRef]

71. Sandström, C.G. The non-disruptive emergence of an ecosystem for 3D Printing—Insights from the hearing aid industry's transition 1989–2008. *Technol. Forecast. Soc. Chang.* **2016**, *102*, 160–168. [CrossRef]

72. Gartner, J.; Maresch, D.; Fink, M. The Potential of Additive Manufacturing for Technology Entrepreneurship: An Integrative Technology Assessment. *Creat. Innov. Manag.* **2015**, *24*, 585–600. [CrossRef]

73. Brooks, G.; Kinsley, K.; Owens, T. 3D Printing As A Consumer Technology Business Model. *Int. J. Manag. Inf. Syst.* **2014**, *18*, 271. [CrossRef]

74. Campbell, R.I.; de Beer, D.J.; Pei, E. Additive manufacturing in South Africa: Building on the foundations. *Rapid Prototyp. J.* **2011**, *17*, 156–162. [CrossRef]

75. Appleyard, M. Corporate responses to online music piracy: Strategic lessons for the challenge of additive manufacturing. *Bus. Horiz.* **2015**, *58*, 69–76. [CrossRef]

76. Baumers, M.; Dickens, P.; Tuck, C.; Hague, R. The cost of additive manufacturing: Machine productivity, economies of scale and technology-push. *Technol. Forecast. Soc. Chang.* **2016**, *102*, 193–201. [CrossRef]

77. Bosqué, C. What are you printing? Ambivalent emancipation by 3D printing. *Rapid Prototyp. J.* **2015**, *21*, 572–581. [CrossRef]

78. Calderon, A.; Griffin, J.; Cristóbal Zagal, J. BeamMaker: An open hardware high-resolution digital fabricator for the masses. *Rapid Prototyp. J.* **2014**, *20*, 245–255. [CrossRef]

79. De Jong, J.P.; De Bruijn, E. Innovation lessons from 3-D printing. *MIT Sloan Manag. Rev.* **2013**, *54*, 43. [CrossRef]

80. Diez, T. Personal fabrication: Fab labs as platforms for citizen-based innovation, from microcontrollers to cities. *Nexus Netw. J.* **2012**, *14*, 457–468. [CrossRef]

81. Dumitrescu, G.C.; Tanase, I.A. 3D printing—A new industrial revolution. *Knowl. Horiz. Econ.* **2016**, *8*, 32.

82. Ebrahim, T.Y. 3D Printing: Digital Infringement & Digital Regulation. *Northwest. J. Technol. Intell. Prop.* **2016**, *14*, 37–74.

83. Gardan, J. Additive manufacturing technologies: State of the art and trends. *Int. J. Prod. Res.* **2016**, *54*, 3118–3132. [CrossRef]

84. Hasan, S.; Rennie, A.; Hasan, J. The business model for the functional rapid manufacturing supply chain. *Studia Commercialia Bratislavensia.* **2013**, *6*, 536–552. [CrossRef]

85. Hull, C.W. The birth of 3D printing. *Res. Technol. Manag.* **2015**, *58*, 25–30.

86. Khajavi, S.H.; Partanen, J.; Holmström, J.; Tuomi, J. Risk reduction in new product launch: A hybrid approach combining direct digital and tool-based manufacturing. *Comput. Ind.* **2015**, *74*, 29–42. [CrossRef]

87. Knofius, N.; van der Heijden, M.C.; Zijm, W.H. Selecting parts for additive manufacturing in service logistics. *J. Manuf. Technol. Manag.* **2016**, *27*, 915–931. [CrossRef]

88. Kurfess, T.; Cass, W.J. Rethinking additive manufacturing and intellectual property protection. *Res. Technol. Manag.* **2014**, *57*, 35–42. [CrossRef]

89. Kyläheiko, K.; Sandström, J. Strategic options-based framework for management of dynamic capabilities in manufacturing firms. *J. Manuf. Technol. Manag.* **2007**, *18*, 966–984. [CrossRef]

90. Lyly-Yrjänäinen, J.; Holmström, J.; Johansson, M.I.; Suomala, P. Effects of combining product-centric control and direct digital manufacturing: The case of preparing customized hose assembly kits. *Comput. Ind.* **2016**, *82*, 82–94. [CrossRef]

91. Meisel, N.A.; Williams, C.B. Design and assessment of a 3D printing vending machine. *Rapid Prototyp. J.* **2015**, *21*, 471–481. [CrossRef]

92. Mohr, S.; Khan, O. 3D printing and its disruptive impacts on supply chains of the future. *Technol. Innov. Manag. Rev.* **2015**, *5*, 20–25. [CrossRef]

93. Negi, S.; Dhiman, S.; Sharma, R.K. Basics, applications and future of additive manufacturing technologies: A review. *J. Manuf. Technol. Res.* **2013**, *5*, 75–96.

94. Oesterreich, T.D.; Teuteberg, F. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Comput. Ind.* **2016**, *83*, 121–139. [CrossRef]

95. Paio, A.; Eloy, S.; Rato, V.M.; Resende, R.; de Oliveira, M.J. Prototyping Vitruvius, new challenges: Digital education, research and practice. *Nexus Netw. J.* **2012**, *14*, 409–429. [CrossRef]

96. Petrick, I.J.; Simpson, T.W. 3D printing disrupts manufacturing: How economies of one create new rules of competition. *Rese. Technol. Manag.* **2013**, *56*, 12–16. [CrossRef]

97. Potstada, M.; Zybura, J. The role of context in science fiction prototyping: The digital industrial revolution. *Technol. Forecast. Soc. Chang.* **2014**, *4*, 101–114. [CrossRef]

98. Potstada, M.; Parandian, A.; Robinson, D.K.; Zybura, J. An alignment approach for an industry in the making: DIGINOVA and the case of digital fabrication. *Technol. Forecast. Soc. Chang.* **2016**, *102*, 182–192. [CrossRef]

99. Rieple, A.; Pironti, M.; Pisano, P. Business network dynamics and diffusion of innovation. In *Symphonya. Emerging Issues in Management*; University of Milano-Bicocca: Milan, Italy, 2012; Volume 2, pp. 13–25.

100. Rogers, H.; Baricz, N.; Pawar, K.S. 3D printing services: Classification, supply chain implications and research agenda. *Int. J. Phys. Distrib. Logist. Manag.* **2016**, *46*, 886–907. [CrossRef]

101. Sasson, A.; Johnson, J.C. The 3D printing order: Variability, supercenters and supply chain reconfigurations. *Int. J. Phys. Distrib. Logist. Manag.* **2016**, *46*, 82–94. [CrossRef]

102. Tatham, P.; Loy, J.; Peretti, U. Three dimensional printing—A key tool for the humanitarian logistician? *J. Humanit. Logist. Supply Chain Manag.* **2015**, *5*, 188–208. [CrossRef]

103. Thiesse, F.; Wirth, M.; Kemper, H.G.; Moisa, M.; Morar, D.; Lasi, H.; Piller, F.; Buxmann, P.; Mortara, L.; Ford, S.; et al. Economic implications of additive manufacturing and the contribution of MIS. *Bus. Inf. Syst. Eng.* **2015**, *57*, 139–148. [CrossRef]

104. Wagner, S.M.; Walton, R.O. Additive manufacturing's impact and future in the aviation industry. *Prod. Plan. Control* **2016**, *27*, 1124–1130. [CrossRef]

105. Chiarello, F.; Trivelli, L.; Bonaccorsi, A.; Fantoni, G. Extracting and mapping industry 4.0 technologies using wikipedia. *Comput. Ind.* **2018**, *100*, 244–257. [CrossRef]

106. Dean, P.R.; Tu, Y.L.; Xue, D. An information system for one-of-a-kind production. *Int. J. Prod. Res.* **2009**, *47*, 1071–1087. [CrossRef]

107. Francalanza, E.; Borg, J.; Constantinescu, C. A knowledge-based tool for designing cyber physical production systems. *Comput. Ind.* **2017**, *84*, 39–58. [CrossRef]

108. Ivanov, D.; Dolgui, A.; Sokolov, B.; Werner, F.; Ivanova, M. A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0. *Int. J. Prod. Res.* **2016**, *54*, 386–402. [CrossRef]

109. Weichhart, G.; Molina, A.; Chen, D.; Whitman, L.E.; Vernadat, F. Challenges and current developments for Sensing, Smart and Sustainable Enterprise Systems. *Comput. Ind.* **2016**, *79*, 34–46. [CrossRef]

110. Büyüközkan, G.; Göçer, F. Digital Supply Chain: Literature review and a proposed framework for future research. *Comput. Ind.* **2018**, *97*, 157–177. [CrossRef]

111. Beckmann, B.; Giani, A.; Carbone, J.; Koudal, P.; Salvo, J.; Barkley, J. Developing the Digital Manufacturing Commons: A National Initiative for US Manufacturing Innovation. *Procedia Manuf.* **2016**, *5*, 182–194. [CrossRef]

112. Fox, S.; Li, L. Expanding the scope of prosumption: A framework for analysing potential contributions from advances in materials technologies. *Technol. Forecast. Soc. Chang.* **2012**, *79*, 721–733. [CrossRef]

113. Rayna, T.; Striukova, L.; Darlington, J. Co-creation and user innovation: The role of online 3D printing platforms. *J. Eng. Technol. Manag.* **2015**, *37*, 90–102. [CrossRef]

114. West, S.; Gaiardelli, P.; Rapaccini, M. Exploring technology-driven service innovation in manufacturing firms through the lens of Service Dominant logic. *IFAC-PapersOnLine* **2018**, *51*, 1317–1322. [CrossRef]

115. Metallo, C.; Agrifoglio, R.; Schiavone, F.; Mueller, J. Understanding business model in the Internet of Things industry. *Technol. Forecast. Soc. Chang.* **2018**, *136*, 298–306. [CrossRef]

116. Dutton, W. Putting things to work: Social and policy challenges for the Internet of things. *Inf. J. Policy Regul. Strateg. Telecommun. Inf. Media* **2014**, *16*, 1–21. [CrossRef]

117. Bals, L.; Daum, A.; Tate, W. From offshoring to rightshoring: Focus on the backshoring phenomenon. *AIB Insights* **2015**, *15*, 3–8.

118. Bechtsis, D.; Tsolakis, N.; Vlachos, D.; Iakovou, E. Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles. *J. Clean. Prod.* **2017**, *142*, 3970–3984. [CrossRef]

119. Brousseau, E.; Eldukhri, E. Recent advances on key technologies for innovative manufacturing. *J. Intell. Manuf.* **2011**, *22*, 675–691. [CrossRef]

120. Caputo, A.; Marzi, G.; Pellegrini, M.M. The internet of things in manufacturing innovation processes: development and application of a conceptual framework. *Bus. Process Manag. J.* **2016**, *22*, 383–402. [CrossRef]

121. de Sousa Jabbour, A.B.L.; Jabbour, C.J.C.; Foropon, C.; Godinho Filho, M. When titans meet—Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. *Technol. Forecast. Soc. Chang.* **2018**, *132*, 18–25. [CrossRef]

122. Gershenfeld, N.; Euchner, J. Atoms and bits: Rethinking manufacturing. *Res. Technol. Manag.* **2015**, *58*, 16–23. [CrossRef]

123. Fox, S.; Alptekin, B. A taxonomy of manufacturing distributions and their comparative relations to sustainability. *J. Clean. Prod.* **2018**, *172*, 1823–1834. [CrossRef]

124. Jin, M.; Tang, R.; Ji, Y.; Liu, F.; Gao, L.; Huisingh, D. Impact of advanced manufacturing on sustainability: An overview of the special volume on advanced manufacturing for sustainability and low fossil carbon emissions. *J. Clean. Prod.* **2017**, *161*, 69–74. [CrossRef]

125. Khan, A.; Nasser, K. Advanced manufacturing technologies for smart and competitive businesses. *IUP J. Oper. Manag.* **2016**, *15*, 7–17.

126. Krawczyński, M.; Czyżewski, P.; Bocian, K. Reindustrialization: A Challenge to the Economy in the First Quarter of the Twenty-First Century. *Found. Manag.* **2016**, *8*, 107–122. [CrossRef]

127. Lan, H.; Ding, Y.; Hong, J.; Huang, H.; Lu, B. A web-based manufacturing service system for rapid product development. *Comput. Ind.* **2004**, *54*, 51–67. [CrossRef]

128. Lan, H.; Chin, K.S.; Hong, J. Development of a teleservice system for RP service bureaus. *Rapid Prototyp. J.* **2005**, *11*, 98–105. [CrossRef]

129. Lan, H. Web-based rapid prototyping and manufacturing systems: A review. *Comput. Ind.* **2009**, *60*, 643–656. [CrossRef]

130. Lerch, C.; Gotsch, M. Digitalized product-service systems in manufacturing firms: A case study analysis. *Res. Technol. Manag.* **2015**, *58*, 45–52. [CrossRef]

131. Majstorović, V.; Mačužić, J.; Šibalija, T.; Živković, S. Cyber-Physical Manufacturing Systems–Manufacturing Metrology Aspects. *Proc. Manuf. Syst.* **2015**, *10*, 9–14.

132. Muñoz-Villamizar, A.; Santos, J.; Viles, E.; Ormazábal, M. Manufacturing and environmental practices in the Spanish context. *J. Clean. Prod.* **2018**, *178*, 268–275. [CrossRef]

133. Oliveira, S.R.M.; Alves, J.L. The next frontier: Open innovation and prospecting of knowledge for value co-creation in complex environments based on new business models by 3D modeling and additive manufacturing. *Afr. J. Bus. Manag.* **2014**, *8*, 884–902.

134. Shu, Z.; Wan, J.; Zhang, D.; Li, D. Cloud-integrated cyber-physical systems for complex industrial applications. *Mobile Netw. Appl.* **2016**, *21*, 865–878. [CrossRef]

135. Sung, T.K. Industry 4.0: A Korea perspective. *Technol. Forecast. Soc. Chang.* **2018**, *32*, 40–45. [CrossRef]

136. Trentesaux, D.; Borangiu, T.; Thomas, A. Emerging ICT concepts for smart, safe and sustainable industrial systems. *Comput. Ind.* **2016**, *81*, 1–10. [CrossRef]

137. Wang, S.; Wan, J.; Zhang, D.; Li, D.; Zhang, C. Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination. *Comput. Netw.* **2016**, *101*, 158–168. [CrossRef]

138. Bonilla, S.H.; Silva, H.R.O.; da Silva, M.T.; Gonçalves, R.F.; Sacomano, J.B. Industry 4.0 and sustainability implications: A scenario-based analysis of the impacts and challenges. *Sustainability* **2018**, *10*, 3740. [CrossRef]

139. Kamble, S.S.; Gunasekaran, A.; Gawankar, S.A. Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. *Process Saf. Environ. Protect.* **2018**, *117*, 408–425. [CrossRef]

140. Kiel, D.; Müller, J.M.; Arnold, C.; Voigt, K.I. Sustainable Industrial Value Creation: Benefits and Challenges of Industry 4.0. *Int. J. Innov. Manag.* **2017**, *21*. [CrossRef]

141. Müller, J.M.; Kiel, D.; Voigt, K.-I. What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability. *Sustainability* **2018**, *10*, 247. [CrossRef]

142. Müller, J.M.; Voigt, K.I. Sustainable Industrial Value Creation in SMEs: A Comparison between Industry 4.0 and Made in China 2025. *Int. J. Precis. Eng. Manuf. Green Technol.* **2018**, *5*, 659–670. [CrossRef]

143. Nagy, J.; Oláh, J.; Erdei, E.; Máté, D.; Popp, J. The role and impact of industry 4.0 and the internet of things on the business strategy of the value chain-the case of Hungary. *Sustainability* **2018**, *10*, 3491. [CrossRef]

144. Piccarozzi, M.; Aquilani, B.; Gatti, C. Industry 4.0 in management studies: A systematic literature review. *Sustainability* **2018**, *10*, 3821. [CrossRef]

145. Rennung, F.; Luminosu, C.T.; Draghici, A. Service Provision in the Framework of Industry 4.0. *Procedia Soc. Behav. Sci.* **2016**, *221*, 372–377. [CrossRef]

146. Brenner, W.; Karagiannis, D.; Kolbe, L.; Krüger, J.; Leifer, L.; Lamberti, H.J.; Leimeister, J.M.; Österle, H.; Petrie, C.; Plattner, H.; et al. User, Use & Utility Research. *Bus. Inf. Syst. Eng.* **2014**, *6*, 55–61.

147. Candel Haug, K.; Kretschmer, T.; Strobel, T. Cloud adaptiveness within industry sectors—Measurement and observations. *Telecommun. Policy* **2016**, *40*, 291–306. [CrossRef]

148. Hamalainen, M.; Mohajeri, B.; Nyberg, T. Removing barriers to sustainability research on personal fabrication and social manufacturing. *J. Clean. Prod.* **2018**, *180*, 666–681. [CrossRef]

149. Yoo, B.; Ko, H.; Chun, S. Prosumption perspectives on additive manufacturing: Reconfiguration of consumer products with 3D printing. *Rapid Prototyp. J.* **2016**, *22*, 691–705. [CrossRef]

150. Demartini, M.; Pinna, C.; Tonelli, F.; Terzi, S.; Sansone, C.; Testa, C. Food industry digitalization: From challenges and trends to opportunities and solutions. *IFAC-PapersOnLine* **2018**, *51*, 1371–1378. [CrossRef]

151. Wu, D.; Terpenny, J.; Gentzsch, W. Cloud-Based Design, Engineering Analysis, and Manufacturing: A Cost-Benefit Analysis. *Procedia Manuf.* **2015**, *1*, 64–76. [CrossRef]

152. O'sullivan, D.; Rolstadås, A.; Filos, E. Global education in manufacturing strategy. *J. Intell. Manuf.* **2011**, *22*, 663–674. [CrossRef]

153. Lu, H.-P.; Weng, C.-I. Smart manufacturing technology, market maturity analysis and technology roadmap in the computer and electronic product manufacturing industry. *Technol. Forecast. Soc. Chang.* **2018**, *133*, 85–94. [CrossRef]

154. Belényesi, P. Sweden: Digital Competitiveness and Digital Evolution-Why Are Nordic Countries Ahead? *Eur. Netw. Law Regul. Q. (ENLR)* **2015**, *3*, 215.

155. Cocca, P.; Marciano, F.; Rossi, D.; Alberti, M. Business Software Offer for Industry 4.0: The SAP case. *IFAC-PapersOnLine* **2018**, *51*, 1200–1205. [CrossRef]

156. Davies, P.; Ng, I. Moving towards the incomplete: A research agenda for the development of future products in the digital economy. *Procedia Manuf.* **2015**, *3*, 3368–3374. [CrossRef]

157. Dekkers, R.; Kühnle, H. Appraising interdisciplinary contributions to theory for collaborative (manufacturing) networks: Still a long way to go? *J. Manuf. Technol. Manag.* **2012**, *23*, 1090–1128. [CrossRef]

158. Dunke, F.; Heckmann, I.; Nickel, S.; Saldanha-da-Gama, F. Time traps in supply chains: Is optimal still good enough? *Eur. J. Oper. Res.* **2018**, *264*, 813–829. [CrossRef]

159. Fox, S. Potential of virtual-social-physical convergence for project manufacturing. *J. Manuf. Technol. Manag.* **2014**, *25*, 1209–1223. [CrossRef]

160. Nywlt, J.; Grigutsch, M. Big Data Analytics Based on Logistical Models. *J. Cent. Cathedra Bus. Econ. Res. J.* **2015**, *8*, 57–62.

161. Opazo-Basáez, M.; Vendrell-Herrero, F.; Bustinza, O.F. Uncovering Productivity Gains of Digital and Green Servitization: Implications from the Automotive Industry. *Sustainability* **2018**, *10*, 1524. [CrossRef]

162. Veit, D.; Clemons, E.; Benlian, A.; Buxmann, P.; Hess, T.; Kundisch, D.; Leimeister, J.M.; Loos, P.; Spann, M. Business models. *Bus. Inf. Syst. Eng.* **2014**, *6*, 45–53. [CrossRef]

163. Walters, D. Market centricity and producibility: An opportunity for marketing and operations management to enhance customer satisfaction. *J. Manuf. Technol. Manag.* **2014**, *25*, 299–308. [CrossRef]

164. Featherston, C.R.; Ho, J.Y.; Brévignon-Dodin, L.; O'Sullivan, E. Mediating and catalysing innovation: A framework for anticipating the standardisation needs of emerging technologies. *Technovation* **2016**, *48–49*, 25–40. [CrossRef]

165. Filieri, R.; Alguezaui, S. Extending the enterprise for improved innovation. *J. Bus. Strategy* **2012**, *33*, 40–47. [CrossRef]

166. Milewski, S.K.; Fernandes, K.J.; Mount, M.P. Exploring technological process innovation from a lifecycle perspective. *Int. J. Oper. Prod. Manag.* **2015**, *35*, 1312–1331. [CrossRef]

167. Veugelers, R.; Cincera, M.; Frietsch, R.; Rammer, C.; Schubert, T.; Pelle, A.; Renda, A.; Montalvo, C.; Leijten, J. The Impact of Horizon 2020 on Innovation in Europe. *Intereconomics* **2015**, *50*, 4–30. [CrossRef]

168. Nam, T. Technology usage, expected job sustainability, and perceived job insecurity. *Technol. Forecast. Soc. Chang.* **2018**, *138*, 155–165. [CrossRef]

169. Weber, K.M.; Schaper-Rinkel, P. European sectoral innovation foresight: Identifying emerging cross-sectoral patterns and policy issues. *Technol. Forecast. Soc. Chang.* **2017**, *115*, 240–250. [CrossRef]

170. Li, L. China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0". *Technol. Forecast. Soc. Chang.* **2018**, *135*, 66–74. [CrossRef]

171. Kim, J. Are countries ready for the new meso revolution? Testing the waters for new industrial change in Korea. *Technol. Forecast. Soc. Chang.* **2018**, *132*, 34–39. [CrossRef]

172. Lorenz, R.; Lorentzen, K.; Stricker, N.; Lanza, G. Applying User Stories for a customer-driven Industry 4.0 Transformation. *IFAC-PapersOnLine* **2018**, *51*, 1335–1340. [CrossRef]

173. Reischauer, G. Industry 4.0 as policy-driven discourse to institutionalize innovation systems in manufacturing. *Technol. Forecast. Soc. Chang.* **2018**, *132*, 26–33. [CrossRef]

174. Tumelero, C.; Sbragia, R.; Evans, S. Cooperation in R & D and eco-innovations: The role in companies' socioeconomic performance. *J. Clean. Prod.* **2018**, *207*, 1138–1149.

175. Stock, T.; Obenaus, M.; Kunz, S.; Kohl, H. Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. *Process Saf. Environ. Protect.* **2018**, *118*, 254–267. [CrossRef]

176. Canciglieri, O., Jr.; Sant'anna, Â.M.O.; Machado, L.C. Multi-attribute method for prioritization of sustainable prototyping technologies. *Clean. Technol. Environ. Policy* **2015**, *17*, 1355–1363. [CrossRef]

177. Marion, T.; Fixson, S.; Meyer, M.H. The Problem with Digital Design. *MIT Sloan Manag. Rev.* **2012**, *53*, 63–68.

178. Siller, H.R.; Estruch, A.; Vila, C.; Abellan, J.V.; Romero, F. Modeling workflow activities for collaborative process planning with product lifecycle management tools. *J. Intell. Manuf.* **2008**, *19*, 689–700. [CrossRef]

179. Anderson, C. *Makers: The New Industrial Revolution*; Random House: New York, NY, USA, 2012.

180. Creswell, J.W. *Research Design Qualitative Quantitative and Mixed Methods Approaches*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2003; pp. 3–26.

181. Eisenhardt, K.M.; Graebner, M.E. Theory Building from Cases: Opportunity and Challenges. *Acad. Manag. J.* **2007**, *50*, 25–32. [CrossRef]

182. Yin, R.K. *Case Study Research: Design and Methods*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 1994.

183. Edmondson, A.C.; Bohmer, R.M.; Pisano, G.P. Disrupted Routines: Team Learning and New Technology Implementation in Hospitals. *Adm. Sci. Q.* **2001**, *46*, 685–716. [CrossRef]

184. Galunic, D.C.; Eisenhardt, K.M. Architectural innovation and modular corporate forms. *Acad. Manag. J.* **2001**, *44*, 1229–1249.

185. Mintzberg, H.; Waters, J.A. Tracking strategy in an entrepreneurial firm1. *Acad. Manag. J.* **1982**, *3*, 465–499.

186. Eisenhardt, K.M. Building theories from case study research. *Acad. Manag. Rev.* **1989**, *14*, 532–550. [CrossRef]

187. Salkind, N.J. *Encyclopedia of Research Design*; Sage, Ed.; Sage Publications: Thousand Oaks, CA, USA, 2010.

188. Blau, J. Revolutionizing Industry the German Way. *Res. Technol. Manag.* **2014**, *57*, 2–3.

189. Ministry of Economic Development. *Italy's National Plan Impresa 4.0*; Ministry of Economic Development: Rome, Italy, 2018.

190. Afuah, A. *Business Model Innovation: Concepts, Analysis, and Cases*; Routledge: Abingdon, UK, 2014.

191. Osterwalder, A.; Pigneur, Y. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*; Wiley: Hoboken, NJ, USA, 2010.

192. Zott, C.; Amit, R.; Massa, L. The Business Model: Recent Developments and Future Research. *J. Manag.* **2011**, *37*, 1019–1042.