Proceedings of the 54th Hawaii International Conference on System Sciences | 2021

A Taxonomy for Data Ecosystems

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Abstract

In the increasingly interconnected business world, economic value is less and less created by one company alone but rather through the combination and enrichment of data by various actors in so-called data ecosystems. The research field around data ecosystems is, however, still in its infancy. With this study, we want to address this issue and contribute to a deeper understanding of data ecosystems. Therefore, we develop a taxonomy for data ecosystems which is grounded both theoretically through the linkage to the scientific knowledge base and empirically through the analyses of data ecosystem use cases. The resulting taxonomy consists of key dimensions and characteristics of data ecosystems and contributes to a better scientific understanding of this concept. Practitioners can use the taxonomy as an instrument to further understand, design and manage the data ecosystems their organizations are involved in.

1. Introduction

The increasing number of digital technologies makes data a key driver of the digital economy [1]. The development of new methods for data processing and analysis leads to changes in existing businesses as well as to the emergence of new business models [2, 3]. Furthermore, in today's networked business world data-driven innovation and creation of economic value is less and less created by a single organization or in traditional value chains [4, 5]. Instead, various data sources from different organizations are combined and enriched in cross-industry, socio-technical networks – so-called data ecosystems [5, 6, 7]. Some authors believe that in today's age, involvement in ecosystems is no longer a choice, but rather a necessity for companies to unlock the benefits of data sharing [6, 8, 9]. This is confirmed by the management consulting firm McKinsey who believes that ecosystems will generate 30 percent of the global gross domestic product by 2025 [10]. However, while data ecosystems are gaining in importance many companies still refuse or fail to share their data and thus are unable to utilize the offerings of data ecosystems [11, 12, 13]. One reason for this is that the research of data ecosystems is still in its infancy, which results in a lack of commonly accepted theories, definitions, and models [14]. In their systematic review of the data ecosystem literature [14] advise conducting further research to gain more knowledge about the characteristics of data ecosystems. In particular, according to [6], researchers and practitioners would benefit from an effective organization and categorization of existing knowledge about data ecosystems. To the best of our knowledge, there is yet no scientific publication addressing the authors' calls in general, or in particular no formal taxonomy showing the key dimensions and characteristics of data ecosystems.

Taxonomies generally help researchers and practitioners to understand and analyze complex domains by providing a structure and an organization of knowledge for the respective research field [15, 16]. Additionally, a taxonomy can be a first step on the way towards the development of a rigorous theory [17]. We, therefore, hypothesize that the development of a taxonomy for data ecosystems would help to understand data ecosystems in its totality and in a more general way and be a contribution to the current body of knowledge [15, 18]. Thus, to address the above-mentioned research gap and to contribute to a deeper understanding of the emerging and developing research field around data ecosystems we aim to answer the following research question in this paper:

Research Question (RQ): *What are the key dimensions and characteristics of data ecosystems?*

To answer the RQ we develop a taxonomy for data ecosystems using the well-used and structured method by [16]. The development of the taxonomy pursues the goal of identifying common characteristics of data ecosystems and making them distinguishable in a consistent taxonomy. Following the method of [16], the process of taxonomy development is carried out successively: First, we analyze previous data ecosystems classifications and related taxonomies.

URI: https://hdl.handle.net/10125/71359
978-0-9981331-4-0

Next, we perform a systematic literature review to complement the findings from prior characterizations by analyzing additional relevant publications on data ecosystems. Third, we derive characteristics by analyzing eighteen data ecosystem use cases to develop a taxonomy with empirical stability and relevance [19]. The triangulation of previous classifications, extant scientific literature, and use cases enables us to develop a taxonomy for data ecosystems with a high relevance for researchers and practitioners. The remainder of this paper is structured as follows: After the introduction, we proceed with outlining the theoretical background on data ecosystems and review related characterization efforts. In section 3, we outline our research approach by describing the taxonomy development method and process. Our developed taxonomy for data ecosystems is presented in section 4. Finally, in section 5, we discuss the implications of our research for theory and practice, limitations, and future research.

2. Research background

2.1 Data ecosystems

The ecosystem concept was introduced by [20], who defined it as follows: "*But the more fundamental conception is, as it seems to me, the whole system, including not only the organism-complex, but also the whole complex of physical factors in the widest sense.*" [21, 22]. Initially, the term was used in biology to describe the interactions between organisms of different species and their environment as an integrated system [23, 24]. Since then new research streams have emerged in which the specific characteristics of the biological ecosystem concept have been transferred to other research contexts [24, 25]. One of the most famous analogies was coined by [26] with the concept of "business ecosystems" [27]. [28] defines a business ecosystem as an "*economic community*" consisting of interacting organizations including producers, suppliers, competitors, and other various stakeholders. The community aims to create new innovative products or services for the customers who are themselves members of the business ecosystem [26, 28]. Thereafter the ecosystem concept has been applied to other research areas e.g. digital ecosystems [9], software ecosystems [29], or platform ecosystems [30]. However, some of these ecosystem concepts overlap both in definition and content [31]. For example are digital ecosystems regarded as "*digital versions*" of business ecosystems and data ecosystems as a special kind of digital ecosystems [32, 33, 34]. The various areas of application share, however, the commonality that the ecosystem concept is used to describe diverse interactions between several actors who contribute to the construction or manipulation of a resource (e.g. business object, service, software or platform) through common activities [6, 11]. In data ecosystems these focused objects are data and their related technologies [6, 35]. On that basis and following other authors ([14, 36]) we see the focus of data ecosystems in the cross-actor generation, processing, and use of data with the goal to create added value for all actors involved.

Due to the different relationships of the actors to the resource, which is in the focus of the ecosystem, various roles with different functions in the ecosystem develop [37]. [6] define a role as a function performed by an actor within the ecosystem. Characteristic for some ecosystem types is the existence of a central role, often referred to as "keystone" actor, which can be largely responsible for the survival and success of the ecosystem [21, 38, 39].

Apart from the existence of a keystone actor, most ecosystems concepts have other specific similarities and characteristics in common which illustrate the differences to traditional value chains and industrial structures [21, 34, 40]. One premise is the lack of clear boundaries of the ecosystem which leads to different degrees of dependency and relationships between the actors and ultimately to a heterogeneous and alternating member base [24, 35]. Another shared characteristic between the ecosystem concepts is referred to as "*co-evolution*" [24, 41]. It describes the process of continuous, interdependent development of multiple ecosystem actors [41, 42]. This is due to the fact that the actors in an ecosystem have cooperative and competitive relationships simultaneously – also known as coopetition [21, 26, 43]. The characteristic "*platform*" is often described as a further similarity between different ecosystem concepts [14, 34]. It describes "platforms" as services, tools, or technologies that ecosystem actors use to contribute to the value creation of the ecosystem [33].

2.2 Related taxonomies

There have already been some efforts in the academic literature to describe the characteristics of data ecosystems, e.g. in the form of typologies or taxonomies. In literature, the two terms typology and taxonomy are often used synonymously [16, 44]. However, one could argue that typologies are conceptually grounded [45], while taxonomies are developed empirically [46, 47]. According to [47], taxonomic classifications are useful in the Information Systems (IS) field because of their practical relevance and their empirical evaluation. In the following we take a closer look at data ecosystem-related taxonomies and systemizations.

[48] developed a framework of specific criteria for a successful establishment of data ecosystems in the humanitarian sector. On that basis, we argue that the authors created a framework for the design and coordination of data ecosystems in a specific sector and not a taxonomy for data ecosystems in general which we aim to develop in this paper.

Regarding the solutions of public problems by making data accessible, [49] developed a taxonomy for so-called "data collaboratives". The authors define data collaboratives as cross-sector collaboration initiatives for the purpose of addressing a societal challenge through the leverage of data [49]. Although [50] see data collaboratives as segmentation of data ecosystems, we argue that the concept of data collaboratives misses some important characteristics of the ecosystem concept such as "co-evolution" or the organizational structures [6, 14].

Based on the works of [48] and [49], [50] developed a framework to characterize data ecosystems based on five dimensions. This framework is, however, focused on the description of data ecosystems in developing countries. We would argue that a framework with a focus on developing countries does not characterize data ecosystems in general, since data ecosystems can emerge in different domains [14] and developing countries have a data-poor context [50].

Focusing on the design of data ecosystems and the relationships among their participants, [51] developed a typology for data ecosystems with the two key criteria resource control and interdependence. This typology, like typologies in general, helps to differentiate between idealized types of data ecosystems but is less assistant when classifying real-world data ecosystems [21], which is the goal of this study. In order to discuss data ecosystem coordination and possibilities for their composition, [52] propose characteristics for the design of data ecosystems. All design dimensions are, however, only two-dimensional which we argue don't reflect the multidimensional character of data ecosystems [36]. Furthermore, the authors give no information about the method they used to develop their design characteristics. Alluding to the multidimensional character of data ecosystems as mentioned above, [36] developed a morphology for data ecosystems using the Service-Dominant Logic (SDL) [53] framework as research perspective. The morphology is, however, focused on the manufacturing industry, which is just one domain in which data ecosystems can emerge [14]. Despite this particular focus, [36] served as a good basis for the first iteration in our taxonomy development process. Table 1 gives a summary of the data ecosystem-related taxonomies and systemizations described above.

Table 1. Examples of data ecosystems-related characterizations and systemizations.

Source	Type	Description
[48]	Success criteria	Framework for data ecosystems in the humanitarian sector
[49]	Taxonomy	Taxonomy of data collaboratives
[50]	Characteristics	Framework for data ecosystems in developing countries
[51]	Typology	Typology of data ecosystems
[52]	Design characteristics	Characteristics for the design of data ecosystem
[36]	Morphology	Morphology of data ecosystems with a SDL perspective

3. Research approach

3.1 Taxonomy development method

For the taxonomy development, we adopted the approach from [16] to the context of our study. This method is well-established in the IS research and has been frequently used in high-ranking journal articles and conference proceedings. The authors provide a taxonomy development approach, which is divided into distinct stages (see Figure 1). In the first stage, one is to define a meta-characteristic and ending conditions that are specific to the purpose the taxonomy strives to achieve. Subsequently, the dimensions of the taxonomy, which need to address the meta-characteristics, are developed. The development can either be done through inductive or deductive iterations. In the first approach, dimensions and characteristics result from a conceptual-to-empirical (C2E) design and are derived from empiricism. The empirical-to-conceptual (E2C) approach focuses on the deduction of dimensions and characteristics from the scientific knowledge base. In the last stage, the taxonomy is evaluated against the ending conditions.

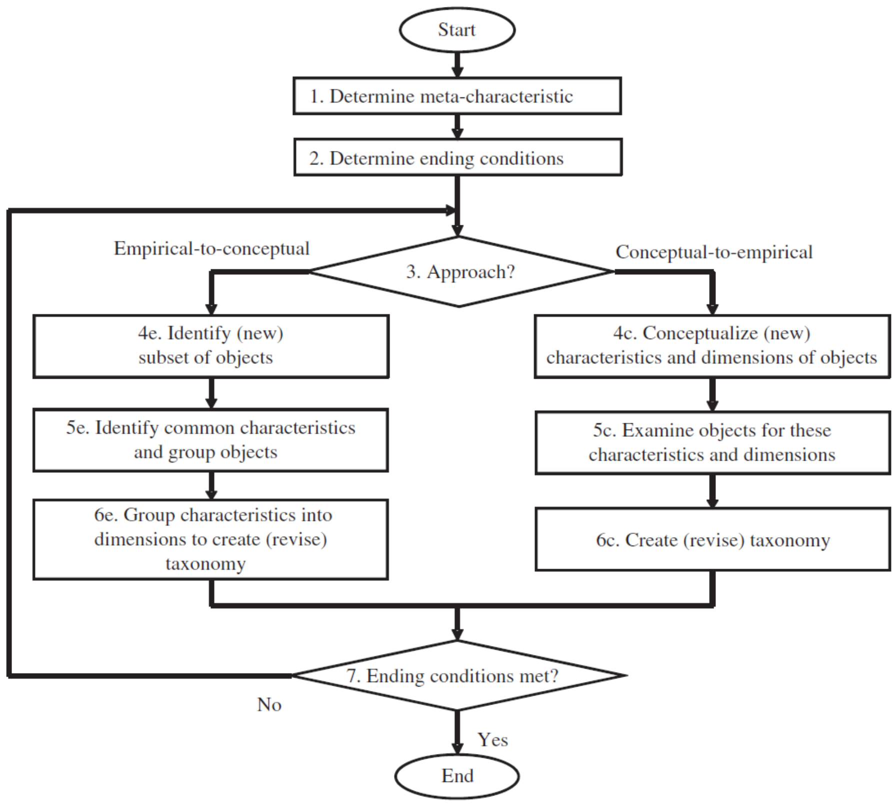

Figure 1. Taxonomy development method by [16]

3.2 Taxonomy development process

Meta-characteristic: In order to contribute to the scientific understanding of data ecosystems, the main goal of our taxonomy is to characterize data ecosystems in general. Therefore, we defined "key-characteristics of data ecosystems" as the meta-characteristic for our taxonomy. This meta-characteristic is the basis for the identification of further dimensions and characteristics.

Meta-dimensions: Our taxonomy has the goal to characterize the concept of data ecosystems in a more general way to include as many heterogeneous data ecosystems as possible [15]. Therefore, it should be more generally designed to cover a large possible field of observation [15, 44]. Following [52] and in the analysis previous classifications, it became obvious that data ecosystems can be examined from the three perspectives economic, technical, and governance. Following previous taxonomies (e. g. [44], [54], or [55]) we chose these three perspectives as meta-dimensions for our study.

First Iteration (E2C): In the first iteration, we derived dimensions and characteristics from previous classifications. We consolidated the in section 2.2 described data ecosystem-related taxonomies and systemizations to serve as a basis for our study. Noteworthy are the works of [14], [36] and [52], which formed, due to their comprehensiveness, a good foundation for our data ecosystem taxonomy.

Second Iteration (C2E): In the second iteration, we reviewed the existing literature on data ecosystems and followed the approach described by [56]. Following the research question, we searched in the Scopus and the AIS eLibrary databases using the search string "data ecosystem" OR "data-driven ecosystem" OR "data-based ecosystem", as these strings were seen as synonyms by the authors. The results were limited to only peer-reviewed and in the English language literature. This resulted in 357 as an initial set of papers. During a first iteration, the results were scanned regarding title, abstract, and keywords for the relevance of data ecosystems. During a second iteration, we searched forward and backward [56]. The result was 28 relevant articles. In addition, we added the 29 articles from a recent systematic review of the data ecosystems literature [14], where the authors selected and reviewed articles based on further searching keywords (e.g. "open data ecosystem" and "big data ecosystem") in further prominent bibliographic databases (e.g. IEEE and ACM).

Excluding the 7 duplicate articles due to the overlap between the two collections, in total 50 (=28+29-7) articles formed a good sample of extant knowledge about data ecosystems.

Third Iteration (E2C): For the third iteration, we again chose the empirical-to-conceptual approach. Through the collection of real-world use cases of data ecosystems, we aimed to extend our findings from literature and provide further empirical evidence. We analyzed the eleven use cases described by [57] to further develop our taxonomy.

Fourth Iteration (E2C): Because not all ending conditions were fulfilled in the third iteration, we conducted a last empirical-to-conceptual approach. We analyzed the seven data ecosystem use cases described by [32] and the two use cases described by [36]. Through the selection of use case descriptions from different sources, we aimed to increase the representativeness of the sample.

Ending Conditions: After the fourth iteration, all objective and subjective ending conditions proposed by [16] were fulfilled as follows: 1) All papers from the sample of the literature review and use cases have been examined. 2) In the last iteration, no object was merged with a similar object or split into multiple objects. 3) Each characteristic of each dimension could be classified with at least one object. 4) No new dimensions or characteristics were added in the last iteration. 5) Neither were dimensions or characteristics merged or split in the last iteration. 6) Each dimension is unique and not duplicated. 7) Every characteristic is unique within its dimension. 8) Each combination of characteristics is unique and not repeated. 9) The taxonomy is concise since no unnecessary dimensions or characteristics were included. 10) There are enough dimensions and characteristics to differentiate every object from each other (robustness). 11) All objects can be classified in the taxonomy, therefore it is comprehensive. 12) The taxonomy is extendible because new dimensions and characteristics can easily be added. 13) Lastly, the taxonomy provides valuable information but non-redundant information for the characterization of data ecosystems (explanatory).

4. A taxonomy for data ecosystems

In this section, we present the final taxonomy in detail, which we derived from the entire taxonomy development process. The taxonomy serves as an answer to the research question of this study, as it identifies the key dimensions and characteristics of data ecosystems. The taxonomy consists of three meta-dimensions, seven dimensions with eighteen characteristics (see Table 2). In addition to the individual dimensions and the corresponding characteristics, the right column shows whether a characteristic is exclusive (E) or non-exclusive (N). We visualize the taxonomy as a morphological box as this is a common type of taxonomy visualization [58] and it generally illustrates the set of relationships contained in a problem complex in an intuitive way [59].

4.1 Meta-dimension: Economic

The first meta-dimension is **Economic**. It considers dimensions from a business-model and competitive dynamics perspective of data ecosystems [32] which is an important perspective to take when analyzing data ecosystem [14].

The dimension **Domain** relates to the environment or setting where a data ecosystem emerges and therefore which data are in the focus of the ecosystem [14]. As noted by [14] data ecosystems can emerge in the *scientific* domain (see e.g. [57] or [60]), the *governmental* domain (see e.g. [61] or [62]) or in an *industry* domain (see e.g. [36] or [63]). Although the term open data ecosystem also exists in the literature, it should be noted that open data can play a role in all three of these domains and therefore does not constitute a domain of its own [61, 62]. This dimension is non-exclusive since one premise of the data ecosystem concept are blurred boundaries and overlapping industries [14, 21, 52].

The dimension **Purpose** describes the strategic focus the data ecosystem is aiming for. The added value of data ecosystems does not come from sharing data alone but rather from the (re-)usage of data by the different, independent actors [32]. One main goal of the data sharing in a data ecosystem can be the creation of *innovation* [64, 65], which can, for example, result in new digital value propositions [32]. The second possible objective of data ecosystems is the *interaction* between the actors [14, 66, 67]. These interactions can consist of communication or the transfer and sharing of knowledge and experience [32, 51, 63]. The third possible purpose of data ecosystems, especially for platform-based data ecosystems, is the facilitation of *transactions* between the data ecosystem actors [32, 68, 69]. Here, the platform or ecosystem provides interfaces to enable transactions between organizations that might otherwise not be able to complete transactions [70]. Since a data ecosystem can have several purposes at the same time the dimension Purpose is non-exclusive.

Table 2. Final taxonomy for data ecosystems visualized as a morphological box

Meta-dimension	Dimension	Characteristics				E/N
Economic	Domain	Scientific	Government	Industry		N
	Purpose	Innovation	Interaction	Transaction		N
	Organization	Keystone-centric	Platform-centric	Marketplace-based	Decentralized	E
Technical	Infrastructure	Centralized		Distributed		E
	Openness	Open		Closed		E
Governance	Interdependence	Tightly Coupled		Loosely Coupled		E
	Control	Central		Decentral		E

In connection with the previous two dimensions is the dimension **Organization**. It refers to the different kinds of relationships, interactions, and organization of the actors which form a data ecosystem [14, 32, 71, 72]. In our research process we found the following forms of data ecosystems organizational structure: *Keystone-centric*, *platform-centric*, *marketplace-based*, and *decentralized*.

A keystone-centered structure can be seen when the actors are organized around a keystone actor (see e.g. [62]) who is directly or indirectly responsible for providing a large part of the data in the ecosystem [6]. In a platform-centric data ecosystem organization structure a platform provides an infrastructure and services to support the sharing and usage of data within the ecosystem (see e.g. [36]). The release of data on a platform can reduce the cost for data provision and mitigate interoperability and usability issues [14, 73]. A marketplace-based structure (see e.g. [57] or [63]) provides, besides a technical platform, additional components and functions, e.g. business models, applications and rules and services for data sharing, as part of the data ecosystem infrastructure [63]. In addition to these more centrally organized forms of organization, we observed data ecosystems in our study that have a more decentralized, distributed form of organization (see e.g. [57]). These data ecosystems are characterized by the absence of a central actor but are connected by their common goal of jointly creating value [14, 57]. Although the organization form of a data ecosystem can change over time [52], we argue that a data ecosystem can only have one dominant form of organization at a time, which makes the dimension mutually exclusive.

4.2 Meta-dimension: Technical

The second meta-dimension is **Technical**. It refers to the characteristics of the technical architecture of the data ecosystem [36, 50].

The **Infrastructure** dimension specifies the main technical infrastructure which is used to share data within the data ecosystem [32, 50]. The collaborative use of data can, on the one hand, take place through a *central* infrastructure, e.g. a proprietary platform [32, 52]. See for example [36] where an organization from the manufacturing industry wants to develop an analytics platform to offer data-driven services to customers worldwide. On the other hand, the data ecosystem can use a *distributed* infrastructure for data sharing through the use of distributed ledger or a peer-to-peer technologies (e.g. the International Data Space) [32, 57]. Data ecosystem use cases using a distributed infrastructure are described by [57]. This dimension is mutually exclusive.

Openness concerns the degree of access to the data ecosystem. This can either be *open* or *closed* [32, 36]. A data ecosystem which is *open* is free for everyone to join [32, 50]. A closed data ecosystem, however, has barriers to entry. These entry barriers can be technical barriers, e.g. the need for a proprietary technical standard or technology, or legal barriers, such as a required membership or multi-lateral contracts [32, 50, 74]. This dimension is mutually exclusive as well.

4.3 Meta-dimension: Governance

The third meta-dimension is **Governance**. It regards data ownership and actor dependency aspects within the data ecosystem [32, 36, 51, 75].

The degree to which ecosystem actors are connected and dependent on each other is described by the dimension **Interdependence** [51]**.** Similar to actor interactions and relationships in other ecosystems [21, 41], actors in data ecosystems can be *tightly* or *loosely coupled* [51].

The dimension **Control** refers to the control of the essential data resources in the data ecosystem [51]. The key data resources can be controlled by a *central* actor, e.g. a keystone actor, or can be *decentralized* and therefore spread across the multiple actors in the data ecosystem [21, 32, 51]. This decentralized data distribution and resource sharing can take place, for example, via shared digital twins technologies or via alliance-driven platform architectures [32, 76]. A decentralized control as a governance mechanism within a data ecosystem generally results in data owners retaining more control and sovereignty over their data [32, 57, 77].

5. Conclusion

Through the application of the taxonomy development method by [16] we developed a taxonomy for data ecosystems. The taxonomy consists of seven key dimensions and eighteen characteristics of data ecosystems and therefore gives an answer to the research question of this paper.

From our results we can draw several implications for theory and practice. Regarding **scientific contributions,** our work contributes to a deeper understanding of the still relatively new and unexplored research field around data ecosystems. Our taxonomy, which was derived from the scientific knowledge base and from empirical use cases, aims to expand the existing body of knowledge and specify the common understandings and definitions of data ecosystems. The results of this study serve as a tool to describe data ecosystems in-depth and explicitly and can, therefore, help researchers to distinguish between different data ecosystems [17]. Furthermore, our results can be the basis for the development of engineering methods and processes for the management and development of data ecosystems which are still missing in the scientific literature [14]. Finally, our taxonomy is a first step towards the development of theories and fundamental concepts of data ecosystems, which are similarly missing in the scientific literature [14, 17].

As for **managerial contributions**, the developed taxonomy provides an instrument to analyze and describe the structure and characteristics of data ecosystems. The taxonomy can, firstly, be used to better understand the ecosystem in which an organization is already involved. Secondly, the taxonomy can then be utilized by practitioners to actively shape the ecosystem to their own advantage. A better understanding of the surrounding data ecosystem helps organizations to better manage the ecosystem in their favor and generate more value from it [14]. Finally, the taxonomy can be leveraged by organizations to build and design new ecosystems with the goal of utilizing the advantages of cross-company data sharing in data ecosystems [17].

Our study is, naturally, limited by a number of **limitations** that must be taken into account when interpreting the results. Due to the continuing rapid technological and organizational progress in the digitization and since it is still an under-explored research area [1, 14], the concepts around data ecosystems are constantly evolving. Thus, our taxonomy is a time-bound snapshot that needs to be updated frequently to remain relevant and to consider new dimensions and features produced by the progress of digitization. Secondly, the lack of a well-accepted definition of data ecosystems makes it difficult to distinguish between related concepts, e.g. alliances and networks, and related ecosystem concepts, e.g. digital and platform ecosystems [14]. Finally, although the taxonomy is based both on the analysis of the scientific literature and on the analysis of empirical use cases of data ecosystems, the data collection itself is open to interpretation, which is why other researchers might derive other dimensions and characteristics depending on their personal influences, preferences and biases. Regarding the selection of literature and use cases, there is also a limitation regarding the extent and scope of the taxonomy. Although the motivation of this study was to develop a more general and cross-sectoral taxonomy, it should be noted that most of the literature examined comes from the IS field and may therefore represent a limitation and could be a bias to this research area. Also the empirical samples examined probably do not cover all domains in which ecosystems can develop, which is why the transferability of the results cannot be fully guaranteed and instead leaves room for further practice-oriented research.

In general, the limitations show possibilities for **future research** avenues. One possible next step, which is common in IS taxonomy research [19], is the derivation of archetypical patterns for data ecosystems. Based on the identified archetypes, it could be investigated whether some archetypes are more successful than others, from which design principles for data ecosystems could be derived. Furthermore, data ecosystems that use distributed technologies, such as distributed ledgers or peer-to-peer technologies, are not yet well studied due to the novelty of the technologies and thus promise further research opportunities [57, 76]. We therefore assume that further dimensions or characteristics may emerge, especially regarding the dimensions *Infrastructure* and *Control*. This study could, for instance, not identify any characteristics regarding incentive systems and the distribution of benefits within the ecosystem. However, these issues are becoming increasingly important, especially in distributed and decentralized data ecosystems [32, 51].

6. References

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