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SURVEY

# Interactions Between Innovation and Digital Transformation: A Co-Word Analysis

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**ABSTRACT** Recent literature suggests there is a natural connection between innovation and digital transformation, two key topics of interest in management and organization that have spawned large, independent and well-defined areas of study. While this connection might be analytically straightforward and notable examples are not hard to find, in everyday life, it materializes in a multiplicity of ways. A need emerges, then, to better understand the interaction between innovation and digital transformation so that it can be explored and exploited by actors in academia and the public, private and third sectors. In this article, we use a co-word analysis, a text mining technique that permits to systematically map the intellectual structure of a research field, to characterize the most notable dynamics of 'innovation-driven digitalization' and 'digitalized innovation'— the two major dimensions of interaction between innovation and digital transformation. The text identifies the relevant themes, subthemes and concepts that appear in the literature, as well as their relationship and level of development. It, then, aggregates them in a taxonomy that, on the one hand, readily displays their connection and, on the other hand, (i) informs about current or potential controversies, (ii) gaps, (iii) lines for novel and further research, and (iv) alternatives to bridge to other areas of study.

**INDEX TERMS** Digital transformation, digitalized innovation, innovation-driven digitalization, industry 4.0, COVID-19, co-word analysis.

## I. INTRODUCTION

Innovation and digital transformation (DT) figure prominently in the contemporary management and organization literature. For decades, the former has been considered a cornerstone of competitiveness and value generation [1], [2]; the latter, a decidedly newer organizational concern, is believed to be central for the performance [3] and survival of firms [4], especially in the context of the COVID-19 pandemic [5].

Recently, some authors have suggested that there is a natural connection or affinity between innovation and DT [6], [7], [8], based on the acknowledgement that, on the one hand, DT is often supported or comes as a direct result of innovation processes [9] and, on the other hand, innovation dynamics have become increasingly digitalized [10], [11]. Even though, from a conceptual standpoint, these two dynamics (referred to from here onwards as 'innovation-driven digitalization' and 'digitalized innovation'), are analytically straightforward, in practice, the interaction between innovation and DT materializes in a multiplicity of ways. Hence, there is a need for further research that supports the exploration and exploitation of this interaction by interested actors in academia and the public, private and third sectors.

This article presents the results of co-word analysis to help flesh out the connection between innovation and DT. Co-word analysis is a content analysis technique [12] that permits to comprehensively and systematically map the intellectual structure of a subject or research field through the co-occurrence of keywords within a corpus of literature. The method is employed in this text to, first, identify different concepts and themes in the literature (clusters), second, explore how these themes are related to each other and, third, assess their transversality (centrality) and internal development (density). Overall, we expect the results to offer a more

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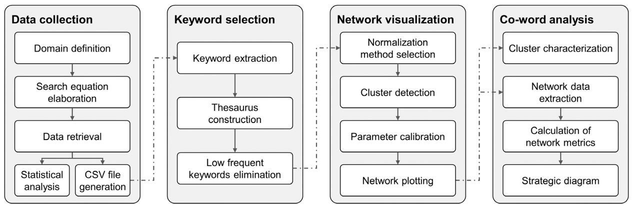



**FIGURE 1. A comprehensive framework to map the interactions between innovation and DT.**

nuanced understanding of the complex bidirectional interaction between innovation and DT from a structural macro point of view.

To do this, the paper is structured as follows: section 2 provides an overview of the methodology (data collection, keyword selection, network visualization and co-word analysis). Section 3 describes the results of the co-word study. Initially, some basics bibliometric statistics are presented. Later, the six major themes identified in the literature, with their respective subthemes, are individually characterized. Section 4 discusses, from a global perspective, major topics, gaps and potential lines of research. It also introduces a taxonomy that classifies, based on the analysis, the interactions between innovation and DT. Section 5 offers some general conclusions.

## II. METHODS

This paper applies co-word analysis to visualize and analyze the interactions between innovation and digital transformation. Co-word analysis reveals the general intellectual structure of a field as a weighted network of interrelated terms and visualizes the different clusters that compose it. Terms are usually derived from textual sources such as keywords, titles, abstracts or full texts. In this paper, the co-occurrence of 'author keywords' in academic literature was considered. The main assumption within co-word analysis is that terms regularly appearing together have a thematic relationship [13]. Therefore, a cluster is a set of terms densely connected to each other, but sparsely connected to other clusters within the network. Clusters are interpreted as research themes, whose development and relevance can be characterized by network metrics within a strategic diagram. In this way, co-word analysis makes it possible to identify the knowledge components, knowledge structure and research trends of a scientific field [14]. Figure 1 shows the methodological framework used in this paper.

### A. DATA COLLECTION

To capture the relationship between innovation and DT, the search terms *digital transformation* and *innovation* (and its variations: *innovative*, *innovativeness*) were used. Terms such as *digitalization* or *digitization* were not considered because, although much of the literature uses them as synonyms for DT [15], they should be rather considered as components of, and therefore different to, DT [16]. The search terms were applied to the titles, abstracts and keywords, according to the following equation:

TITLE-ABS-KEY (innovati* AND "digital transformation")

The search was conducted on 08/14/2021 and included all types of documents available in Scopus, which has been one of the most frequently used databases in bibliometric research [17]. 1916 documents were found, of which 1563 contained author keywords. The records were stored in a CSV file. The descriptive statistical analysis below was performed using the full set of documents, for they are still relevant to the bibliometric characterization of the literature. Yet, only those containing author keywords were used for the co-word analysis, since these are required for the network mapping.

### B. KEYWORD SELECTION

The extraction of the keywords from the CSV file allowed 4536 terms to be recovered. Such terms were filtered in a thesaurus based on the following criteria: (i) standardization of singular and plural words (e.g., capabilities into capability); (ii) combination of equivalent expressions in American and British English (e.g., servitisation into servitization); (iii) integration of acronyms with their corresponding full names (e.g., artificial intelligence into ai); (iv) normalization of hyphenated expressions (e.g., ehealth into e-health); (v) reduction of synonymous expressions (e.g., COVID-19 pandemic into COVID-19); (vi) stemming of derived words in justified cases (e.g., agility into agile), and (vii) elimination of references to the territory (e.g., Africa, Australia), research methodologies (e.g., case study, systematic review), and irrelevant or general terms (e.g., innovation, process, model). Some instances of the last three criteria required the use of subjective judgement. In those instances, the decision to combine or remove keywords was made based on prior literature and the research team's expertise. After preprocessing, 4363 unique terms were obtained. Finally, the keywords that had an occurrence of less than 5 were not selected. A total of 189 keywords were included in the co-word network.

### C. NETWORK VISUALIZATION

The co-word network was generated based on a co-occurrence matrix that was calculated and mapped using VOSviewer software [18]. In the network, each node represents a keyword, and its size indicates the keyword's occurrence within the corpus (i.e., the larger the node, the more frequent the keyword it represents). The edge between a pair of nodes depicts their co-occurrence. The edges thickness represents the occurrence of co-occurrences between keywords. The keywords that have the highest affinity will appear closer on the map, and those that are dissimilar will be located far from each other. Colors, in turn, signal thematic clusters that can be characterized from the nodes and edges that compose them.

To map the keyword co-occurrence matrix, the LinLog normalization algorithm [19] included in VOSviewer was used. The attraction and repulsion parameters of the algorithm were calibrated at values of 1 and -1, respectively. For the detection of clusters, the VOS clustering technique was used, which is a weighted and parameterized variant of modularity-based clustering developed in physics [20] that creates non-overlapping clusters based on the quantification of attractive and repulsive forces among nodes and a desired resolution parameter. The higher the value of the parameter, the larger the number of clusters produced. In this case, the parameter was set to 1:00. Additionally, the minimum cluster size was adjusted to 10 keywords. In VOSviewer, normalization and clustering are complementary and, therefore, integrated under a unified paradigm [21]. Consequently, the calibration of the mentioned parameters was carried out jointly and iterated several times. In the end, six clusters were detected.

### D. CO-WORD ANALISYS

The discovered clusters were characterized by interpreting the features of the network and reviewing relevant documents within the corpus. Additionally, a strategic diagram depicting the centrality and density of the clusters was elaborated. Centrality and density are network metrics that indicate, respectively, the importance of a cluster within the network and its internal cohesion. The equations considered to calculate these metrics were those employed by [22]:

$$C_L = \sum_{i \in L} \sum_{j \in M} w_{ij} e_{ij}$$

where $C_L$ is the centrality of the cluster $L$ and $i$ represents the nodes of $L$. $M$ is the set of the other clusters contained in the network and $j$ the nodes in all the clusters of $M$. $e_{ij}$ is a binary variable that is equal to 1 if there is an edge between nodes $i$ and $j$, and 0 if there is no edge that joins them. Finally, $w_{ij}$ is the weight of the edge between nodes $i$ and $j$.

$$D_L = \frac{2E}{N(N-1)}$$

where $D_L$ denotes the density of the cluster $L$. $N$ is the total number of nodes in $L$ and $E$ is the total number of edges in $L$. Network metrics were calculated using an *ad-hoc* script developed in the Python language.

The strategic diagram (Figure 2) is a two-dimensional coordinate plane that allows for the classification of clusters into four quadrants, depending on their centrality and density values [23]. The X- and Y-axis represent centrality and density, respectively, and the origin is determined based on the average values for both. In quadrant I, well-developed and important themes in the intersection between innovation and DT are found. Themes in quadrant II are developed internally, but have only marginal importance within the corpus. Quadrant III includes themes that are both weakly developed and peripheral. These can be interpreted as either emerging or declining themes. Finally, quadrant IV groups themes that are important for the corpus, but are not sufficiently developed.

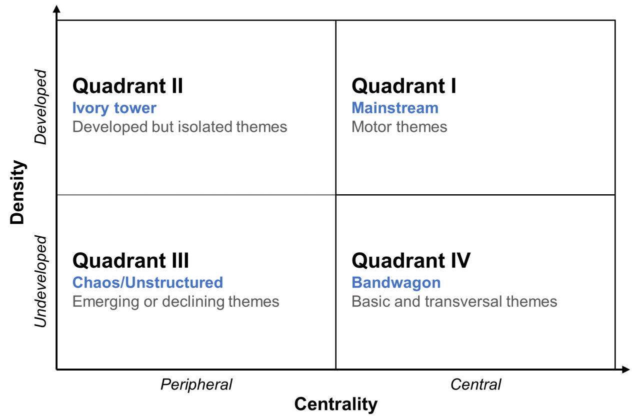



**FIGURE 2.** Characterization of a strategic diagram. Source: adapted from [22].

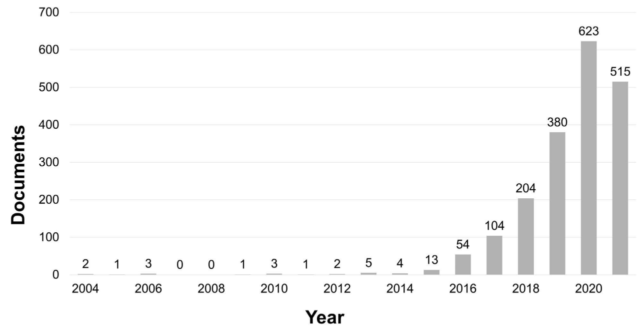



**FIGURE 3.** Documents by year. Scopus reports documents since 1961, with trend similar to what we see in the figure from 2004 to 2012. Source: own elaboration based on Scopus data.

## III. RESULTS

### A. DESCRIPTION OF THE FIELD: DOCUMENTS, AUTHORS, JOURNALS AND KEYWORDS

Figure 3 shows the evolution of the literature at the intersection between innovation and DT. It is an evidently novel academic interest. Before 2014, the yearly number of published texts was below 5. Since then, there has been a steep increase, reaching 623 publications in 2020, driven probably by the progressive advancement of digital transformation. This growing trend is likely to continue in the short term, as researchers explore in more detail new or significantly modified business models, technologies and innovations that firms, industries and regions implement to mitigate the effects or take advantage of the new reality generated by the current pandemic.

Table 1 shows the leading outlets in terms of publications within the corpus. *Sustainability*, *Journal of Business Research*, *Technological Forecasting and Social Change*, and *Journal of Business Strategy* are the top four journals, and account for 9,09% of the publications. This low percentage for leading journals is expected in interdisciplinary and transdisciplinary subjects or areas of research, such as the one dealt with in this paper. It is worth noting that the mission statements of most journals with higher percentages center on

**TABLE 1. Leading journals that publish research on the field (869 journal papers from 1916 documents). Source: own elaboration based on Scopus and Scimago data.**

| No. | Journal | Quartile | H-index | Freq. | % |
|---|---|---|---|---|---|
| 1 | Sustainability | Q1 | 85 | 38 | 4,3728 |
| 2 | J Bus Res | Q1 | 195 | 20 | 2,3015 |
| 3 | Technol Forecast Soc | Q1 | 117 | 12 | 1,3809 |
| 4 | J Bus Strategy | Q2 | 38 | 9 | 1,0357 |
| 5 | IEEE T Eng Manage | Q1 | 92 | 8 | 0,9206 |
| 6 | Int J Innov Manag | Q2 | 44 | 7 | 0,8055 |
| 7 | J Open Innov Technol Mark Complex | Q2 | 22 | 7 | 0,8055 |
| 8 | Eur J Inno Manag | Q2 | 63 | 6 | 0,6904 |
| 9 | Front Psychol | Q2 | 110 | 6 | 0,6904 |
| 10 | IEEE Eng Manag Rev | Q3 | 20 | 6 | 0,6904 |

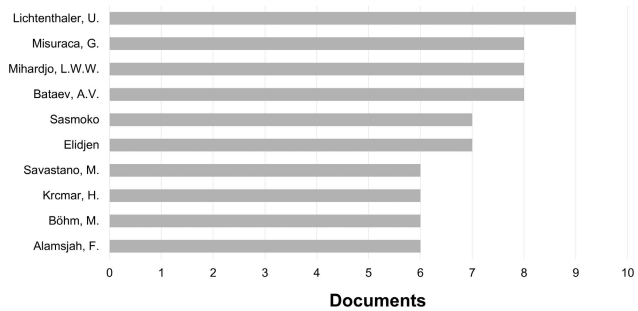



**FIGURE 4. Documents by author. Source: own elaboration based on Scopus data.**

areas related to business and technological innovation, rather than the technical aspects of innovation and digitalization.

The top four authors in the corpus (Figure 4) are Lichtenthaler, Misuraca, Mihardjo, and Bataev. These authors have published a combined 33 articles. The topics addressed are relatively diverse. For example, Lichtenthaler focuses on the synergies created between data analytics, innovation, AI and management; Misuraca explores issues related to digital social innovation, AI for governance, and the social implications of the DT; Mihardjo examines the interplay between customer experience, business model innovation and DT; finally, Bataev focuses on DT technology trends and on the digital transformation of the financial sector.

The two most cited papers were published by Vial [24] and Zhu [25] (Table 2). The latter focuses on the determinants of DT; the former reviews the available literature on DT. These two papers were published in information systems journals. Yet, the rest of the most cited papers were published in management journals, showing the increasing importance that the intersection between innovation and DT is gaining among management scholars. Of the most cited publications, only Zhu's [25] and Karimi & Walter's [26] precede 2017, which evidences the dynamicity of this emerging area of research.

Table 3 shows the most frequent keywords. The list includes a diversity of digital technologies e.g., artificial intelligence, iot (Internet of things), blockchain; typical innovation concerns e.g., business model (innovation), open innovation, dynamics capability; sectors and areas

**TABLE 2. Most cited papers. Source: own elaboration based on Scopus data.**

| No. | Document title | Cited by | Reference |
|---|---|---|---|
| 1 | Understanding digital transformation: A review and a research agenda | 377 | [24] |
| 2 | Innovation diffusion in global contexts: Determinants of post-adoption digital transformation of European companies | 353 | [25] |
| 3 | Digital innovation and transformation: An institutional perspective | 184 | [27] |
| 4 | Open innovation: Research, practices, and policies | 184 | [28] |
| 5 | The role of dynamic capabilities in responding to digital disruption: A factor-based study of the newspaper industry | 176 | [26] |
| 6 | The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes | 170 | [11] |
| 7 | Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal | 157 | [29] |
| 8 | Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective | 148 | [30] |
| 9 | External knowledge and information technology: Implications for process innovation performance | 133 | [31] |
| 10 | Industry 4.0, digitization, and opportunities for sustainability | 111 | [32] |
| 11 | Digital transformation of business models-best practice, enablers, and roadmap | 110 | [33] |
| 12 | Business model innovation through Industry 4.0: A review | 108 | [34] |

of application e.g., higher education, digital economy; key ecosystem dynamics and transformation processes e.g., industry 4.0, smart city; and keywords that are more clearly positioned within the intersection between innovation and DT e.g., digital innovation.

Degree centrality and betweenness centrality metrics were also calculated for the keywords (Table 4). The former measures the total direct links to a keyword. Thus, a keyword with high degree centrality is connected to a multiplicity of other keywords. Betweenness centrality, alternatively, measures how often a keyword appears in the shortest path between any other pair of keywords i.e., it helps bridge between them. The similarity found between both lists shows that the most frequent keywords are, at the same time, the most influential, for thematic links will often be established through them. Most of the highest ranked keywords on both lists account, first, for the transformational and novel nature of the intersection between innovation and DT (e.g., transition from industry 3.0 to 4.0 or from innovation and economy to *digital* innovation and *digital* economy), second, for some digital technologies (e.g., artificial intelligence, iot, big data) and, third, for some relevant organizational challenges and contexts at the intersection (e.g., business model (innovation)). It is worth noting that, although COVID-19 is a fairly recent subject, it has relatively high levels of centrality and betweenness centrality. The pandemic has altered the way

**TABLE 3.** Most frequent keywords in 1563 documents (OCC: occurrence of keywords).

| No. | Keyword | OCC | % | No. | Keyword | OCC | % |
|---|---|---|---|---|---|---|---|
| 1 | digitalization | 168 | 6,1584 | 16 | higher education | 31 | 1,1364 |
| 2 | industry 4.0 | 141 | 5,1686 | 17 | blockchain | 28 | 1,0264 |
| 3 | digital economy | 109 | 3,9956 | 18 | digital platform | 27 | 0,9897 |
| 4 | digital innovation | 88 | 3,2258 | 19 | smart city | 27 | 0,9897 |
| 5 | artificial intelligence | 87 | 3,1891 | 20 | open innovation | 26 | 0,9531 |
| 6 | digital technology | 73 | 2,6760 | 21 | cloud computing | 26 | 0,9531 |
| 7 | iot | 62 | 2,2727 | 22 | dynamic capability | 25 | 0,9164 |
| 8 | business model innovation | 54 | 1,9795 | 23 | sustainability | 25 | 0,9164 |
| 9 | business model | 54 | 1,9795 | 24 | information technology | 25 | 0,9164 |
| 10 | digitization | 50 | 1,8328 | 25 | ict | 24 | 0,8798 |
| 11 | big data | 48 | 1,7595 | 26 | strategy | 22 | 0,8065 |
| 12 | covid-19 | 36 | 1,3196 | 27 | fintech | 22 | 0,8065 |
| 13 | technology | 34 | 1,2463 | 28 | entrepreneurship | 22 | 0,8065 |
| 14 | sme | 31 | 1,1364 | 29 | data analytics | 21 | 0,7698 |
| 15 | management of innovation | 31 | 1,1364 | 30 | digital twin | 20 | 0,7331 |

**TABLE 4.** Keywords with highest degree centrality (DC) and betweenness centrality (BC).

| No. | Keyword | DC | Keyword | BC |
|---|---|---|---|---|
| 1 | digitalization | 116 | digitalization | 0,1687 |
| 2 | industry 4.0 | 104 | industry 4.0 | 0,1359 |
| 3 | digital economy | 84 | digital economy | 0,0797 |
| 4 | artificial intelligence | 77 | digital innovation | 0,0742 |
| 5 | digital innovation | 74 | artificial intelligence | 0,0717 |
| 6 | digital technology | 69 | digital technology | 0,0455 |
| 7 | Iot | 63 | iot | 0,0387 |
| 8 | digitization | 55 | digitization | 0,0284 |
| 9 | big data | 53 | big data | 0,0240 |
| 10 | business model | 47 | technology | 0,0197 |
| 11 | technology | 47 | business model innovation | 0,0168 |
| 12 | business model innovation | 44 | business model | 0,0160 |
| 13 | sme | 39 | covid-19 | 0,0145 |
| 14 | information technology | 39 | information technology | 0,0129 |
| 15 | covid-19 | 35 | information system | 0,0123 |

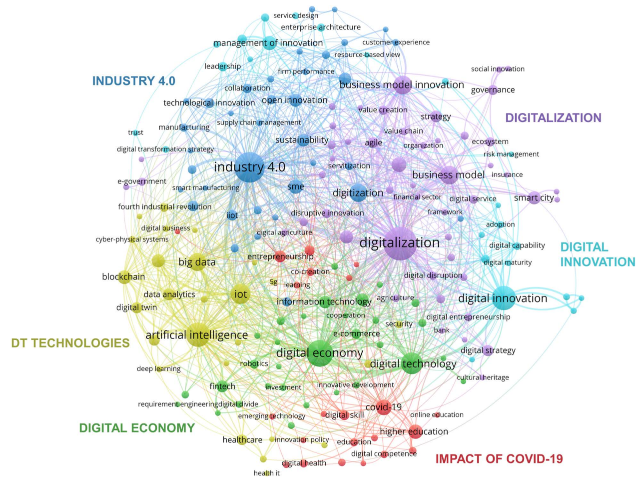



**FIGURE 5.** Co-word network of innovation and DT interactions.

we work, study and live, accelerating and even forcing the transition from physical to virtual transactions, interactions, and communications. This transition is enabled by or associated with artificial intelligence, digitalization, iot, big data and business model innovation.

### B. DIFFERENT THEMES (CLUSTERS) INTERSECTING INNOVATION AND DT RESEARCH

After running the VOSviewer algorithm [35], six clusters were generated (Figure 5). Based on an analysis of the constitutive keywords and the manual inspection of relevant publications within the corpus, the clusters were labelled: ''Digitalization'', ''Industry 4.0'', ''Digital economy'', ''DT technologies'', ''Digital innovation'', and ''Impact of COVID-19''.

Table 5 shows the total size of each cluster (total number of nodes) and the top-10 co-occurrent nodes for each of the six clusters, with their respective total link strength. The strength of a link is given by its frequency. Total link strength, thus, is the added sum of links weighted by their occurrence. This indicator offers insights into the relative importance of a node from the perspective of co-occurrence, instead of centrality.

#### 1) DIGITALIZATION CLUSTER

This is the largest cluster (Figure 6), both in terms of number of nodes and link strength. In turn, the 'digitalization' node itself has the highest centrality and link strength in the entire network. The cluster, however, is not thematically homogenous. It groups five general subclusters, each focused on independent and well-delineated areas, transversally connected by issues of innovation and DT[1]: *business model innovation*, *smart cities*, *digital platforms*, *technology management* and *digital strategy*.

*Business model innovation* is a key topic in innovation management. It is a matter of how organizations strategically explore and adopt novel ways to create and deliver value (hence, the inclusion of the nodes 'value creation', 'value chain' and 'value network' in this subcluster). In this specific form of innovation, the literature has explored a twofold use of digital technologies. Organizations may, on one hand, leverage digital technologies to achieve superior performance e.g., improving its value creation processes through big data

[1]Clusters use double quotes and capitalization (e.g., ''Digitalization'' cluster), nodes use single quotes (e.g., 'digitalization' node), and subcluster use italics (e.g., business model innovation subcluster).

**TABLE 5.** Top-10 co-occurrence nodes by cluster. LS: Link strength.

| **Digitalization** (50 nodes) | | **Industry 4.0** (36 nodes) | | **Digital innovation** (24 nodes) | |
|---|---|---|---|---|---|
| *Node* | *LS* | *Node* | *LS* | *Node* | *LS* |
| *digitalization* | 319 | *industry 4.0* | 272 | *digital innovation* | 141 |
| *business model innovation* | 100 | *digitization* | 84 | *management of innovation* | 43 |
| *business model* | 95 | *sme* | 61 | *business process management* | 25 |
| *technology* | 74 | *dynamic capability* | 57 | *digital capability* | 25 |
| *agile* | 40 | *iiot* | 49 | *change management* | 23 |
| *digital platform* | 40 | *open innovation* | 47 | *enterprise modeling* | 18 |
| *strategy* | 39 | *sustainability* | 40 | *adoption* | 17 |
| *smart city* | 34 | *collaboration* | 34 | *digital leadership* | 17 |
| *disruptive innovation* | 31 | *manufacturing* | 33 | *leadership* | 17 |
| *ecosystem* | 31 | *technological innovation* | 32 | *business modeling* | 16 |
| **Digital economy** (31 nodes) | | **DT technologies** (26 nodes) | | **Impact of Covid-19** (22 nodes) | |
| *Node* | *LS* | *Node* | *LS* | *Node* | *LS* |
| *digital economy* | 199 | *artificial intelligence* | 66 | *covid-19* | 47 |
| *digital technology* | 137 | *iot* | 49 | *higher education* | 39 |
| *information technology* | 54 | *big data* | 41 | *entrepreneurship* | 34 |
| *ict* | 45 | *cloud computing* | 21 | *design thinking* | 29 |
| *fintech* | 43 | *digital twin* | 21 | *digital skill* | 24 |
| *e-commerce* | 25 | *data analytics* | 19 | *co-creation* | 22 |
| *business* | 23 | *machine learning* | 17 | *education* | 20 |
| *robotics* | 23 | *blockchain* | 16 | *digital competence* | 17 |
| *internet* | 22 | *healthcare* | 15 | *educational innovation* | 14 |
| *information* | 20 | *fourth industrial rev.* | 12 | *university* | 13 |

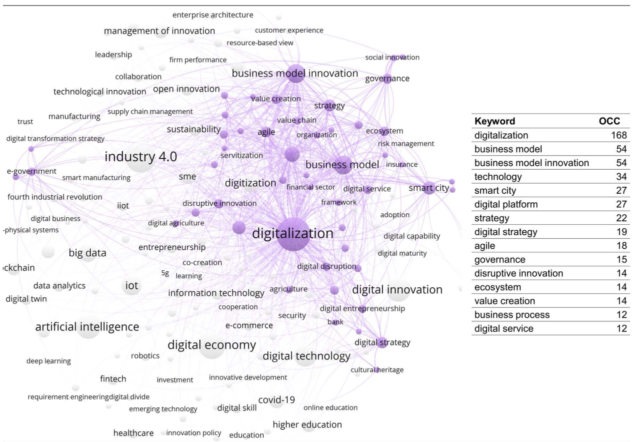


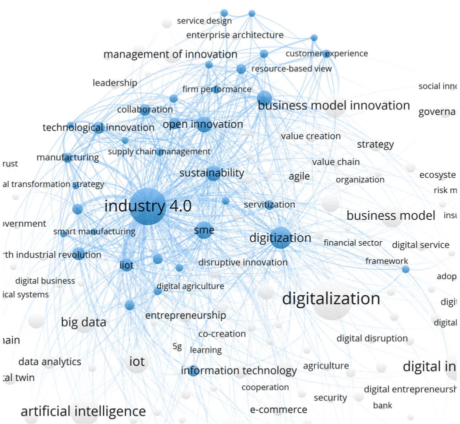

**FIGURE 6.** Co-word network of "Digitalization" cluster.

analytics [36] and, on the other hand, develop innovative business models that build upon a diverse set of digital technologies e.g., incorporate 'additive manufacturing' [37] to the production line or improve communication with customers through 'social networks' [38].

Digital technologies have also paved the way for new data-intensive forms of city management that are more effective, decentralized, and empowering. While the literature on *smart cities* is significantly diverse, the subcluster is relatively simple and, in general, centers on three major aspects of this theme: first, the recognition of smart cities as an issue of management at the system level, where digital technologies facilitate or make possible the coordinated interaction of several stakeholders ('public-private partnership', 'ecosystem', 'public administration') (e.g., [39]), second, the focalized and collaborative nature of the decision-making that digital technologies applied to smart cities allow for ('social innovation', 'governance', 'resilience') (e.g., [40]) and, third, the technological enablers of smart cities ('digital service', 'platform') (e.g., [41]). A smart city, viewed as a large-scale development, may result in innovation-driven digitalizations (e.g., AI to track traffic, face recognition to identify criminals, sensors to measure environmental variables) that facilitate real time decision making, city management and allocation of resources.

Digital technologies can naturally drive changes of different nature and scope. The *digital platforms* subcluster, however, reflects an acknowledgement that some of these changes may be truly disruptive ('digital disruption', disruptive innovation') (e.g., [42]), may occur in different sectors ('automotive industry', 'digital government') and need not involve market incumbents ('digital entrepreneurship') (e.g., [43]). The interlink between disruptive business models and new ways to capture value through digital platforms may generate innovation-driven digitalization. Digital technologies have a higher chance of becoming disruptive when they are embedded in a physical and social infrastructure that supports everyday interactions among different individual and institutional actors. 'digital platform[s]', for example, have increased in popularity not simply because they aid or support decision making, but because they can be potentially used to create novel 'digital ecosystem[s]' [44].

In spite of the great potential for transformation of digital technologies, disruptive innovation through digitalization is not possible, needed or wanted in every context. The *technology management* subcluster includes some considerations that are often addressed when engaging with digitalization processes. The subcluster, however, seems to be thematically too broad or general. 'Technology' the most important and central node, links out to several items that are important both from the perspective of innovation and the everyday operation




| Keyword | OCC |
|---|---|
| industry 4.0 | 141 |
| digitization | 50 |
| sme | 31 |
| open innovation | 26 |
| dynamic capability | 25 |
| sustainability | 25 |
| iiot | 17 |
| knowledge management | 17 |
| technological innovation | 16 |
| collaboration | 13 |
| start-up | 13 |
| competence | 13 |
| smart factory | 12 |
| manufacturing | 11 |
| automation | 11 |

**FIGURE 7.** **Co-word network of "Industry 4.0" cluster.**

of the organization e.g., 'strategy', 'change', 'agile', 'performance', 'business process'. 'Strategy' is the node with the second highest frequency, but it does not seem, for a conceptual point of view, to significantly influence the configuration of the subcluster. Interestingly, the last subcluster, *digital strategy*, shows the same level of generality. Most nodes refer to areas of application ('cultural heritage', 'bank', 'agriculture', 'digital agriculture') rather than proper strategy-related concepts. These findings concerning the effect of strategy on the general network will be discussed further in section 4.

### 2) INDUSTRY 4.0 CLUSTER

Figure 7 shows the co-word network of the cluster "Industry 4.0", which generally involves the use of advanced information analytics and networked machines to carry out processes more efficiently, collaboratively and resiliently [45], and facilitate decision-making [46]. This cluster shows that, besides the manufacturing-related side of industry 4.0, which has been abundantly explored and is represented by the nodes 'manufacturing', 'smart factory', 'smart manufacturing' and 'digital manufacturing', the literature also pays attention to the leadership ('digital leadership', 'leadership'), collaboration ('triple helix', 'collaboration'), and customer ('customer experience') sides of industry 4.0. This cluster contains five distinct subclusters: *digitization*, *dynamic capabilities*, *technological innovation*, *knowledge management*, and *industry 5.0*.

The *digitization* subcluster contains the node 'digitization', which is the second largest in the entire cluster (after the 'industry 4.0' node). This may be explained by the predominant research interest in the role of digital technologies in the industry 4.0 context, and by the fact that digitalization – along with digitization – is a transversal concept explored both from the technical/operational (e.g., [47]) and strategic (e.g., [48]) levels. Digitization is tied to management ('servitization', 'human resource management') and operations ('smart manufacturing', 'automation'), not merely technology ('technology adoption', 'iiot'), which shows that this theme has been approached comprehensively from several perspectives.

'Sustainability' is another key node of the digitization *subcluster*. The literature that explores the interaction between sustainability and industry 4.0 generally focuses on how the latter facilitates sustainable innovation practices related to green absorptive capacity, sustainable partnerships, and eco-friendly products, sustainable performance and circular business models, and sustainable value chains [49]. The 'sme' (small and medium enterprise) node is relatively large, since some of these firms capitalize on digitalized innovations as a leverage for competitiveness [50].

The *dynamic capabilities* subcluster has 'open innovation' and 'dynamic capabilities' as the largest nodes. 'Open innovation' strategies accompanied by adequate 'absorptive capacities' and the right balance between exploration and exploitation ('ambidexterity') serve to accrue some 'dynamic capabilities' at the firm level [51] and, hence, foster 'firm performance'.

The *technological innovation* subcluster highlights the relevance of 'technological innovation' and 'r&d' as key sources of competitive advantage. Most of the research focuses on the 'manufacturing' sector, in which 'collaboration' and the right 'supply chain management' may favor value creation, value delivery and competitiveness.

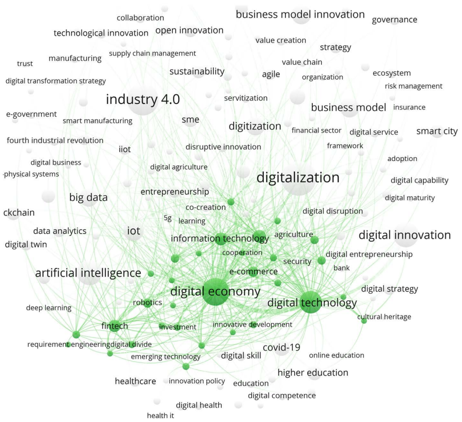
The *knowledge management* subcluster is structurally disperse and is one of the smallest in the "Industry 4.0" cluster. This subcluster involves the nodes 'knowledge transfer' and 'knowledge sharing', which are key elements that accompany the generation, organization and use of knowledge at the firm, industry and ecosystem level, and mediate the adoption of technological innovations and processes associated with industry 4.0.

Some aspects related to social and environmental sustainability are not clearly addressed by industry 4.0, which emphasizes efficiency and smart factories. These sustainability aspects as well as human-machine interactions are, however, at the core of the subcluster *industry 5.0*, in which the interactions between academia, government and industry ('triple helix') and adequate processes of 'transformational performance' are essential to foster a better 'customer experience' without generating too much pressure on the planet's resources (again, 'sustainability' and 'circular economy').

### 3) DIGITAL ECONOMY CLUSTER

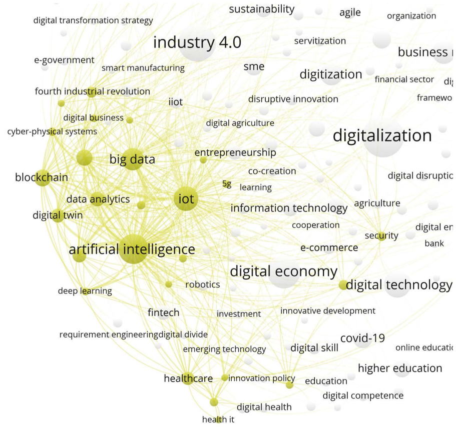
The cluster on "Digital economy" (Figure 8), which generally refers to the dynamics and activities mediated by digital technologies to connect heterogeneous actors and carry out transactions over the internet [52], shows the importance that the literature has placed on the fields of *digital technology*, *information and communication technology (ICT)*, and *robotics* as enablers of the digital economy, as well as on *fintech* as key outcomes of the digital economy expansion. These fields are grouped into four subclusters.

The *digital technology* subcluster deals with the 'digital infrastructure', the 'innovative developments', resources 'integration' and the 'managerial practices' that are at the center of this new digital economic wave to reach high levels of




| Keyword | OCC |
| --- | --- |
| digital economy | 109 |
| digital technology | 73 |
| information technology | 25 |
| ict | 24 |
| fintech | 22 |
| e-commerce | 15 |
| robotics | 12 |
| sustainable development | 11 |
| diffusion of innovation | 10 |
| management | 10 |
| innovation system | 9 |
| business | 8 |
| technological change | 8 |
| innovative development | 8 |
| internet | 7 |

**FIGURE 8.** Co-word network of "Digital economy" cluster.




| Keyword | OCC |
| --- | --- |
| artificial intelligence | 87 |
| iot | 62 |
| big data | 48 |
| blockchain | 28 |
| cloud computing | 26 |
| data analytics | 21 |
| digital twin | 20 |
| machine learning | 19 |
| healthcare | 18 |
| fourth industrial rev. | 12 |
| cybersecurity | 10 |
| security | 9 |
| cyber-physical system | 7 |
| telemedicine | 7 |
| augmented reality | 7 |

**FIGURE 9.** Co-word network of "DT technologies" cluster.

'innovation performance' and efficiency. Research on 'digital literacy' and 'sustainable development' plays an important role in this subcluster. Research on the former centers on knowledge and skills for capitalizing on digital technology advances; on the latter, it emphasizes on the opportunities and challenges of the digital economy for sustainable development (e.g., [53]) and on the relation between sustainability and digital economy (e.g., [54]). The 'digital technology' node is the second largest in the cluster and is directly tied to the 'digital economy', 'information technology', and 'digitalization' nodes, which play an important role in the network and conceptually complement each other.

The synergic combination between 'digital talent' and different hardware and software to capture, store, process and manipulate information ('information technology') using 'internet' is also at the core of the digital economy cluster. This combination is represented in the *ICT* subcluster, which has allowed the development of different types of scalable 'businesses' and 'e-commerce', fostering 'economic growth', but also a 'digital society', despite all the downsides that come with it (pervasive surveillance, targeted marketing, etc.).

For the subcluster on *robotics,* the literature addresses prominently 'diffusion of innovation' and 'technological change'. Studies on diffusion of innovations focus on how the widespread adoption of some technological innovation can cause job loss due to automation (e.g., [55]), the end-user involvement in the development of products and services, and the creation of regional innovation systems to foster digitalization (e.g., [56]). Research on technological change emphasizes on productive complementarities, skills, policies and value chain transformations to foster technological change and facilitate the digital economy, as well as the downsides of the digital transformation (job loss, pervasive automation and job redundancy) (e.g., [55]). The 'investment' required and the practices to properly manage information technology resources according to different needs and priorities ('it management') are also at the core of the *robotics* subcluster.

The *fintech* subcluster integrates both the relational capabilities ('cooperation') and the information resources ('information', 'information systems') that enable, facilitate or decelerate the delivery of 'financial services'. This subcluster also involves research on 'digital divide', which focuses on the levels of digitalization required to strengthen the digital economy (e.g., [57)] and on the mechanisms to facilitate digital transformation (e.g., [58]).

### 4) DT TECHNOLOGIES CLUSTER

This cluster (Figure 9) may, arguably, offer the most succinct account of the current level of maturity of the discussion on the connection between innovation and DT. Most nodes included in the cluster refer exclusively to digital technologies. This is explained, in part, by the fact that truly innovative digital transformations are believed to require the implementation of multiple digital technologies. The lack of strong links to "thematic" nodes, however, is also because, to date, a large portion of the literature on digital technologies centers on the exploration of how the technologies work and the identification of possible areas of application, either from a general perspective (e.g., [44], [59]) or applied to specific sectors (e.g., [60], [61]). Part of the literature, the analysis shows, is still centered on setting the foundations for the successful incorporation of these technologies in diverse innovation scenarios.

Three major subclusters can be identified within the "Digital technologies" cluster. There is, first, a subcluster on typical *disruptive technologies* that, interestingly, groups exclusively the nodes for technologies that drive digital transformation more prominently, i.e., 'artificial intelligence', 'iot', 'machine learning', 'blockchain', 'cloud computing', 'deep learning', '5g'. The AI node is the largest and most central of both the subcluster and the "DT Technologies" cluster. Yet, the cluster is, overall, highly interconnected. This configuration is understandable: AI offers the most robust and comprehensive cognitive capabilities for a digital transformation process, but all these technologies, and in different combinations, are able to improve value proposition, operational efficiency, decision-making and firm performance.

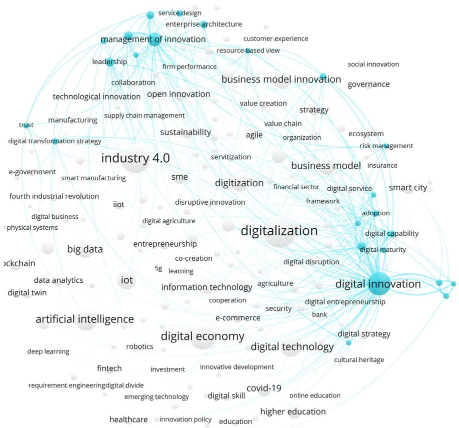
A second subcluster groups issues of *big data and analytics*. While 'big data' and 'data analytics' are also key digital technologies, these nodes are part of a different subcluster for, in conjunction, they are the digital technologies with higher levels of penetration i.e., actual instances of implementation in different settings [62]. 'Big data' and 'data analytics', are the two largest and most central nodes of the subcluster, and are multiply linked to thematic nodes, such as 'fourth industrial revolution', 'digital business', 'data management', 'information management' and 'decision making', evidencing the multiple scenarios in which the technologies are used and the innovative ways of digital transformation they allow for. They are also strongly tied to the technologies in the previous subcluster, particularly 'iot' and 'artificial intelligence', and to a critical organizational challenge for the implementation of digital technologies that is increasingly gaining relevance: 'cybersecurity' (and 'security') [63].

The third subcluster, *digital health technologies*, is not as closely integrated with the other two subclusters and is, decidedly, strongly influenced by the current COVID-19 pandemic (hence, the strong connection to the "Impact of COVID-19" cluster in the general network (see Figure 5)). One of the biggest challenges for the 'healthcare' sector has been to guarantee service provision amid the pandemic. The current crisis, thus, has accelerated an already ongoing process of digitalization of health provision ('health it', 'telemedicine') in two main ways: it has, on the one hand, led to emphasize the use of digital technologies to avoid direct physical interaction during the provision of service (e.g., [64], [65]) and, on the other hand, encouraged further advances on the incorporation of 'virtual reality' and 'augmented reality', two digital technologies that seem to have progressively found a niche in the healthcare sector (e.g., [61], [66]).

### 5) DIGITAL INNOVATION CLUSTER

The cluster on "Digital innovation" (Figure 10), which is often conceptualized "as innovative digital solutions that enable digital transformation of businesses across industries" [67] (p. 177), incorporates the *innovation management*, *business process management*, *digital capability*, *enterprise modeling*, and *DT strategy* subclusters.

While management of innovations is fundamental for planning and organizing the resources to achieve higher performance outcomes at the innovation level, leadership is a key component to foster the cultural and organizational changes required for a fluid and long-lasting innovation and DT. This is shown by the strong ties that exist between the 'management of innovation' node and the nodes 'digital leadership', 'leadership', 'change management', and 'organizational culture', which belong to the *innovation management* subcluster. However, besides leadership and change, it is also key to manage the risks inherent ('risk management') to platform deployment, new product development and technological implementation, and to generate and inspire 'trust' to




| Keyword | OCC |
|---|---|
| digital innovation | 88 |
| management of innovation | 31 |
| leadership | 14 |
| change management | 13 |
| business process mgmt. | 12 |
| enterprise architecture | 11 |
| digital leadership | 10 |
| digital capability | 9 |
| adoption | 8 |
| organizational change | 8 |
| enterprise modeling | 8 |
| it capability | 7 |
| digital trans. capability | 7 |
| service design | 7 |
| process innovation | 6 |

**FIGURE 10.** Co-word network of "Digital innovation" cluster.

facilitate both long-lasting cultural changes and the design of services that enhance value proposition ('service design') from a digital innovation perspective.

The subcluster on *business process management* integrates research that explores the interplay between BPM (Business Process Management), digital innovation and DT, and on the role of BPM in the digital age. This subcluster aggregates the nodes 'enterprise architecture', 'capability', and 'adoption'. Digital innovations do not emerge in the vacuum; they are often supported by an 'enterprise architecture' that sets the structures, strategies, and functions that allow innovations to emerge and be sustainable, as well as a set of capabilities to adapt to fast changes, recombine resources, and generate value ('capability'). These capabilities may create the environment for digitalized innovations to flourish. Moreover, this subcluster also integrates research on 'adoption', which focuses mostly on the assimilation of information technologies, digital business models and digital innovations, and research on 'process innovation', which centers on digital process innovation, innovation performance, and influence of process innovation on the supply chain [68].

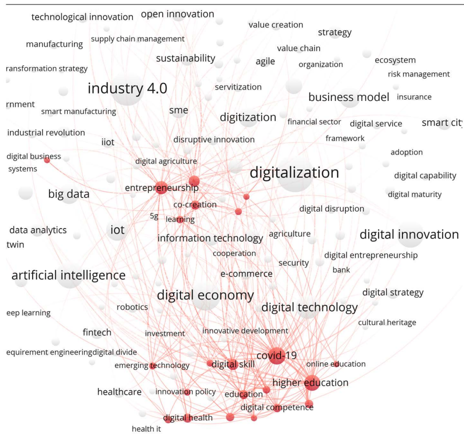
Digital capabilities i.e., the set of skills needed to use and leverage digital technologies [69], are strongly connected to 'digital innovation[s]'. The *digital capability* subcluster connects two internal elements of the firms: first, the ability to cost-efficiently identify, process and deploy IT-related resources to achieve business goals ('it capabilities') and, second, the ability to quickly create, disseminate and capture value through the use of digital technologies ('digital maturity'). IT capabilities and digital maturity go hand in hand. It is hard to envision a firm that reaches high digital maturity levels without strengthening and taking advantage of different devices, software, interfaces, applications, personnel, and IT skills. Since these two elements are internal to the firms, it makes sense that the 'resource-based view' emerges as an important node in the *digital capabilities* subcluster. This view, rather than focusing on external factors, trends, and industrial structures, emphasizes on the internal resources and capabilities ('it capabilities') exploited by the firm to reach sustainable competitive advantage and organizational performance [70].

The ''Digital innovation'' cluster strongly integrates the smaller subclusters on *enterprise modeling* and *DT strategy*: there should be harmonization between these elements to generate, capture and distribute value within the organizations [71]. In general, the right business model aligned with the adequate digital strategy facilitates the deployment of digital innovation initiatives in an efficient and optimal way [72]. Research on business modeling focuses on business model innovation and strategy for sustainable growth, digital transformation, and industry 4.0. This subcluster also deals with the set of rules and governance structures to set and materialize the vision and the strategy ('enterprise architecture management'), and with the specific mechanisms to create and capture value ('business modeling'). The *DT strategy subcluster* is tied specifically to the virtual context and involves the strategies to develop and scale technology and internet-based businesses ('digital business strategy'), but also the changes required to sustainably take advantages of digital solutions ('digital transformation strategy'). At the general level, research on DT strategy centers on the dynamics between digital strategy and entrepreneurial orientation, cultural and human resources, digital transformation, and multi-sided platforms, and on elements of digital strategy.

### 6) IMPACT OF COVID-19 CLUSTER

As a result of the multiple lockdown and social distancing measures put in place to stop the spread of the virus, the COVID-19 pandemic has, undeniably, increased the speed and scope of digitalization processes worldwide. Much of the literature that loads heavier onto this cluster (Figure 11) addresses digitalization and innovation with a sense of urgency: rapid and major change (i.e., radical innovation), supported in diverse ways by digital technologies, is considered necessary to overcome the crisis. This need for change, however, is approached differently depending on the time of publication. Several articles that appeared early during the pandemic discuss digital transformation in terms of challenges and opportunities (e.g., [73], [74]), whereas more recent articles often report on successful instances of digital innovation or offer a more grounded expectation for the 'new normal' (e.g., [75], [76]).

Nodes belonging to this cluster are grouped in three major subclusters, tackling issues of *innovation in education*, *digital education* and *entrepreneurship*. While these topics end up grouped together in a cluster because of the need to counter the effects of the COVID-19 pandemic, most key issues addressed pertaining to innovation and DT predate the current crisis. The first two subclusters, *innovation in education* and *digital education*, are strongly interconnected. The former is approached in a twofold manner, both tied to a general concern with (digital) business model innovation in the education system, particularly in 'higher education', which is the largest and most central node in the subcluster. The literature




| Keyword | OCC |
|---|---|
| covid-19 | 36 |
| higher education | 31 |
| entrepreneurship | 22 |
| design thinking | 16 |
| digital skill | 15 |
| co-creation | 10 |
| education | 10 |
| digital health | 10 |
| digital competence | 9 |
| e-learning | 9 |
| educational innovation | 9 |
| university | 8 |
| learning | 8 |
| e-health | 7 |
| emerging technology | 6 |

**FIGURE 11.** Co-word network of ''Impact of COVID-19'' cluster.

centers, on the one hand, on the digitalization of teaching practices ('online learning') and the need for curriculum overhaul ('educational innovation') to better account for the skills and knowledge required in highly digitalized contexts (e.g., [77], [78]) and, on the other hand, on the digitalization of the operation of education institutions (e.g., [79], [80]). Innovation-driven digitalization is seen, initially, as a matter of finding ways to respond to the pandemic, but, perhaps more interestingly, as a matter of rethinking the education system through digital technologies.

The subcluster on *digital education* deals especially with the changes in practices and curriculum mentioned above. Yet, it also incorporates a relatively distinct set of literature that addresses these topics from the perspective of the skills and knowledge required for dynamics of online learning to take place in an appropriate manner. Success, for instance, hinges on the level of 'digital competence' of both students and teachers and on an approach to online learning that is more than a one-to-one analog to digital replacement of curricular content and activities (e.g., [81], [82]). *Digital education*, thus, centers on issues of efficient implementation and execution, whereas *innovation in education* tackles the institutional incorporation of digitalization as a mean to innovate in the education system.

*Entrepreneurship*, the third subcluster, is not as well integrated. In the global network (Figure 5), this cluster is positioned farther up to the center because there are multiple connections between entrepreneurship and the overall corpus on innovation and DT. The node 'entrepreneurship' and the subcluster, however, end up within the ''Impact of COVID-19'' cluster because a large amount of literature deals with the other two major underlying subthemes. The education system, initially, may have an important role to play in providing entrepreneurs with key skills and knowledge (e.g., about innovation methods such as 'design thinking' and 'co-creation'), particularly in the context of digital transformation ('digital skills', 'digital age') (e.g., [83], [84], [85]. Entrepreneurs, at the same time, face increased opportunities for novel value creation during the pandemic, especially

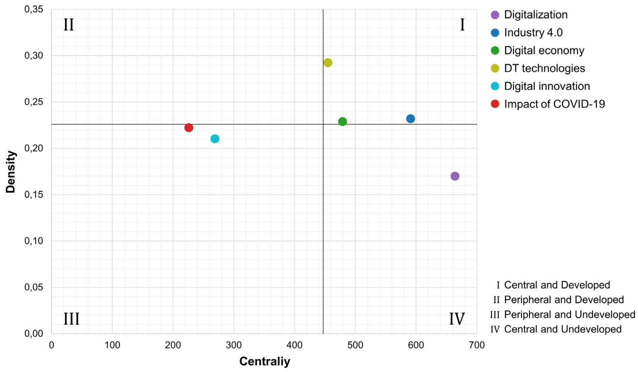



**FIGURE 12.** Strategic diagram.

**TABLE 6.** Network metrics.

| Cluster | No. nodes | No. edges | Centrality | Density |
|---|---|---|---|---|
| Digitalization | 50 | 208 | 664 | 0,1698 |
| Industry 4.0 | 36 | 146 | 591 | 0,2317 |
| Digital economy | 31 | 105 | 479 | 0,2288 |
| DT technologies | 26 | 95 | 455 | 0,2923 |
| Digital innovation | 24 | 58 | 269 | 0,2101 |
| Impact of COVID-19 | 22 | 52 | 226 | 0,2221 |

supported by digital technologies, either as a response to COVID-19 crisis ('e-health') or as an anticipation to alternative market dynamics in a post-pandemic scenario ('digital business transformation') (e.g., [5], [86]). As it will be discussed below, this more general concern with entrepreneurship and the 'new normal' might significantly reshape the link between innovation and DT in the future.

### C. STRATEGIC DIAGRAM

The strategic diagram (Figure 12) establishes a simplified and synthetic representation of the state of the general network (Figure 5). Likewise, it allows describing the position and degree of development of the clusters that compose it. Table 6 presents, in addition to the number of nodes and edges for each cluster, the measures of centrality and density used for the construction of the strategic diagram. The origin of the diagram was estimated from the averages of the centrality and density metrics (447.33, 0.2258).

Figure 12 shows that the clusters "DT Technologies", "Industry 4.0" and "Digital economy" are in QI (motor themes), meaning they are well connected to other themes and are, overall, the ones most significantly driving the discussion at the intersection between innovation and DT. "Industry 4.0" and "Digital economy" have just above average density i.e., internal consistency, which, in part, could be explained by the relative novelty of the corpus and the more established status of these concepts, which is decidedly not limited to concerns about innovation and DT. The higher density of the "DT technologies", at the same time, might be linked to the regularity with which digital technologies are addressed together in the corpus. As DT processes advance in different contexts and scenarios, this cluster might fragment into more specialized themes, similar to the *big data and analytics* subcluster. The future interplay of the three clusters in QI and, especially, the potential fragmentation of the "DT technologies" cluster, could be used as a maturity indicator of the intersection between innovation and DT. Right now, it seems, it lacks an exclusive thematical or theoretical identity.

The clusters "Impact of COVID-19" and "Digital innovation" are in QIII. This quadrant is meant to group emerging and declining themes. Yet, in this case, both are better classified as emerging. They are relatively unstructured and only of marginal importance to the general network. The "Impact of COVID-19" cluster will likely keep gaining centrality, at least in the short-term future. It is not clear, however, if it will gain density or if it will, instead, split into more differentiated topics and thematically homogeneous themes. Beyond the behavior or the cluster as such, it is clear that the COVID-19 pandemic will have a long-lasting effect on the way organizations experience and experiment with innovation-driven digitalization and digitalized innovation.

The cluster on "Digital innovation" should be also expected to gain centrality, given the progressive digitalization of different innovation dynamics and activities. Unlike the "Impact of COVID-19", it is also possible that it gains density, led mainly by those nodes associated to innovation management. Looking forward, there is an interesting question about whether, given the progressive digitalization of innovation, an interest in *digital* innovation management will emerge as a result of the progressive strengthening of the interaction between innovation and DT.

"Digitalization" is the only cluster placed in QIV (basic and transversal themes). It has the highest centrality level and the lowest density level in the network. Both could be explained by the centrality and strength of the 'digitalization' node. It is a pervasive concept in the literature on the intersection between innovation and DT and is also multiply connected to relevant topics (some of which got pulled into the cluster). The future of this theme depends on whether more specialized terminology emerges and popularizes e.g., *digital* business model innovation. It will be worth exploring the evolution of the subclusters in more detail, though, for they will probably vary in centrality and density at a different pace. Concerns about business model innovation and innovation ecosystems, for example, fall within separate research agendas, yet both have the potential to individually reshape the research on the intersection between innovation and DT.

## IV. DISCUSSION

Figure 13 shows a taxonomy that succinctly depicts the six clusters and 25 subclusters identified through the co-occurrence analysis. The results are, initially, informative about the overall intellectual structure of the literature at the intersection between innovation and DT. They provide, as well, interesting insights about current or potential (i) controversies, (ii) gaps, (iii) lines for novel and further research, and (iv) alternatives to bridge to other areas of study.

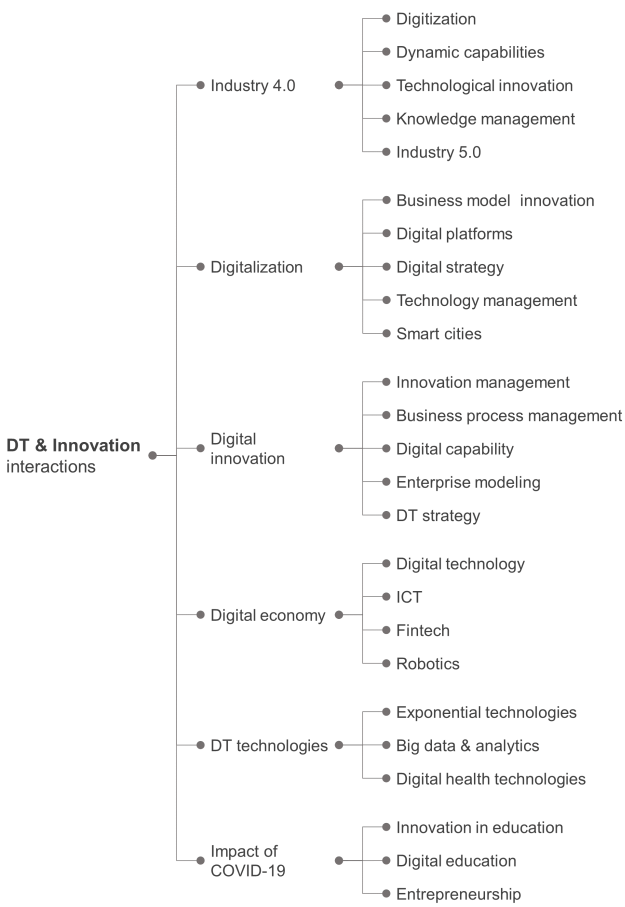



**FIGURE 13. The main themes intersecting innovation and digital transformation.**

For example, as mentioned above (subsection III.4 DT technologies cluster), the cluster on "Digital technologies" is useful to understand the overall level of development of the intersection between innovation and DT. Most digital technologies appear together in the same cluster because a large portion of the literature is describing or introducing to these technologies. This is not entirely a limitation of the intersection, but, rather, a reflection of the more general state of the knowledge about digital technologies and their applications in different settings. The results suggest there is still an unrealized potential for digitalized innovation and innovation-driven digitalization in diverse organizational settings.

The network can equally be used to comparatively identify the relative importance of some concepts in the literature. For instance, the innovation and DT literatures show an increasing interest in cybersecurity [87], [88], and associated concepts such as privacy or ethics, due to the novel risks associated with the progressive digitalization of diverse business settings. Related keywords such as 'cybersecurity' and 'security' ('privacy' and 'ethics' did not have enough occurrences to be included in the analysis), however, have low frequency and play only a peripheral role, even at the level of subcluster. Comparatively, thus, the concern in cybersecurity may either be too novel or advance at a pace that is not high enough to impact the general network.

The pace and extent to which the interest in a concept or theme changes over time could naturally be linked to contextual factors. The network includes an entire cluster about the "Impact of COVID-19", an unexpected episode with worldwide implications that heavily influenced our approach to innovation and DT and will likely reshape their intersection moving forward. The restrictions imposed by the pandemic to physical interaction, for instance, revitalized two digital technologies that have been available for decades, but had yet to be robustly incorporated in digital transformation scenarios: virtual and augmented reality. They have found a new niche in e-health and will probably expand to other markets, given the changes observed during the pandemic in consumer behavior. These restrictions, as well, have opened the door to the materialization of innovative business models that respond to the digital requirements of the 'new normal'.

The co-occurrence analysis also offers some results that are interesting but require additional data for an adequate interpretation. For instance, some concepts or areas of work that figure prominently when the literatures on innovation and DT are addressed separately, do not play a major role at the level of clusters or subclusters. Strategy, for example, has been hailed as the only way to select among trade-offs in innovation practices [89]. It has also been argued to trump technology when it comes to conceptualizing digital transformation [90]. In the analysis, however, 'strategy', 'digital strategy', 'digital transformation strategy' and 'digital business strategy' have relatively low occurrence and centrality. They, in addition, belong to subclusters that are either small and with low impact, or dominated by other nodes (i.e., 'technology' in the *technology management* subcluster).

Similarly, some concepts that play a major role in one of literatures seem to significantly lose relevance when considering the intersection. Knowledge management is a fundamental concept in the innovation literature. In fact, there is a popular and long-standing line of work that approaches innovation primarily from the perspective of knowledge management (see e.g., [91]). Yet, in the network, there is only a small peripheral subcluster (within the "Industry 4.0" cluster) with low centrality and frequency grouping the nodes on knowledge management. This apparent unbalance between the intersection and the literatures taken separately invites several questions about the thematic nature of the intersection, its level of development and the relative contribution of each literature.

It is important to be mindful of a potential limitation: the corpus and, therefore, the network, clusters and subclusters, are the result of specific intellectual and disciplinary dynamics. As mentioned in the introduction, 'digital transformation' does not cover every instance and context of digitalization, thus, it might be biased towards or against certain concepts and topics. In digitalization processes in the public sector, for example, terms such as 'e-government' and 'digital government' are often used over 'digital transformation'. Digitalized innovation and innovation-driven digitalization, however, offer new management alternatives for governments and, more generally, national and regional innovation systems that could greatly benefit the present discussion. Looking forward, then, there is a need to explore how to better define the intersection, so that it captures the interplay between innovation and digitalization in different contexts and levels of analysis.

In the future, it is also worth exploring the intersection between innovation and DT at a finer level of granularity to understand their interplay in more detail. In the innovation literature, for example, there has been a long-standing separation between manufacture and services, small and large enterprises, established and new firms, high-tech and low-tech sectors, among others. Do the different alternatives offered by digital transformation maintain, accentuate or blur these traditional separations? Similarly, there are several areas where organizations must innovate to fully realize the potential of some digital technologies e.g., culture, business model, strategy. How will these areas change to allow for the complete incorporation of truly disruptive technologies and, at the same time, how will they adapt to it?

## V. CONCLUSION

This article explored the interactions between innovation and digital transformation through a co-occurrence analysis. Initially, it provided a bibliometric characterization of the journals, authors and keywords that are included in the literature. Since 2014, innovation and DT have progressively converged in the literature, likely due to the growing virtualization of processes and offerings and the pervasiveness of platform-based businesses, industry 4.0 and digital twins.

Later, this paper described the intellectual structure of each of the six major themes identified: digitalization, Industry 4.0, digital innovation, digital economy, digital transformation technologies, and impact of COVID-19. Taken as a whole, the interactions between and within these themes show the scholarly attention on digitally-enabled processes, products and services, the digital economy dynamics, the role of artificial intelligence and IoT in firms and industrial configurations, and the causes and effects of the pandemic on the accelerated adoption of digital technologies. When exploring possible changes in the interaction, we can see that there are specific research problems or areas that will likely gain centrality, such as digital innovation [92], digital business model innovation [93], digital entrepreneurship [86], innovative development (in the context of digital economy) [94], and innovation and digital transformation to overcome crises [95].

Finally, it presented a strategic diagram where clusters were classified according to their density and centrality. In general, the clusters "DT Technologies", "Industry 4.0" and "Digital economy" are motor – mainstream – themes with high density and centrality. Further research, it was suggested, is likely to increase the density of the last two. "Impact of COVID-19" and "Digital innovation", alternatively, are emerging themes that are relatively unstructured and peripheral, but will probably gain in importance in the future. Lasty, "Digitalization" is a basic and transversal theme, whose influence seems to be driven by the 'digitalization' node. The cluster seems to be a miscellaneous arrangement of seemingly disparate areas that may fragment and become independent and well-developed clusters, should more research be carried out. This may be the case, for example, for business model innovations, digital platforms, and smart cities.

At the general level, we found that, in accordance with previous results, DT affects the way in which innovations are produced, managed and disseminated [11]. Innovation and DT in the context of crises, such as COVID-19, have brought organizational *readiness* to the foreground, stressing the need to tackle challenges at a faster speed. Those organizations that do not gain or develop that *readiness* will more likely struggle to survive.

As shown in Figure 3, this is a relatively novel literature that is only expected to grow, considering the increasing importance of innovation and DT for contemporary organizations. During this anticipated growth, there are a few dynamics that are worth paying attention to, for they have the potential to significantly influence further research on both areas. Changes in the way innovation and DT are approached could come, initially, from dynamics that do not entirely conform to the orthodoxy in these literatures. Historically, for example, innovation studies have disproportionately centered on innovations in an organization's offer i.e., innovation that are commercialized in the market. Yet, a large portion of digitalized innovations are consumed by organization themselves. There are, as well, interesting mechanisms of innovation and value creation in the offer that do not necessarily result from direct intervention on it e.g., data networks effects [96]. Are these dynamics just a matter of novelty or are they evidence pointing towards a deeper change in how organizations approach innovation and how the gain value from it?

Changes in the literature might also come as a result of dynamics that foster major transformations in the market. COVID-19, as mentioned, has brought business model innovation to the foreground. Initially, this is due to the need to respond to the challenges generated by the pandemic. More interestingly, though, the current crisis has offered an opportunity to rethink the building blocks and the cogs and wheels of the economy. A digital economy can be designed simply to support the delivery of traditional goods and services; it can be designed, alternatively, to reshape or work parallelly to a physical economy. A goal that might be worth innovating for in a fully-fledged digital economy is sustainability. Digitalized innovation and innovation-driven digitalization could help, among other things, to increase the scope and impact of novel production trends such as zero-growth or dematerialization. In spite of the challenges, innovation and DT can be paired to produce novel approaches to value creation, not necessarily for the world we live in, but for *desirable possible worlds*: more efficient and resilient and, more importantly, truly sustainable.

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