

Article

# How Can Organisations and Business Models Lead to a More Sustainable Society? A Framework from a Systematic Review of the Industry 4.0

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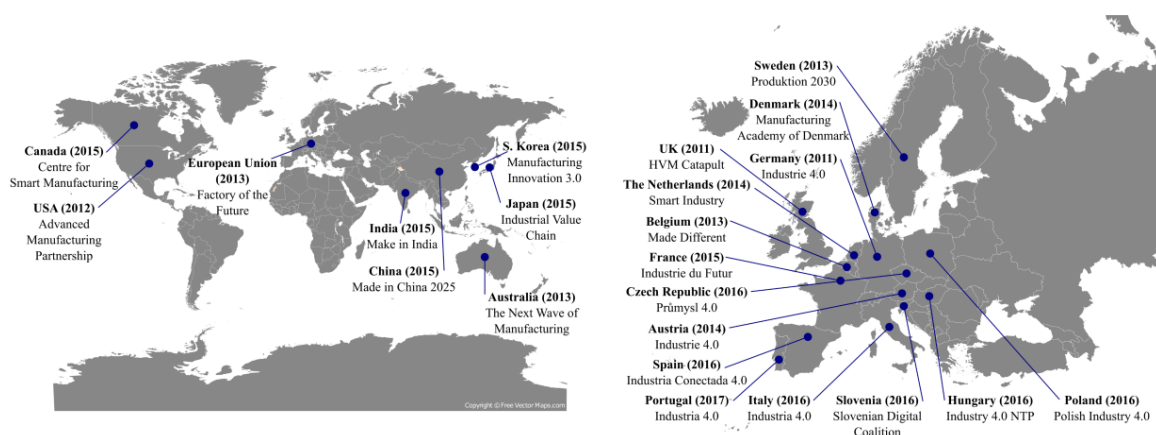


**Abstract:** The concept of Industry 4.0 has been mainly addressed by the current literature from a technological perspective, overlooking the organisational and even ethical challenges related to this recent paradigm. In order to become ‘4.0 compliant’, an enterprise must adapt its organisation and business approaches, and these changes may lead to a significant impact on sustainability. Therefore, we performed a systematic literature review to investigate the most recent Industry 4.0 research streams by adopting a multi-perspective approach. This analysis led to collect insights on the key traits of an Enterprise 4.0: integration, decomposed hierarchy, flexibility, and autonomy. Each of these keywords involves work environments, business and organisational models, and educational approaches, which constitute the key traits of the novel framework proposed in this study.

**Keywords:** Industry 4.0; organisation; sustainable business model; sustainability; smart enterprise; enterprise 4.0

## 1. Introduction

In the current scenario, organisations are increasingly called upon to tackle challenges that require them to be smarter, more efficient, and sustainability-oriented [1–7]. More specifically, firms’ survival depends on the ability to react, in an efficient and reliable way, to rapid product changes and disturbances through re-configuring their organisational and business models through the intensive use of digital and connected manufacturing technologies [8–11]. These features are related to the novel concept of Industry 4.0, which is gaining increasing attention at the academic, industry, and policy levels [12–14]. National and supranational governments have, in fact, been developing various initiatives to support companies in embracing this future manufacturing vision; Germany defined the ‘Industrie 4.0’ programme in 2011, followed by other countries, as synthesised in Figure 1. Interestingly, eight out of the 17 European initiatives include the ‘4.0’ label, highlighting the impact of the German initiative.



**Figure 1.** Map of the Industry 4.0 initiatives undertaken around the world.

The popularity of this topic and its potential impact has encouraged academic research, which, however, has mostly focused on disruptive technological innovation and its industrial applications [15]. Indeed, at its start, Industry 4.0 was reconducted mainly to automation and digitalization processes [16]. Therefore, it is not surprising that most of the research that has been conducted to date has a strong engineering focus, analysing specific industrial applications (e.g., robotics, big data, cloud computing, artificial intelligence, etc.), cyber-physical systems, information integration and interoperability, service provision, and business process management [17]. In this regard, [18] for example, proposed a framework for analysing smart factories in relation to: (i) the adopted technologies, which have led to efficiency improvements and flexible production systems; and (ii) the industrial network, which is able to vehicle big data to the cloud and optimize the organization of the system, as well as its self-decision making processes. A more recent contribution from Lu [19], aimed at performing a comprehensive systematic literature review, also analyses the phenomenon from an engineering and technological point of view. Indeed, the author identified five different research streams related to (i) Industry 4.0's concept and perspectives, (ii) cyber-physical systems, (iii) information interoperability, (iv) key technologies, and (v) Industry 4.0 applications, concerning smart factories, smart products, and smart cities.

According to Piccarozzi et al. [20], other streams linked to Industry 4.0 that emerge from the literature are related to the management field, such as to the study of new business models [21,22] and the adaptation of companies' strategies [23]. Smaller efforts have been devoted to intertwined aspects, such as the role of humans in the future factory, the appropriate organisational models, the approaches for long-term value creation, and the outcomes on society, e.g., in terms of individual employability and sustainability-related issues.

Since a more multidisciplinary approach has been rarely adopted by previous studies, the need to analyse enterprises from a perspective capable of focusing on the intersection of these areas has been called on by scholars [24] and governments who have drawn up programmes to develop a strategy to implement Industry 4.0 principles effectively.

This paper aims to fill this gap by exploring Industry 4.0 and its recent evolutions through the adoption of an approach as comprehensive as possible, aimed at investigating the complementarity and the interconnections among the following traits: work environments, business and organisational models, and educational approaches. As a consequence, the following, purposefully broad, research questions have been set:

**RQ1.** *What are the emerging features of the Industry 4.0 phenomenon in theory and practice?*

**RQ2.** *How do the technological, economic, environmental, social, and organisational perspectives interrelate with each other?*

To answer these questions, a systematic literature review has been performed and, based on it, a novel interpretative framework has been developed for understanding how Industry 4.0 can help to address the three dimensions of sustainability (i.e., economic, environmental, and social), collecting both the critical traits of the phenomenon and its multidisciplinary application areas.

The remainder of the study is structured as follows. In the next section, the methodological approach is described. Then, data analysis and descriptive results are presented. After, the main themes arising from our review are discussed. Last, final remarks and further research developments are presented.

## 2. Methodology

Literature reviews should offer fresh insights into a well-defined research topic, based on a rigorous and transparent methodology [25]. They can be adopted for different reasons, for example, because the existing literature on a concept is fragmented or because an emerging research area requires further expansion [26], to complement an existing body of literature [27], or to conceptually rather than empirically consolidate a specific research field [28]. Accordingly, different approaches can be adopted, depending on the aim of the review and the topic under study. Denyer and Tranfield [29] describe a five-step model in producing a systematic review: question formulation, locating studies, studies selection/evaluation, analysis/synthesis, and reporting/using results. This approach has been explicitly adopted by many authors in management and innovation studies [28,30,31]. Further approaches can be adopted to structure the collected knowledge; for example, [26] employed an inductive approach, designed to organize the core subject matter of articles. Accordingly, the five steps model elaborated by [29], which is synthesised in Figure 2, has been adopted and then applied to an inductive approach to data analysis.

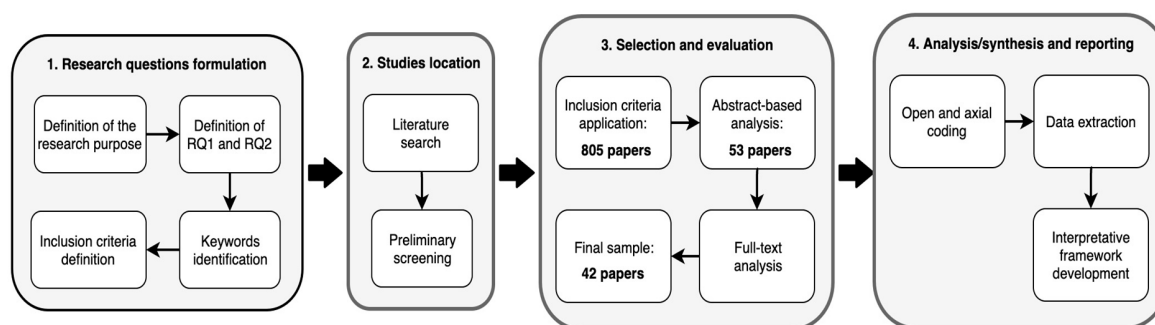


Figure 2. Research design and protocol.

(1) *Research Question formulation.* Due to the current chaos around the topic, an intentionally broad objective is set: assess the range of definitional, conceptual, operational, and theoretical similarities and differences found in the Industry 4.0 research domain.

(2) *Locating studies.* The keyword 'Industry 4.0' is mainly used in Europe, while in the Americas and Asia this paradigm is mostly called 'Smart Factory' or 'Smart Manufacturing'. Therefore, the keywords 'industr\* 4.0', 'smart manufactur\*', 'smart factor\*', 'enterpris\* 4.0', 'smart enterpris\*' have been chosen to be searched throughout the whole manuscript. Wildcards are enabled to avoid issues concerning, for example, plural forms. The search area has been restricted to engineering, computer science, automation and control systems, business, economics, management and accounting, operations research, decision sciences, social sciences and sociology, mathematical methods in social sciences, and psychology. The type of searched articles has been limited to issued or in-press articles with an English version available. Conference papers were not included in the search, as tight length constraints limiting authors' contributions are usually set, although conference papers later published in journals have been considered. Lastly, the search has been limited to papers issued after 2011,

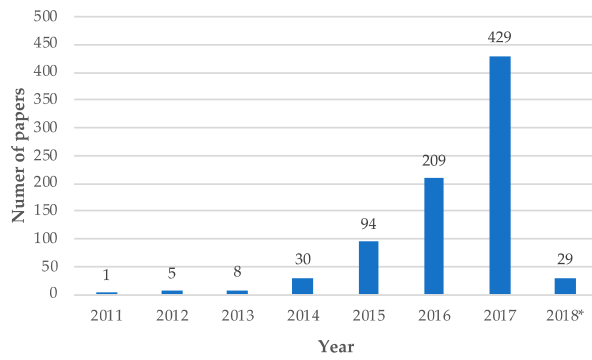
i.e., when Industry 4.0 was defined. To include as many results as possible, the article search has been performed on different databases, including Scopus, Web of Science, Proquest, and Jstor.

(3) *Selection/Evaluation*. A list of contributions fitting the criteria were downloaded from each source on September 30th, 2019. In a preliminary data cleaning, papers found in multiple sources were merged into a single entry. The final sample consisted of 805 articles. Then, the selection/refinement step were split into two sub-steps. First, to refine the sample, a set of definitions were established as reference points. The definitions (i.e., technology, organisation, social impact, economic impact) are presented next, and were explored at the macro and individual company levels. *Technology*: methods, systems, and devices which are the result of scientific knowledge being used for practical purposes. *Organisation*: a social unit of people that is structured and managed to meet a need or to pursue collective goals. All organizations have a management structure that determines relationships between the different activities and the members, and subdivides and assigns roles, responsibilities, and the authority to carry out different tasks. Organizations are open systems—they affect and are affected by their environment. *Social impact*: the effect of an activity on the social fabric—i.e., the composite demographics of a defined area, which consists of its ethnic composition, wealth, education level, employment rate and regional values—and the community and well-being of its individuals and families. *Economic impact*: a macro or micro economic effect on commerce, employment, or incomes produced by a decision, event, or policy. At a macro system level: a set of direct and indirect implications on regional richness, labour, wealth system. At a company level: the cost–revenue effects on the input–output company business model. (Sources: Collins Dictionary, Business Dictionary). An initial, abstract-based analysis was conducted to filter those papers considering Industry 4.0 in a multi-faceted way, i.e., dealing with at least three out of the four perspectives at stake. This selection enabled the identification of 53 papers to be further investigated: their full texts were carefully read and, in some cases, the number of discussed areas was smaller than the abstract-based expectation. Therefore, this second refinement reduced the sample to 42 articles.

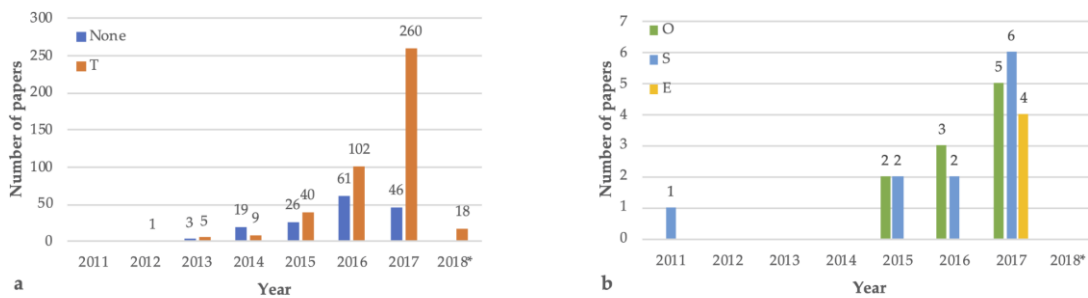
(4) *Analysis/synthesis and reporting*. Once the final corpus was defined, data were synthesised in recurrent themes that were identified by using recognized open and axial coding procedures [32]. Each author separately broke down the data by taking apart a sentence or a paragraph and assigning conceptual labels to each expressed idea (open coding). Then, each author structured the concepts into sub-categories and grouped them into coherent conceptual categories (axial coding). As a final stage, all the authors discussed the emerging subcategories and mutually linked the subcategories. Finally, the conceptual categories were related to each other in a coherent explanatory scheme, as discussed in the following section.

### 3. Analysis and Results

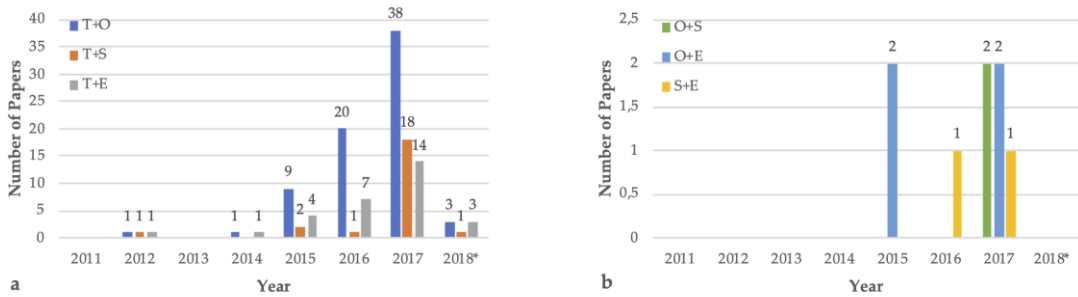
As shown in Figure 3, Figure 4a,b, Figure 5a,b, Figure 6, and Figure 7 (for what regards 2018, only papers published until January, 30th, have been included) the descriptive analysis of the whole sample shows that the scientific community is increasingly interested in this field; the number of published papers is roughly doubled every year. Among them, 155 papers were discarded, either because the focus was out of our scope or because an English full-text was unavailable; in many cases, English abstracts and German full-texts were found.



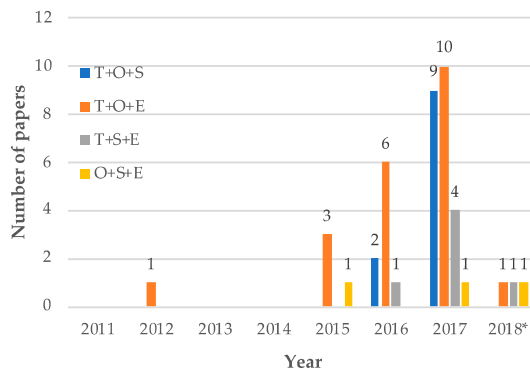
**Figure 3.** Time distribution of the sample. Legend: \* only papers published until January, 30th, were considered.



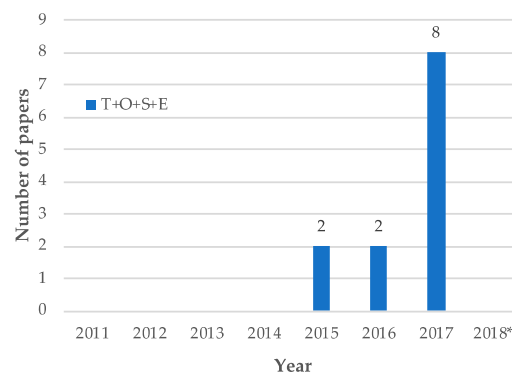
**Figure 4.** (a) Papers dealing with no perspectives or technology perspective (T); (b) Papers dealing with organization (O), social (S) or economics (E) perspectives. Legend: \* only papers published until January, 30th, were considered.



**Figure 5.** (a) Papers dealing with two perspectives, one technological; (b) Papers dealing with two perspectives, but no technology perspective. Legend: T = Technology; O = Organisation; S = Social; E = Economics; \* only papers published until January, 30th, were considered.

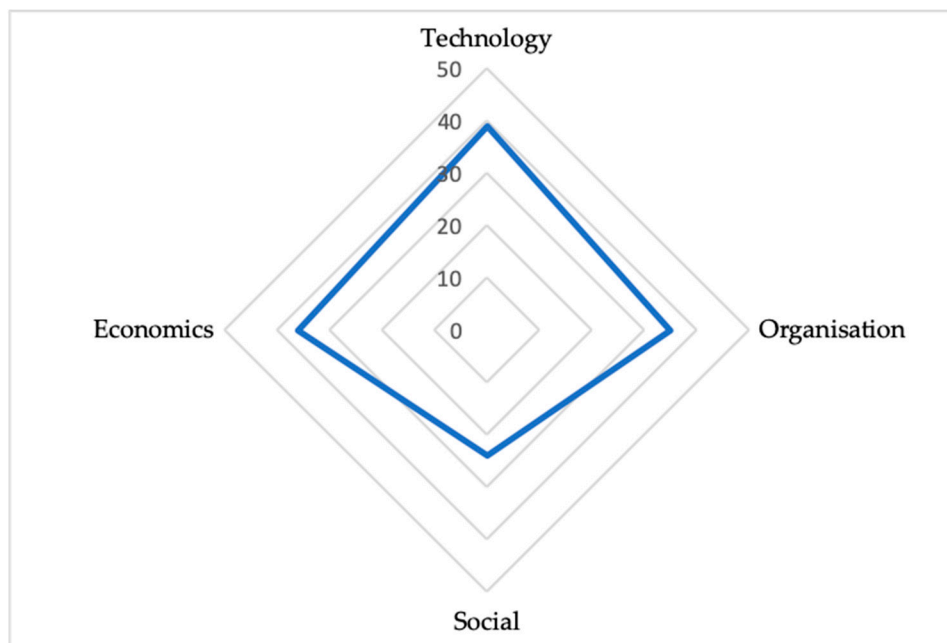


**Figure 6.** Papers dealing with three perspectives. Legend: T = Technology; O = Organisation; S = Social; E = Economics; \* only papers published until January, 30th, were considered.



**Figure 7.** Papers dealing with four perspectives. Legend: T = Technology; O = Organisation; S = Social; E = Economics; \* only papers published until January, 30th, were considered.

In its infancy, Industry 4.0 research had a mere technical focus: 37 out of the 44 papers issued by 2014 dealt with technological topics only and, over the whole sample, more than 50% of the contributions concern technological developments specifically. However, organisational, social, and economic perspectives have recently gained interest. The distribution, by topic, of the selected papers is shown in Figure 8. Indeed, since 2015 an increasing number of multi-perspective analyses have been published; 13 papers matching all of the researched areas have been identified.



**Figure 8.** Distribution of selected paper by topic.

The final sample of 42 papers is detailed in Table 1. Firstly, information on their 103 authors was collected. Most of them are researchers in engineering or technical sciences; only eight scholars in economics and five in social sciences were found. Around one-third of the authors present in the sample are working in German institutions, as a result of the efforts spent by this country in the field. UK, Italy, and the USA presented around 10 authors each and no French researchers were found. Asian authors were found in China, Malaysia, Japan, South Korea, and Taiwan. No contributors from Canada and South America were identified. Information on the number of citations has been collected during the dataset download (2018, January 31st).

**Table 1.** Sample of papers adopted for in-depth analysis. Legend: P = Procedia; J = Journal; T = Technology; O = Organization; S = Social; E = Economics; Emp = Empirical. Citations from Scopus and Web of Science.

Authors (year)	Type	Citations from:		Areas	Methodology
		Scopus Sep 30	Web of Science Sep 30		
Barreto et al. (2017)	P	40	21	T,O,E	Theoretical
Bauer et al. (2015)	P	36	19	T,O,S,E	Emp—Benchmark
Bogle (2017)	J	8	6	T,O,S,E	Theoretical
Caruso (2017)	J	2	2	O,S,E	Theoretical
Davies et al. (2017)	P	11	4	T,O,E	Theoretical
Davis et al. (2012)	J	240	185	T,O,E	Emp—Practice/use cases
Dombrowski et al. (2017)	P	14	4	T,O,E	Emp—Survey
Ganzarain and Errasti (2016)	J	37	25	T,O,E	Emp
Gerlitz (2015)	J	6	-	T,O,S,E	Emp—Multiple case-studies
Hsu (2016)	J	9	9	T,O,E	Emp—Survey
Jensen and Remmen (2017)	P	15	12	T,O,S,E	Theoretical
Kamensky (2017)	J	1	1	T,O,S	Theoretical
Kamp et al. (2017)	J	11	6	T,O,E	Emp—Single case-study
Kiel et al. (2017)	J	43	29	T,O,S,E	Emp—Multiple case-studies
Kuch and Westkämper (2017)	P	1	1	T,O,S	Theoretical
Li (2018)	J	71	55	T,S,E	Emp—Survey
Mazali (2018)	J	2	3	T,O,S	Emp—Single case-study
Müller et al. (2018)	J	54	38	T,O,E	Emp—Multiple case-studies
Oesterreich and Teuteberg (2016)	J	119	81	T,O,S,E	Theoretical
Ooi et al. (2018)	J	3	16	T,O,E	Emp—Survey
Pereira and Romero (2017)	P	39	25	T,O,S,E	Theoretical
Peruzzini et al. (2017)	J	8	8	T,S,E	Emp—Quantitative case-study
Peruzzini and Pellicciari (2017)	J	21	12	T,O,S	Emp—Prototype + Use case
Präuse (2015)	J	34	-	T,O,E	Emp—Multiple case studies
Reuter et al. (2017)	P	9	8	T,O,S	Emp—Prototype
Roblek et al. (2016)	J	110	76	T,S,E	Theoretical
Roy et al. (2016)	J	77	53	T,O,E	Theoretical
Sackey and Bester (2016)	J	15	8	T,O,S	Emp—Survey
Salento (2018)	J	2	1	T,O,S,E	Theoretical
Sanders et al. (2016)	J	79	46	T,O,E	Theoretical
Sferra (2017)	J	0	0	T,S,E	Emp—Use case
Shamim et al. (2017)	J	16	11	T,O,E	Emp—In-depth interviews
Siemieniuch et al. (2015)	J	31	22	O,S,E	Emp
Sung (2018)	J	32	22	T,O,S,E	Theoretical
Synnes and Welo (2016)	P	0	0	T,O,E	Emp
Trstenjak and Cosic (2017)	P	15	8	T,O,E	Emp—Prototype
Vogl et al. (2016)	J	22	32	T,O,E	Theoretical
Waibel et al. (2017)	P	24	19	T,S,E	Theoretical
Walsh et al. (2017)	J	4	3	O,S,E	Emp—Single case-study
Yao et al. (2015)	J	24	15	T,O,E	Emp—Practice/use case
Yao and Lin (2016)	J	32	19	T,O,S,E	Theoretical
Youssef and Youssef (2015)	J	2	-	T,O,E	Emp—Survey

Few articles have a strong methodological design. However, albeit often only superficially designed, the sample is mostly made of empirical studies (25 out of 42). Among them, use-cases (4 papers), single or multiple-case study designs (8), surveys or benchmarks (7), in-depth interviews (1), prototypes (3), and empirical contributions with no clear methodology (2) were found. The remaining 17 papers mainly review previous works or present conceptual frameworks.



In the following, a comprehensive analysis is made on the 42-paper sample to define the Industry 4.0 phenomenon and the involved industry sectors.

### 3.1. *Shedding Light on a Foggy Concept and Its Cross-Industry Boundaries*

Besides being a non-consensual concept [23,33,34], 'Industry 4.0' is also a non-consensual term: similar phenomena are also denoted through the terms 'smart manufacturing' [35–41] or 'smart systems' [30]. However, according to Davis et al. (p. 146) [35], 'smart manufacturing envisions the enterprise that integrates the intelligence of the customer, its partners and the public'; thus, a smart factory is the physical result of smart manufacturing [35,42–44]. Smart factories are also recognised to be socio-technical systems, as they involve complex interactions of people and technology within the workplace [42,45–47].

Some authors state that 'Industry 4.0' is a new paradigm or a paradigm shift [37–39,45,48–50]. A common opinion is that 'Industry 4.0' is the 'Fourth industrial revolution' [40,42–44,51–56]. However, as noted particularly by Sung [34] and Li [57], Industry 4.0 is not the Fourth Industrial Revolution; it is rather the strategic plan—first introduced by Germany in 2011—stimulated by the Fourth Industrial Revolution. Furthermore, the term 'fourth industrial revolution has been applied to significant technological developments over the years' while Industry 4.0 'specifically focuses on manufacturing in the current context, and it is thus separate from the fourth industrial revolution in terms of scope' (p.2) [34].

From a technological perspective, all the authors agree that the underlying idea of the smart factory is the connection among physical systems, software, and Internet of Things (IoT) systems within the firm, as well as among companies. It also implies a new level of organisation and control over the entire product lifecycle value chain [52,57], both directly and remotely, by using integrated digital devices and thus allowing continuous adjustment of production and consumption cycles [56].

The analysis highlights that, while initially focused on the manufacturing sector only, Industry 4.0 has recently started to broaden its boundaries to other sectors and industries. It now appears to embrace every industry and sector and concerns the way any company employs the digitisation process in their business models [23,45,51,58]. In our sample, a few non-manufacturing related papers have been found. Oesterreich and Teuteberg [59] explored state of the art and practice of Industry 4.0 in the construction industry, while some research focused on (i) logistics and supply chain or maintenance services [48,51,60], (ii) tourism and hospitality [61], (iii) and Prognostics and Health Management [39].

Therefore, this topic should be considered from the point of view of different industries (e.g., logistics, tourism, healthcare) and areas (e.g., strategic approaches, management control systems, organisational structures, enterprise resource planning), as it involves the company vision, policy, strategy, organisation, processes, and business culture, regardless of reference sector [58,61].

### 3.2. *Emerging Themes*

The inductive analysis led to the identification of four themes emerging from the ground of our study, which are synthesised in Table 2. A comprehensive discussion is provided in this section.



**Table 2.** Coverage of the themes that emerged from the literature.

Topic	Sub-Category	Papers (n)	% (N = 42)	Author(s)
Novel images of work and workers	Role of workers	7	16.67%	[33,45,46,56,62–64]
	Skills and competences	6	14.29%	[33,42,47,49,59,65]
Transformative business models	Customer and service centred business models.	9	21.43%	[32,36,40,45,50,53,54,58,66]
	Integrated and networked business models.	4	9.52%	[32,53,55,58]
	Sustainable business models	5	11.90%	[37,44,65,67,68]
The organisational transformation	Fragmentation, self-organisation, and fractals	7	16.67%	[33,50,56,60,68–70]
	The organisation of employees and organisational culture	8	19.05%	[32,34,38,42,45,49,59,65]
	Organisation of intra-company activities	3	7.14%	[32,45,52]
	The organisation of extra-company activities	7	16.67%	[32,40,42,43,55,58,71]
Training and educational patterns		4	9.52%	[35,42,60,72]

### 3.2.1. Novel Images of Work and Workers

Industry 4.0 would seem to induce a general workforce reorganisation [56]. In this vein, two major research streams can be identified: (i) the role of workers in the smart factory and (ii) the skills and competences they will be required to have. However, the topic is controversial [56,62] since technologies neither create prosperity nor foster unemployment by themselves. Moreover, the real impact of digitalisation on employment rates, work conditions, performance, and relationships can hardly be predicted.

*The role of workers.* Digital work has many ambivalences, as critically discussed by Caruso [62]. The individualisation of the employment relationship, job insecurity, the pressure for competition among workers exerted by firms, and the only rhetorical request to participate in horizontal decision-making processes are only some of the issues identified by the author. Notably, this last invitation may be only function to reorganise command methods and contribute to a general reinforcement of vertical decision-making processes. Further, Mazali [45] stresses the rhetoric of collaborating workers in co-responsibilisation practices, stating that the same participation rhetoric can be found within the broader society. She then focuses attention on the importance of corporate background; a company with rooted practices and culture has to strategise and carefully incorporate a digital, flexible production model. Thus, teams and tutors linking different generations of workers will have to spread the smart production paradigm among the community of workers. Salento [56] also envisions a potential ‘re-appropriation’ of autonomy for workers; the adoption of technology is a decision made by upper management, but workers can shape it by inventing alternative uses.

The work of Bauer et al. [63] posits flexibility as the key feature of different tools for the adjustment of personnel capacities and timely response to Industry 4.0 demands. Flexibility will impact on time and space involvement (e.g., working times, hiring out, secondment) and content-related factors (e.g., job rotation, multi-skilling). Business-specific flexibility strategies must be systematically designed, organised, and targeted toward the long term, in cooperation with employees or specific categories of workers. As an example, Peruzzini and Pellicciari [64], underline the need to focus on issues concerning aged workers and consequently target companies’ strategies.

To foster the connection between industry and society, Reuter et al. [46] envision smart factory workers as ‘industrial citizens’, empowered and able to participate in designing and implementing technology within their factories. Mazali [45] proposes the ‘resilient worker’ paradigm, a participative,

resilient, and proactive employee, as opposed to the twentieth century resistant or reactive factory worker. The novel interactions between operators and machines and the coexistence of humans and robots pushed Pereira and Romero [33] to predict the ‘augmented operator’, a role strictly related to the worker’s technological support that is required in the new working environment. Lastly, Caruso [62] proposes the idea of the ‘empathic robot’, as the few workers not replaced by automation will likely be a kind of intersection between men and machines. In fact, they will be endowed with very high technical, informatics, and computational skills, as well as relational and communicative skills, resulting in kind of empathic robot-workers.

*Skills and competences.* Corporate workforces increasingly need IT skills, particularly in modelling and simulation, problem-solving, distributed team-working [49], as well as interdisciplinary thinking and skills in social and technical domains [33]. Oesterreich and Teuteberg [59] highlight the need to integrate different skills and Yao et al. [47] strengthen this idea by proposing a ‘Wisdom Manufacturing’ system designed to support humans through a holistic vision, centred on skills integration, with explicit and tacit knowledge.

Interestingly, Davies, Coole, and Smith [42] identify the main challenge in the change in interactions among people at each organisational level, and the technical system. The executives will need closer relations with the operational level. Thus, conventional relationships—mainly aimed at controlling workers—will probably be replaced by workers’ active engagement. Moreover, ‘it is likely that the management hierarchy divisions will become blurred leading to a more homogeneous sharing of knowledge’ (p. 1293) [42]. In the new environment, operational level workers will shift from being passive agents to being knowledge workers. Industry 4.0 could foster an additional form of knowledge professional, who will be ‘multi-faceted and will include advising each distinct discipline on the optimal course of action to maintain alignment within the heterogeneous network and particularly to the dynamics of the customer base and market trends’ (p. 1294) [42]. Similarly, Kiel et al. [65] forecast an enhanced demand for skilled workers, able to plan, monitor, and supervise manufacturing processes and facilities. The new environment will finally be ideally characterised by open-minded mentalities, flexibility, and collaborative dynamics facilitating vertical and horizontal connection throughout the supply and value chains.

### 3.2.2. Transformative Business Models

Industry 4.0 may offer opportunities for innovative business models (BMs) based on new products and services, better ways to serve customers, and improved integration across and along the value chain [23,65–67]. Three prevailing research streams emerged in our analysis: (i) customer and service centred BMs, (ii) integrated and networked BMs, (iii) and sustainable BMs.

*Customer and service centred business models.* Digital, connected technologies enable the development of novel BMs relying on data-based products and services [36,45,51,55] promoting, in turn, increased customer orientation based on closer relationships [23,56,66] and involvement in value creation, starting at the design phase, to best match market needs [40]. This approach leads to a more responsive and agile system, supported by technologies, such as additive manufacturing, that enable enhanced flexibility and mass customization capabilities, allowing the profitable production of tiny series or even one-piece-batches and offering economies of scale and scope [40,58]. Data technologies enable companies to gather after-sales feedback and achieve deeper customer understanding [45], as well as to approach a service-based BM. So, companies can integrate their offer with novel services, in addition to physical objects, to improve business operations’ efficiency, revenue growth, and competitiveness [42,50]. However, to move towards ‘servitisation’, a company must be able to determine relevant metrics; capture and transmit data; understand the available datasets; and build trustworthy, mutually beneficial relationships between users and producers to make data accessible [58].

*Integrated and networked business models.* Advanced analytics and cloud computing promote interactions across the horizontal and vertical value-chains, enabling suppliers, customers, institutions, investors, and research entities to integrate information from many different sources to support

effective decision-making [58]. In this way, they can result in improved agility when responding to environmental changes [55], in predicting new conditions rather than only reacting to them [53], and increasing aptitude to thrive in a completely new and competitive market [23]. Further, open, innovative design approaches can serve to develop new products or services in a collaborative manner [53], as shown by the strategies of German small and medium enterprises (SMEs) [23]. In this field, governmental and industrial initiatives can help SMEs by bringing together companies with complementary capabilities.

*Sustainable business models.* A general concern regarding the objectives of sustainable operations, environmental protection, and process safety, is emerging [37,65,67]. Scholars highlighted that sustainability and Industry 4.0 are linked twofold. On the one hand, Industry 4.0 can promote sustainable development by assuring the preservation of resources on behalf of future generations [67]. On the other hand, environmental, economic, and social sustainability are crucial for companies willing to effectively compete in the current scenario and are thus pushing technological and industrial developments [65,68].

Further, a more sustainable model, driven by the circular economy principles, extends the responsibility of the manufacturer throughout the product lifecycle. Jensen and Remmen [67] analysed how different ‘product stewardship’ (a term interlinked with the concept of ‘extended producer responsibility’) and ‘end-of-life’ strategies can support the circular economy. Nonetheless, research is mainly focused on environmental sustainability, i.e., reducing waste, overproduction, and energy consumption through intelligent energy management systems and network technologies [44]. Indeed, effective adoption of the Industry 4.0 technologies could foster sustainability at a higher level by reshaping organisations, strategies, policies, and operations [37]. Digital technologies can transform the means of designing, producing, delivering, recycling, and discarding products [44], promoted by tools for sustainability evaluation. In this vein, Peruzzini et al. [37] proposed a new Social Life Cycle Assessment (S-LCA) methodology to support enterprise modelling and knowledge management aimed at assessing company sustainability—including social impacts—in the context of smart manufacturing.

### 3.2.3. The Organisational Transformation

The transformation induced by the Industry 4.0 cannot disregard changes in the organisation models, as confirmed by Kiel et al. [65]: they interviewed 46 German managers in different manufacturing fields, and more than half agreed there was need for an organisational transformation to make the Industrial IoT operational. The debate mostly concerns four topics: (i) the models for company organisation and fragmentation, (ii) the organisation of employees and corporate culture, and the organisation of (iii) intra- and (iv) extra-company activities.

*Fragmentation, self-organisation, and fractals.* Disruptive technologies promote novel control and coordination capabilities to remotely manage work and exchange information, resulting in a separation between organisation and localization [33,56]; further, automation and digitisation enable a reduction in the overall impact of labour cost. Therefore, many Western companies are discouraging delocalization to low-cost countries by triggering investments to increase in-house production [50] and promote a decentralised ‘self-organisation’ model based on hierarchy decomposition [60]. Dombrowski, Richter, and Krenkel [69] enrich this idea through the term ‘self-optimization’ and Prause [55] further adds the concept of ‘fractals’. In its original formulation [57], a fractal enterprise is characterised by self-similarity, self-organisation, self-optimization, goal-orientation, and flexible and adaptable manufacturing organisation. In this vision, intrapreneurship—that is the innovative act of employees behaving like entrepreneurs within their organisations—acts as a further success factor. Fractal organisations are timely, optimal structures, changing their shape according to local needs, linked via high performing ICT systems and individually deciding on the type and scope of available access to their data. Prause (p. 162) [68] stresses the coherence between the fractal concept and sub-organisation in smart factories. He concludes that ‘fractals can be considered as the new structural and organisational

building blocks of Industry 4.0, where the different fractals are connected by related information flows, which control the processes inside and between the networks and the fractals.

*The organisation of employees and organisational culture.* Davies, Coole, and Smith [42] define Industry 4.0 as a 'socio-technical system' to stress that humans in the system hold complex interactions with machines and the surrounding environment. All organisation levels are involved in the implementation of new technologies, through in-depth re-evaluation and re-engineering of business practices [59]. Furthermore, a shift in focus from tasks to accomplish towards roles to perform will take place. Roles, authorities, responsibilities, and skills will be largely rearranged and re-distributed [49].

Cultural barriers must be considered when redesigning a company organisation and corporate culture must support the Industry 4.0 adoption [23,65]. Indeed, resistance, reluctance to change, and emotional reactions may significantly affect the adoption of smart factory technologies [34,38]. So, a knowledge and culture upheaval is necessary to redesign products, incorporate recycling considerations, create new processes and their associated technology, and create new jobs [49]. In this vein, Mazali [45] discusses a 'participatory culture' focused on workers participation, concerning the new models of the relationship between top management and workers and the participation in decision-making and operational processes in work organisation. The lean model can be seen as one of the most famous examples of this. However, none of the authors really expanded on the organisational culture issues and its implications with respect to smart factory principles at a theoretical level, nor at a practical one.

*Organisation of intra-company activities.* As previously discussed, company executives will need closer relationships with the operational level; however, this implies that they will need to know the right questions to ask and understand the answers they are given. Therefore, the conventional relationship of a management system, where workers are predominantly controlled, will give way to active engagement, based on a mutual knowledge transfer between the management and operational levels that enables collective decision-making processes [45]. This shift is even more important for SMEs, which often adopt conservative investment strategies and tend to avoid being early technology adopters. In fact, many SMEs cannot afford experts in Industry 4.0 and, therefore, require support from governmental institutions to understand the necessary prerequisites [23,53]. The authors explain that the exploitation of Industry 4.0 benefits requires, besides significant investments, a transformation in corporate structure and culture: open-minded, flexible, collaborative environments and systematic discussions to innovate established routines are necessary.

*The organisation of extra-company activities.* Smart technologies enable a further layer of information exchange in the provider–user relationship [58] which can promote connections within a value chain and improve agility in responding to environmental changes [55]. To exploit such an advantage, businesses have to organise networks with other firms accurately and coordinate with each other to ensure that the correct information is available for the targeted users [71]. Moreover, they have to deal with new technical, ethical, and legal approaches: sensitive data about production and business have to be carefully handled, as companies are responsible for data security in their own organisation, as well as for supply chain partners [23]. Similarly, the novel ICTs enable diverse forms of customer involvement. Yao and Lin [40] propose the 'social manufacturing' approach: social computing, social networking software and online communities are exploited to produce novel products or services, that meet customers' needs in an innovative, collaborative way with a short time to market.

The organisation of intra-and extra-company activities, along with the employees' involvement, are presented with a holistic view by the Lean manufacturing approach. According to this paradigm, tight relationships among company employees, as well as with customers and suppliers, are to be defined in order to share product expectations and expertise. Nonetheless, only a few authors [42–44] approach this topic.

### 3.2.4. Training and Educational Patterns

Since the early stage of Industry 4.0 development, the need for appropriate educational and training approaches has been debated. Indeed ‘there is considerable need for focusing education and training so that the science, engineering and operating practices for Smart Manufacturing and the necessary skills and expectations for the workforce are always in concert’ (p.154) [35]. Roblek, Meško, and Krapež [60] state that approaches for education and employees’ development must be adapted according to the transformation of job profiles. Sackey and Bester [72] focused on the skills required by new industrial engineers, and based on a literature review identified the following seven crucial areas:

- (i) Data science and analytics, as complex datasets are increasingly adopted to optimise production quality and support real-time decision-making;
- (ii) Advanced simulation and virtual plant modelling, to early evaluate the performance of optimizations and resources settings;
- (iii) Data communication, networks, and system automation, to increase the capabilities in problem-solving;
- (iv) Human–machine interfaces, since robots are expected to be widely adopted to work in cooperation with humans (the ‘Robot coordinator’ will be a likely new job);
- (v) Digital-to-physical transfer technologies, such as 3D printing, as they enable the manufacture of complex parts, eliminating the need for assembly operations and reducing inventories of spare parts;
- (vi) Closed-loop integrated product and process quality control/management systems, as automated, data-driven systems for quality control will enable the quick solution of issues;
- (vii) Real-time inventory and logistics optimisation systems, as novel traceability technologies such as RFID enable the monitoring of parts throughout the production chain.

However, besides novel topics, new education formats are expected to educate students of the smart enterprise. Sackey and Bester [72] envision a laboratory-based format in flexible production systems and virtual environments. Nonetheless, new working disciplines are still to be discovered and will become more evident as the implementation of Industry 4.0 matures [42].

Currently, the digital revolution is driven by technical experts, data analysts, managers, and knowledge workers at the operational level. An additional form of knowledge professional will likely emerge in the near future, capable of merging the essential elements of each discipline, thus providing an informed and holistic view of the system.

## 4. Discussion

In an attempt to shed light on Industry 4.0 a lot of ideas and, in some cases, conflicting opinions have been found. First, Industry 4.0 appears to be an umbrella term denoting a supposed new industrial paradigm, embedding a strong potential for organisations which, besides industry transformation, will impact the design of products and services, business models, markets, economy, work environment and skills development. Industry 4.0 results in the ‘smart factory’, namely a socio-technical cyber-physical system for the complex interaction between smart manufacturing technologies and people where Industry 4.0 principles physically take shape. Second, Industry 4.0 does not concern only ‘manufacturers’ anymore. Rather, it is about the ways in which digital technologies are brought together, and, specifically, how organisations can harness them to drive competitive business models, market and sustainable growth. It goes beyond the realm of manufacturing and production to focus on the entire ecosystem of partners, suppliers, customers, the workforce, and operational considerations. Therefore, a shift in the application of the term ‘smart’ from merely industrial fields (smart manufacturing, smart factory) to the whole enterprise can be observed and, in turn, the Industry 4.0 paradigm is evolving into an emerging Enterprise 4.0.



In the former section, four themes emerged from the analysis shown. In the following sections, they will be further discussed to answer **RQ1**: *what are the emerging features of the Industry 4.0 phenomenon in theory and practice?*

#### 4.1. Smart Middle Managers and Augmented Resilient Workers

Sixty years ago, in a brilliant and futuristic work, Leavitt and Whisler [73] predicted how the pervasive introduction of the ICTs would change top and middle management in middle- and large-business firms. They foresaw a future organisation with few middle managers—comprising mainly ‘routine technicians rather than thinkers’—with the separation between the top and the middle organisation levels drawn ‘more clearly and impenetrably than ever, much like the line drawn in the last few decades between hourly workers and first-line supervisors’ (p. 44) [73]. Therefore, in recent decades, cutting criticism permeated middle management roles and technology became a means to reduce the number of hierarchical levels [74]. Nonetheless, some authors here highlighted the reverse of this trend, as they foresaw—albeit implicitly—the rise of a new professional role resembling that of the ‘neglected’ middle manager. Mazali [45] recognises a form of ‘tutors’ linking different generations of workers and, consequently, in charge of incorporating and spreading the new smart production models. Davies, Coole, and Smith [42] and Kiel et al. [65] predict a managerial knowledge professional, able to merge elements of different disciplines and provide an informed holistic view of the system. These considerations highlight the need for a new professional acting as an informed connection point between the old and the new, and between the operational and the top levels. This new, multi-faced knowledge worker can be named a ‘smart’ middle manager, due to the attitude required to fluently move into the new ‘viscous’ pervasive technological environment. Workers at operational levels are supposed to consistently change, as well. As new, industrial citizens [46], these workers will be participative and proactive—i.e., resilient [45]—provided with technology increasing their capabilities—i.e., ‘augmented’ [33]—and required to combine technical expertise with relational and communicative skills—i.e., ‘empathic’ [62].

#### 4.2. Innovative Business Models: Sustainable, Customer and Service centred, Integrated and Networked

To date, research has contributed to the identification of novel business modelling approaches to exploit disruptive innovations triggered by Industry 4.0, but does not discuss in depth how to put them into practice.

Industry 4.0 technologies promote interactions between every point of a value-creation network, enabling stakeholders to integrate information from many different sources to make better decisions [44,58], affecting the way customers, consumers, employees, suppliers, and other partners of the business landscape expect to integrate their experience and interact [51,53]. The flexibility promoted by digitisation enables customised mass production through data-driven products and services [36,40,50,58], while the integration of customers into the value chain enables the adaption of the final product to individual tastes by choosing from a wide range of options, as customers become active participants in the value creation process or even co-producers [40,45].

Innovative technologies potentially foster sustainability [65,67,68,75] and a recent research stream has shown how appropriate business modelling approaches enable the profitable exploitation of sustainable value creation [76–78]. Inigo, Albareda, and Ritala [79] distinguish two ways to approach business model innovation for sustainability purposes. First, evolutionary approaches, based on adjusting value creation to respond to the changing environment and gradually incorporating sustainability objectives in the market. Second, radical approaches, based on introducing a completely new value proposition either to match a new sustainability challenge or to tackle an issue in a radically novel manner. The former approach is preferred by well-established, large companies, while the latter is most suitable for novel companies or spin-offs.

More generally, business models are no longer fixed, and technological solutions can offer a sound basis for continuously evolving approaches to exploit the strategic opportunities presented by the

business environment. Accordingly, in recent years, new ways of adapting business models to market opportunities, leveraging on disruptive technologies, have been described and applied. Concerning the Industry 4.0 challenges, one promising model could be self-tuning, proposed by Reeves, Zeng, and Venjara [80] and first employed by the start-up company Alibaba. The self-tuning model leverages the basic principles of algorithms to continuously retune or refine the strategy, organisation, and business model of the enterprise. It monitors, analyses and takes action, therefore it continuously improves the model by testing (discovering what works) and adapting it according to the surrounding environment. Similarly to the model, experimentation and innovation, generally limited to products and services, are also applied to the business model domain. Further, the self-tuning model perfectly matches the idea of fractals and the self-organised enterprise depicted by some authors in our sample.

#### *4.3. The Open, Fractal, Lean Organization*

Organisational culture and technology adoption have been recognised as two of the most critical issues that today's organisations are facing [81]. Companies have to focus not only on existing cultural attributes that promote successful technology adoption, but also on the ones that can slow or halt success. Firms seriously concerned with cultural issues may be supported by technology to build a greater company culture [82]. From this perspective, lean manufacturing can play a key role. This is an approach to organise production activities, aiming to provide customers with the best possible value by—ideally—eliminating non added-value activities [83] that mostly rely on continuous improvement routines involving company management and workforce, rather than advanced technological tools only [42]. The Lean approach can play a twofold role in a smart factory environment. The systematic identification of added-value processes promotes the adoption of Industry 4.0 technologies, but only on worthy operations. In turn, the Industry 4.0 technologies trigger the adoption of Lean practices: information systems enable people (employees, customers, suppliers) to tighten relationships, share knowledge and provide feedback to improve process and product quality, review established practices, and enhance safety. Further, traceability technologies enable the real-time monitoring of inventories, improve production planning and promote the Just-in-Time paradigm [42,43]. The Lean approach, however, must be framed within an open and self-optimised organisation model capable of fostering the Enterprise 4.0 approach. The adoption of open fractals, relying on optimal and timely structures, able to digest the information flow coming from the digital technologies and change according to local needs, can support this process. Further, a fractal-related concept is intrapreneurship; this idea grounds the employee-driven innovation (EDI) approach. EDI implies conceiving all the employees as users and designers of innovations developed in their organisation and can be included within the 'open innovation' model [84,85], which involves actors at different levels, including employees, users, communities, public administrations. Further, EDI has outcomes relating to human resource management, intellectual property (IP), business models and customer interface, and governance structures [86]. Nonetheless, proper approaches for IP protection must be adopted, especially in design-intensive industries [87].

#### *4.4. Technology-Related and Laboratory-Based Educational Paths*

The analysis of the educational and training aspects highlights the need for a specific education approach to promote the Enterprise 4.0. However, most of the research is focused on training engineers (e.g., through learning factories). Conversely, no authors highlighted the importance of other disciplines, such as economics, law, labour psychology or sociology. Interestingly, no contributions that concern the training of professionals and long-life learning were found in the sample, despite a general call for a multidisciplinary approach and soft skills necessary to workers 4.0.

Beyond our sample, the novel roles envisaged for humans pushed academics to propose different competence models to support the smart factory. The work of Pinzone et al. [88] identified five key skill areas that an Enterprise 4.0 cannot disregard: (i) operations management, including ICT tools and human resources management; (ii) supply chain design and management; (iii) product-service



innovation management, design and analysis; (iv) data science management, design of appropriate architectures and analytics; (v) management and integration of information and operations technologies.

The work of Curia Piñol et al. [89], Fantini et al. [90], Hecklau et al. [91] explored the operators' perspective and identified skills belonging to three main areas: (i) technology, as operators have to proactively deploy the Industry 4.0 technologies and understand processes, thus needing coding skills to program devices and IT knowledge to comprehend possible issues and safety risks; (ii) methodology, as operators will need creativity, problem-solving and decision-making abilities, capabilities in sharing knowledge, entrepreneurial thinking and business management; and (iii) personal skills, such as flexibility, adaptation to changes, autonomy, leadership and teamworking. The importance of languages is also highlighted, as the internationalization of value chains is increasing, along with work environments that are now composed of people with different cultural backgrounds.

These afore-discussed features, together, promote a shift from Industry 4.0 to the Enterprise 4.0: a supposedly smarter enterprise characterised by informed middlemen and resilient workers, as well as business models that are customer- and service-centred, integrated and networked, and sustainable. Further, this enterprise is self-organised and lean, with open organisational cultures and structures, along with participative and agile management styles, and its employees are trained through new technology-related and laboratory-based educational paths.

#### 4.5. An Enterprise 4.0 Framework Proposal

To answer RQ2—how do the different elements of the phenomenon—the technological, economic, environmental, social, and organisational ones—interrelate with each other?—four key recurring concepts, that act as a baseline for the future smart enterprise have been identified. The different perspectives were then connected and a different meaning, depending on the application theme, has been assumed: integration, decomposed hierarchy, flexibility, autonomy. They have been collected in a framework, which is shown in Figure 9.

*Integration* involves all the discussed themes. Workers are increasingly required to integrate different hard and soft skills, while work has to promote distributed teamwork and interdisciplinary thinking. Appropriate education and training patterns are necessary to support this transformation: different kinds of expertise are to be combined to educate different job profiles, and an additional form of knowledge professional will emerge in the next future, capable of further combining the essential elements of each discipline. Integration plays a twofold role in business modelling. Horizontal integration across and along the value chain enables the creation of an ecosystem of cooperating companies; vertical processes integration within a company promotes the flexibility and adaptability of manufacturing systems. Both horizontal and the vertical integrations are empowered by the analytics of production processes and services, and must be supported by an appropriate organisational approach; strategic, innovation management and open innovation principles have to be explored, for a practice-oriented design integration approach in developing new products or services. At the organisational level, more 'integrative' and participative leadership styles are necessary to promote workers' increased autonomy, creativity and participation. Integration also relates to organisational culture issues, as the participation of all the workers is further stressed. This culture will concern the new models of relationship between top management and workers.

*Hierarchical decomposition* mainly applies to work and workers' issues and organisational transformation. In a work organisation, the executive firm level will need a more direct relationship with the operational level. Therefore, workers' active engagement with a mutual knowledge transfer between the management and the operational levels will be crucial. The decentralization dynamics also fit with a decomposition of the classic production hierarchy, leading to a flatter organisation.

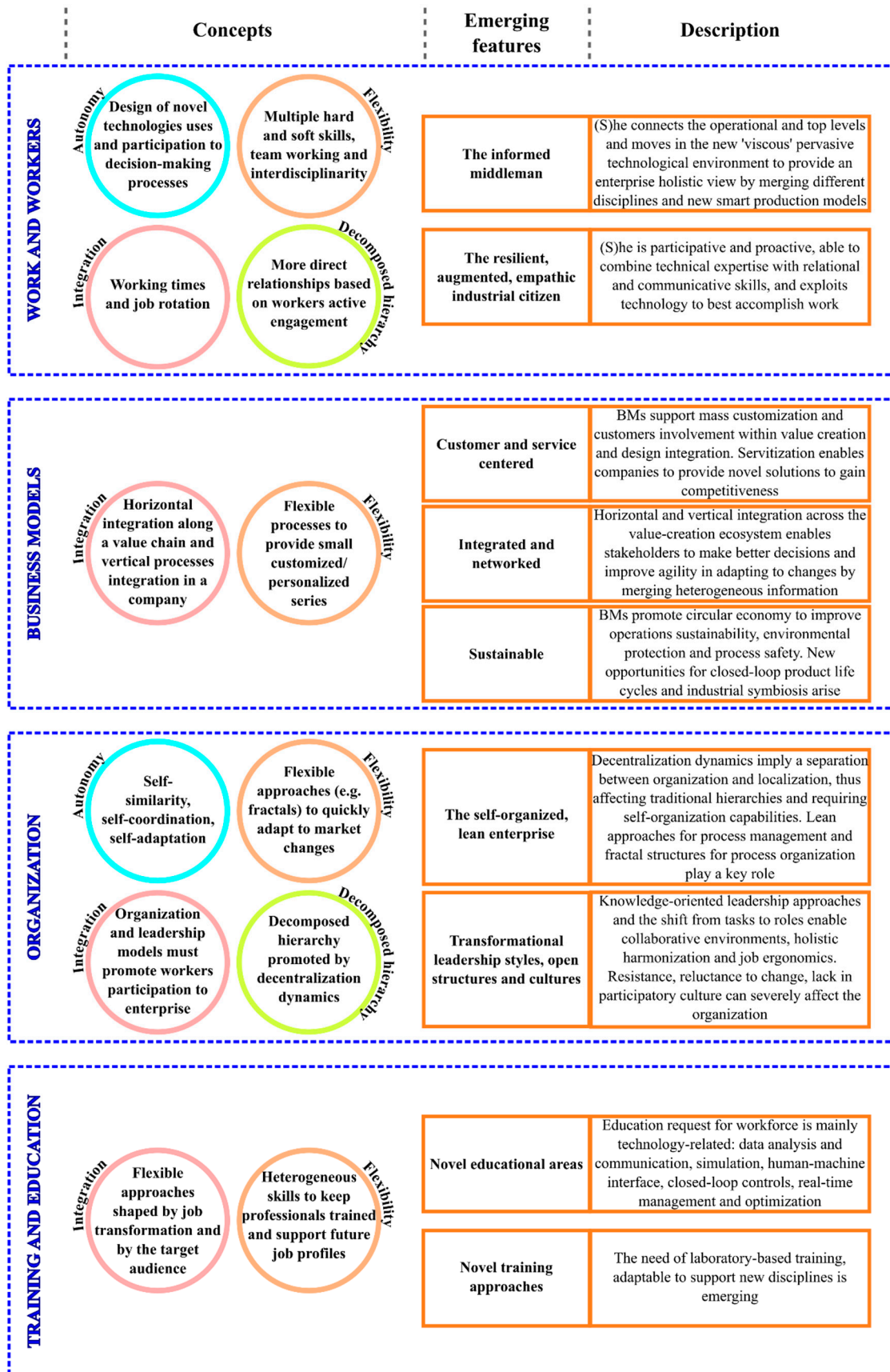


Figure 9. The interpretative framework.

*Flexibility* involves all these themes. Industry 4.0 technologies enable flexible management of workers' capacities and working times, as well as content-related factors, such as job rotation, multi-skilling, and spatial flexibility. Work organisation must be adapted to best exploit these novelties. In business modelling, flexibility promotes customised mass production, and implies the profitable personalization of small scale products or services. Organisational flexibility concerns the adaptive approaches required to more quickly respond to market changes; fractals are flexible by definition, as they represent timely and optimal structures, that change their shape according to their local needs. Lastly, flexible approaches for education and employees' development must be designed, and adapted according to the transformation of job profiles and to the target audience, to promote lifelong training programmes.

*Autonomy* concerns both work and workers, and the organisational transformation. Smart enterprise employees will experience a kind of 're-appropriation' space of autonomy, as workers will concretely design alternative uses of a technology. Further, they will experience higher potential autonomy and levels of participation in decision-making processes. In the organisational transformation, conversely, autonomy refers to 'self-adaptation' and goes along with vertical and horizontal integrations, information consistency, flexibility, monitoring, traceability, real-time locating, visualization, and digitalisation. The 'autonomous' enterprise thus exhibits self-similarity, self-coordination and self-adaptation.

These four concepts, along with the identified emerging features, are crucial for the definition of an Enterprise 4.0. Companies paying attention to such concepts will have the opportunity to surf the Industry 4.0 wave with outstanding performances from organisational, economic, social, and technological standpoints.

## 5. Conclusions

This research develops a theoretical analysis, contributing to the whole body of literature related to the emerging issue of Industry 4.0. Notably, the phenomenon has been analysed with a multidisciplinary lens, advancing the business and organisational knowledge related to this novel topic. In particular, the authors outlined an emerging Enterprise 4.0 paradigm—embodying the evolution from a technocentric vision to a holistic one—along with its distinctive traits. The practical contribution of this paper also relies on the developed framework, which can help both managers and policy-makers embrace the Industry 4.0 paradigm. The following features of the phenomenon have been identified: an involved and resilient workforce, alongside 'smart' middle managers; sustainable, networked, and customer-centred business models; a lean self-organisation; and participative leadership styles. The research aimed to identify the inner connections between such themes. Integration, hierarchical decomposition, flexibility and autonomy were found to be the recurrent, common concepts, and the framework was defined to outline a potential future, where Industry 4.0 encompasses the Smart(er) Enterprise. Thus, the smartness of a company will probably depend on its ability to concretely adopt these features and concepts, and policy-makers could be helped to understand their role in shaping Industry 4.0, and fostering innovation and economic growth. However, this research suffers some limitations, which open the field to future research. The first limitation is related to the keywords which have been chosen in this research. For instance, the inclusion of words such as "digital transformation" and "digitalization" could have led to different and more comprehensive results. However, in this research they have been excluded, in order to narrow the focus of the results on the specific paradigm of Industry 4.0. Another limitation regards the choice to analyse only those papers that are compliant with at least three out of the four topics considered (i.e., technology, organisation, social, and economics). Finally, the proposed framework, which is, to date, purely theoretical, may be further validated by the analysis of case-studies.

Since the phenomenon is relatively young, several policy-making efforts by national and local governments can be observed worldwide, to foster the development of Industry 4.0, regarding the regulation of political, financial, and fiscal aspects, as well as the provision of infrastructures, services,

knowledge, and a skilled workforce [12,92–94]. Further steps could be taken to better explore these issues. Furthermore, most of the existing studies only focus on a technology-related perspective, leading to a reduced analysis of Industry 4.0's complexity; many themes, such as the role of the organisational culture or the social and environmental impact need further investigation, and institutional theories could help in this regard [95,96].

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