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TOWARDS A COHERENT PERSPECTIVE: A LITERATURE REVIEW ON THE INTERPLAY OF THE INTERNET OF THINGS AND ECOSYSTEMS

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Abstract

The success of the IoT is inextricably linked to the balanced interplay of technological, organisational and economical interdependencies that occur in the cyber physical IoT ecosystem. Despite growing scientific interest, recent literature lags behind cumulativeness and focuses on individual constitutions of the IoT rather than on a comprehensive and coherent understanding. To better position the IoT as a whole - that is more than the sum of its parts - we take an ecosystemic perspective on the phenome and systematically identify and analyse a collection of 70 relevant publications on the IoT ecosystem. We intend to give the first comprehensive overview of the ecosystem construct in the IoT, including a systematization of the existing literature and thus contribute to the synthesis of prior fragmented literature. Drawing on an ecosystem view we aim to reveal research avenues for the IS community that none of the IoT' s individual constitutions can provide.

Keywords: Internet of Things, Ecosystem, Literature Review

1 Introduction

Imagine your refrigerator recognizing the products you have consumed after breakfast and immediately sending a shopping list to a partnering grocery store. After leaving work, you get a notification on your car´s board computer where you can choose whether you want to pick up the groceries at the store or have them delivered directly to your house. On the way home, the heating in your house notices that the temperature has dropped and regulates the thermostat just before your arrival.

All these activities take place without human interaction, only on the basis that these objects are equipped with sensors and wireless technologies that provide information about their environment, context and location (Pueschel et al., 2016). This interconnection between everyday objects and the digital world is coined as the Internet of Things (IoT) and implies a crucial trait: The IoT does not function in isolated individual systems or industries but reveals its actual value as a representation of the whole, which is more than the sum of its objects. Therefore, the identity of the IoT can be constructed by its objects - such as cars, heaters or refrigerator – and the ongoing interactions between them, enabling things that none of these objects could perform on their own e.g., turning on the heater when the vehicle is near (Hoffman and Novak, 2018).

In the literature, Hoffman and Novak (2018) describe the IoT as a collection of heterogeneous objects that interact with each other in three different dimensions: within-assemblage (component-to-component), part-whole (component to assemblage) and between-assemblage (assemblage to assemblage). However, the multivalent interactions within the IoT space are not limited to physical devices only. There is a socio-technological phenomenon encompassing individual organizations and entire markets. Against this background, current IoT literature points to three characteristic notions: First, actors in the

IoT depend on multivalent actor to actor relationships to cover the broad spectrum of technical resources, data and know-how (Bilgeri et al., 2017). Second, the IoT is diverse and includes individual entrepreneurs, small communities, public sectors and large organizations from large industries (some of them with leading roles in the second and third industrial revolutions) with diverse organizational logics (Nicolescu et al., 2018). Third, the IoT does not follow any classical segmentation, such as markets in industrial, business and consumer segments, or domains such as public and private. Rather, actors from one domain can complement actors and services in the others (Wortmann and Flüchter, 2015; Nicolescu et al., 2018). Given these inherent characteristics of the IoT - complementary dependencies, heterogeneous organizational formations and a high compulsion for actor-to-actor exchange - a certain degree of structure is required, giving rise to the concept of *IoT ecosystem* (Ng and Wakenshaw, 2017).

Looking at the current ecosystem research specific for the IoT, a fragmented picture emerges that (i) treats individual static aspects (such as sensing, communication and processing technologies) rather than the phenomenon and its inherent dynamic setting as a whole and (ii) largely evolved in relatively isolated silos, not building on the existing body of ecosystem research and (iii) is conducted in research projects such as ETSI or AIOTO of the European Union, which have not yet made it into the mainstream IS literature. However, the increasing interconnection of the physical and digital worlds calls for a deeper understanding of the interplays within the IoT ecosystem. A systematic literature review that focuses on the interrelations between the IoT and the ecosystem construct retains the possibility to, first, contribute to consolidating the perspectives of prior fragmented research, second, relate the existing immature contributions of the IoT ecosystem to established ecosystem bodies, and third, identify important research gaps for the IS community (Webster and Watson, 2002). By reviewing existing works, we aim to contribute a more precise understanding of the IoT ecosystem and enable future research to position this construct as unit of analysis. Specifically, the literature review strives to answer the following two research questions:

1. What is the current state of research regarding the ecosystem construct in the IoT?

2. What are future avenues for IS-Research considering the IoT as an ecosystem?

To answer the research questions, we systematically selected and analyzed 70 peer reviewed contributions (Webster and Watson, 2002) covering relevant topics related to IoT and ecosystems. According to Rivard (2014), an important preliminary step in constructing theory on new IS-enabled phenomenon, such as the IoT, is a concise review of existing literature body with the goal of contributing to construct clarity. While doing so, guided by Suddaby (2010), we paid special attention to the used definitions of the construct, underlying theoretical concepts (e.g. platform or innovation ecosystems) and the scope of application (e.g. in a certain domain), as well as logical consistency, i.e., coherence of all of the aforementioned aspects. Thus, we followed distinguished representatives and their accompanying literature reviews which have advanced the understanding of important IS constructs (e.g. Burkhart et al. 2011 with regard to business models or Nischak et. al 2017 regarding business ecosystems).

This research in progress paper is structured in four phases: First, we provide a brief review on digital ecosystems literature and outline existing ecosystem-conceptualizations in the IoT. Second, we present the methodical approach of our conducted literature review. Third, we give an initial insight into the analysis of the selected literature and our expected contributions.

2 Background

In the following, we briefly describe the important characteristics of digital ecosystems and outline three conceptualizations of the IoT which are discussed in prior research.

2.1 Theoretical background on ecosystems

In existing work, the term ecosystem emerged in different research domains, including innovation ecosystem (Adner and Kapoor, 2010), business ecosystem (Nischak et. al, 2017), service ecosystem (Barrett et al., 2015), digital business ecosystems (El Sawy and Pereira, 2013), platform-based ecosystems (Tiwana et al., 2010), technology ecosystem (Adomavicius et al., 2008), all while emphasizing different aspects of the construct depending on the issued unit of analysis. However, the general reasoning behind ecosystems is not a newfound stance in the scholarly conversations. Drawing on analogies to biology, the term generally refers to a group of interacting organizations that depend on each other's activities. Particularly, in the IS domain the construct have taken a front-seat in elaborating ecosystems dynamics in platform settings such as personal computers (Bresnahan and Greenstein, 1999), video game consoles (Iansiti and Zhu, 2007), smartphones (Tiwana et al., 2010; Yoo et al., 2010; Ghazawneh and Henfridsson, 2011) and web systems (Evans et al., 2006; Ghazawneh and Henfridsson, 2011). Here, the rich body of ecosystem literature provided some sort structural lens for studying innovations, products, or services, who might belong to different industries and need not be bound by contractual arrangements - but have significant interdependence. Particularly, the ecosystem perspective allowed researchers to explain the ecosystem's inherent value creation process i.e. what value is created how and for whom and the associated governance and interaction structures i.e. who does what, who controls what and how everyone will benefit (Adner, 2016; Edelmann, 2015; Eisenmann et al., 2011; Iansiti and Levien, 2004). Given this powerfulness of current ecosystem thinking (Basole, 2014), we see the construct in a pole position to explore the IoT phenomenon.

2.2 Prior conceptualization of the IoT as ecosystem

In current IoT literature, three ecosystem conceptualizations are discussed: First, IoT as a service-ecosystem in which collaboration is focused on the exchange of services. Second, the IoT as a system of systems where different IoT sub-systems evolve and form the overall IoT ecosystem. Third, the IoT as a platform-ecosystem where different modules are shared by as software core and add functionality.

First, the basic principles of the *IoT as a service ecosystem* become clear if IoT services represent the constitutional basis of actions. The focus of this conceptualization shifts away from physical objects such as light bulbs and cars (goods dominant logic) towards the service that IT-enabled objects in the IoT can provide (Vargo and Lusch, 2018). Against this background, the IoT service ecosystem is a community of interacting entities (including consumers, firms, regulators and artificial intelligent actors) coevolving their capabilities and roles while relying on one another (similar to Hoffman and Novak, 2018). The theoretical foundation can be derived from the conceptualization of a service ecosystem as a self-contained, self-adjusting system of mostly loosely coupled actors connected by mutual value creation through service exchange (Lusch and Nambisan, 2015). Given these conceptualizations, scholars have utilized the service perspective on the IoT from different perspectives, e.g. regarding proper service design paradigms for the IoT (Suparna et al., 2015), frameworks supporting the integration of various IoT services (Spiess et al., 2009) or specific business models emphasizing the service character e.g., sensing as a service (Perera et al., 2014).

Second, the fundamental characteristics of the *IoT as a system of systems* (SoS) is the interconnection of various independent and detachable IoT-sub-systems, subsequently forming an IoT super-system. A system is described as the interconnection and organization of objects, which are embedded in a given environment (Karcanias and Hessami, 2010). Alkhabbas et al. (2016) considers the IoT as a collection of sub-systems. In this context, the components of an IoT SoS are individual systems posing inherent configurations. As an example, Alkhabbas et al. (2016) illustrate a smart street lamppost system, in which the dimming factor and light color (lamp configurations) depends on the distance and speed (cars configurations) of passing cars. Particularly the linkage between systems (e.g., cars and lamps) enabled through shared interfaces, lays the foundation for an IoT-super-system comprised of independent and detachable subsystems (Smedlund et al., 2018).

Third, the concept of the *IoT as a platform ecosystem* is characterized by a software core and specific modules that add to its functionality. In turn, IoT platform ecosystems refer technically to collections of modules specific to the platform, e.g. games, apps or add-ons (Gawer, 2014; Tiwana et al., 2010). The IoT can therefore be further conceptualized as architectural modules related to the notion of modularity specific to one or multiple platforms. Although there is no common consensus in the literature on what a platform in the IoT is, more than 450 IoT platforms have already been launched in practice, exploiting the economic opportunities of the IoT (IoT Analytics, 2017). Drawing on current IoT literature (Hodapp et. al 2019) they can be interpreted as a particular type of digital platform that (i) enables the interaction between smart objects and end users (Mineraud et al., 2016), (ii) by providing a core functionality to third party developer to support the development of modular applications (Wortmann and Flüchter, 2015), (iii) on the basis underlying infrastructure and different data sources. In the IoT as a platform ecosystem, the transfer of skills, information and know-how between human actors, objects and/or digital agents poses a significant aspect and can be represented through modules specific to an IoT platform (Ng and Wakenshaw, 2017).

The systematic analysis of the existing IoT ecosystem conceptualizations present several limitations i) The conceptualizations are not systematically derived but were rather developed ad-hoc and neglecting the already existing mature body on ecosystem literature. ii) The presented conceptualizations were mostly developed in a “thing focused” manner and not linked to important business or organizational facets of the ecosystem concept, thereby neglecting components of a holistic consideration. For instance, roles, activities and relevant actors - behind the "things" - remained largely unexplored. (iii) The introduced concepts do not build on prior IoT literature, that contains important fragments of the IoT ecosystem - such as organizational capabilities (Bilgeri et al., 2017), rules of exchanges (Nicolescu et al., 2018) or collaboration behaviors (Zhou et al., 2015) - all crucial constitutional elements of the ecosystem concept - leading to a lack of coherence and cumulativeness. Therefore, a comprehensive literature review containing literature from a broad spectrum of IoT domains supports systematization and synthetization of IoT and contributes to cumulativeness of the phenomenon.

3 Methodology

3.1 Building a literature sample

For a better understanding the nature of the IoT-Ecosystem, we applied a two-step literature review. The first step comprises the building of a sufficient and complete set of the relevant literature (Webster and Watson, 2002). For that reason, we applied a key word search. We included the two main keywords “Internet of Things” and “IoT” and selected articles focusing on ecosystems, based on the motivation of this study. The title, abstract and keywords of the articles were searched for parts of this term. We conducted the search in five well-known databases AIS electronic Library (AISeL), ScienceDirect, EBSCO EconLit, EBSCO Business Source Complete and ICS Web of Knowledge, resulting in an initial set of 802 publications.

In order to achieve a scientific publication sample, we focused on contributions with a VHB-JOURQUAL3-Ranking (JQ3) from A+ to C[1] (similar to Nischak et al., 2017). The focus on a broader spectrum of journals is particularly necessary, as the IoT is a new and little researched phenomenon, hence IoT literature is slowly diffusing into high-quality journals. In turn, a focus on top journals could a priori exclude relevant parts of IoT research. Nonetheless, to meet the necessary scientific rigor, each considered publication needed to be published in a peer reviewed journal or conference. In following that approach, we obtained a set of 426 publications that meet the necessary scientific requirements and serves as a starting point for an in-depth analysis. For this purpose, the abstract, introduction, discussion and conclusion parts were examined in detail with regard to their respective contributions. Articles that either did not explicitly highlight ecosystems and elements of their relationship to the overall IoT or did not provide a conception of the Internet of Things and related elements were excluded, resulting in a final set of 70 research articles. Table 1 illustrates the selection process and gives an overview of the research domains, publication dates and sample composition. The latter points out the increasing importance the IoT ecosystem in related literature since 2013.

[1] http://vhbonline.org/vhb4you/jourqual/vhb-jourqual-3/

VHB Ranking	Journal	Number of Pub.	VHB Ranking	Journal	Number of Pub.
A	European Journal of Information Systems	2	B	International Journal of Production Research	2
A	ICIS 2016 Proceedings	2	B	Technological Forecasting and Social Change	7
A	ICIS 2017 Proceedings	3	C	Business Horizons	4
A	Research Policy	1	C	Business Process Management Journal	3
B	ACM Computing Surveys	3	C	Computers in Industry	2
B	Business & Information Systems Engineering	1	C	Hawaii International Conference on System Sciences 2017 (HICSS-50)	4
B	Communications of the ACM	1	C	Hawaii International Conference on System Sciences 2018 (HICSS-51)	7
B	Computers & Industrial Engineering	2	C	IEEE Software	4
B	Computers & Operations Research	1	C	Journal of Marketing Management	1
B	ECIS 2014 Proceedings	1	C	PACIS 2016 Proceedings	1
B	Information Systems	3	C	Production Planning & Control	1
B	International Journal of Innovation Management	2	C	Sustainability	4
B	International Journal of Production Economics	3	C	Telecommunications Policy	1
B	International Journal of Production Research	2			

Table 1: Classification of the Literature Sample according to VHB Jourqual 3 [1]

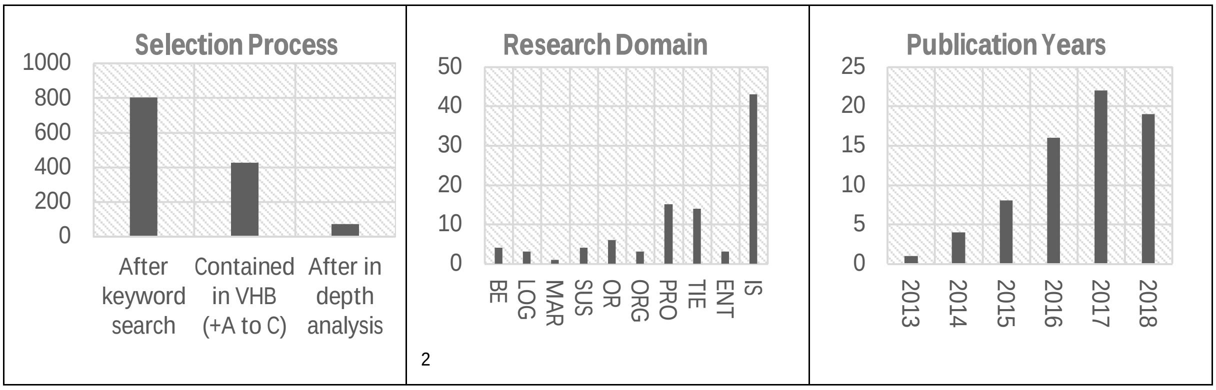

Table 2: Characteristics of the literature selection process and the resulting sample

3.2 Development of a concept matrix

The second step comprises the development of a concept matrix to classify the collected articles (Webster and Watson, 2002). To identify text similarities and patterns in the individual articles we applied a

[2] The classification is following the VHB logic where a journal can be assigned to several research domains. BE = Business Economics; LOG = Logistics; MAR = Marketing; SUS = Sustainability Management; OR = Operations Research; ORG = Organization and human resources; PRO = Production Economics; TIE = Technology, Innovation and Entrepreneurship; ENT = Entrepreneurship; IS = Information Systems

qualitative content analysis. The qualitative content analysis approach of Mayring (2014) seemed most appropriate as it is an established and in multiple research streams successfully applied analytical technique. Following the approach by Mayring, it is recommended to (1) define units of analysis, (2) develop a category system with regard to the respective research questions, (3) code all relevant passages in the text with regard to the categories, (4) extend or refine the ex-ante developed classification framework, (5) identify source-overarching core statements, and (6) interpret and discuss the final results. The first step consists of defining a single sentence as the smallest encodable analysis unit. While reading all identified articles carefully, relevant assessed sentences for answering the research questions were highlighted Next, by recapitulating our formulated research goals as well as Burkhart et al. (2011) and Nischak et al. (2017) category catalogues, we derived an initial category system which was successively refined as we proceeded in analyzing the literature.

Category	Dimension			
Classification of IoT Literature(d_1)	Data Sources (d_1)	Ecosystem Focus(d_2)	Ecosystem Consideration(d_2)	
IoT Ecosystem Grounding(d_2)	Ecosystem Conceptualization(d_2)	Descriptive Ecosystem Characteristics(i)		
IoT Ecosystem Enablement (i)	Technical Layer (d_2)	Enabling IS (i)	Ecosystem Integration (i)	Standard Setting (i)
IoT Ecosystem Contextual Conditions (d_2)	Ecosystem Roles (i)	Members Motivation (i)	Domain (d^2)	
Legend: deductively derived from (d_1) = Burkhart et al. (2011) or (d_2) = Nischak et al. (2017); (i) = inductively derived from publication sample				

Table 3: Concept Matrix Framework

A final category system with 4 categories (e.g., ecosystem grounding, ecosystem enablement) and 12 dimensions (e.g., technical layer and ecosystem integration) was created. The four categories were deductively obtained on the basis of the concept matrix framework by Nischak et al. (2017) and Burkhart et al. (2011). During the entire analysis process, they were revised and successively refined. Each category was either defined by theoretical considerations or resulted from recurring text patterns and phrases, with most of the categories encapsulating a deductive character. The categories and attributes developed, however, were usually derived inductively from the text. Each identified and relevant text element was then assigned to a category. Subsequently, the information and segments of the categorical sentences were discussed and compared, resulting in 47 individual attributes (description not part of the manuscript) specifying the dimensions (Webster and Watson, 2002). In the course of this work, they are referred to as attributes. In order to ensure the reliability of the content analysis and the derived research model, the whole process was conducted by two independent researchers. The last step of the qualitative content analysis according to Mayring (2014), the initial critical discussion, is carried out in the chapter "Initial results and expected contributions". An overview of the entire categories and dimensions of qualitative literature research can be found in the following table 2.

3.2.1 Classification of IoT literature

The first category "classification of IoT literature" is deductively derived from Burkhart et al. (2011) and contains categories supporting the classification of IoT ecosystem literature. The dimension "data source" presents the origin of the studied IoT ecosystem data i.e. either the analyzed IoT publications build on empirical or literature-based information (Burkhart et al., 2011). Moreover, the dimension "ecosystem focus" presents the significance of the ecosystem construct in IoT literature sample; either as a central element or only as a sub-topic (Nischak et al., 2017). The "ecosystem consideration" category represents the addressee of the ecosystem-related study and is borrowed from Burkhart et al. (2011), outlining whether the ecosystem is presented primarily for a business or technical purpose.

3.2.2 IoT ecosystem grounding

The category "ecosystem grounding" is deductively derived from Nischak et al. (2017) and is well-fitting category considering the motivation of our study to elaborate on the theoretical saturation of the construct in the IoT. The dimension "ecosystem consideration" clarifies the theoretical foundation and underlying constructs of IoT ecosystems and expresses dominant types of perspectives in in the analyzed IoT literature. i.e., are the applied IoT ecosystem perspectives anchored in prior ecosystem literature (Nischak et al., 2017). Since the IoT ecosystem has an ambivalent nature, the next dimension "descriptive ecosystem characteristics" represents recurring attributes applied to specify the ecosystem construct in the IoT.

3.2.3 IoT ecosystem enablement

The third dimension “IoT ecosystem enablement” is mostly inductively derived and focuses on empowering categories, supporting the rise and formation of an IoT ecosystem. First, to understand on what technological level IoT ecosystems are being analyzed, we employ the concept of a layered architecture deductively derived by Yoo et al. (2010). Second, the category "enabling IS", like the remaining three, poses an inductive character and includes the relevant technologies that have been studied for the formation of the IoT ecosystem. Third, to better comprehend the dependencies between different physical and digital IoT spaces within the IoT ecosystem, the category "ecosystem integration" is employed. Fourth, as the procedures for "setting standards" play a crucial role in the IoT ecosystem, e.g. the commitment to a common protocol to facilitate exchange, the category aims to cover the standard setting mechanisms that have been studied in the IoT.

3.2.4 IoT Ecosystem contextual conditions

The fourth category “contextual conditions” is derived deductively and aims to create a deeper insight into current gravitas shaping the IoT ecosystem. The dimension "ecosystem roles" contains a number of generic roles that are typically addressed by participation in the IoT ecosystem and have been adopted by the role configurations in the digital platform ecosystem literature (Tiwana et al., 2010). The “members motivation” dimension refers to the motivational spectrum for actors to participate in an IoT ecosystem. Since the IoT is a ubiquitous phenomenon, the category "domain" represents the specific industry background of the respective ecosystem studies.

4 Initial Results and Expected Contributions

Following the methodology outlined in the previous section, a first initial concept matrix with 48 individual attributes presenting the role of the ecosystem construct in the IoT are derived from the 70 identified articles (table 3). The developed classification framework provides a preliminary answer to our first research question. Due to the research’s ongoing progress, it is necessary to acknowledge that we are still defining and refining the presented dimensions and respective attributes. However, initial analyses of our literature sample and concept matrix indicate that the consideration of IoT as an ecosystem holds some valuable research avenues for the IS community that have not yet been answered. In the following, we will delineate a first initial research gap:

How is collaboration designed in the IoT ecosystem? If we take a closer look at the current collaborations in the IoT, they represent different formations: (i) Some standard-setting organization have emerged, including traditional such as the IEEE, and novel IoT specific ones, e.g. OneM2M, providing the technological foundation for collaboration. (ii) Contrarily, major technology firms, e.g., Cisco and Intel, are participating in alliances to increase collaboration in a certain domain for example, the ‘Industrial Internet Consortium’ in the US, the “Industrie 4.0” in Germany. (iii) There is also an increasing popularity of open source activities, promoting the collaboration on the basis of an community, e.g. IoT Eclipse Foundation (Eclipse IoT Foundation, 2018). Given these technological foundations, the companies in the IoT are free to pursue these standards and lay the foundation for collaboration (Wortmann and Flüchter, 2015). However, while multiple authors elaborated the antecedents of collaboration in the IoT - namely technical interoperability - we observe a lack on what kind of collaboration behaviours emerge after a technological basis (e.g., via common protocols and APIs) is established? Our analysis suggests that, depending on the IoT ecosystem role of the firm, we will get a different set of behaviours and, most likely, organizing structures too. Our three identified roles, IoT platform owner, module producer and facilitator, provide an appropriate starting point for further theoretical considerations (particularly suited for a platform environment). As we further know, that actors in the IoT depend on multivalent actor to actor relationships to canvas the broad spectrum of technical resources, data and know-how (Bilgeri et al., 2017), there is benefit to a comparative analysis of different collaborative approaches that firms exercise for similar problems. For instance, some companies can engage in existing or even manifesting completely different types of ecosystems, while others can choose to collaborate in focal markets, and still others become system integrators and vertically integrated providers across multiple IoT domains (e.g. home, city or car). Is there an inherent benefit to the different approaches for a specific set of IoT ecosystem roles?

In summary, the potential contributions of this paper are as follows. Theoretically, we intend to add to a stream of research that studies the Internet of Things via an ecosystemic consideration, in order to reveal research avenues for the IS community that none of its individual elements could provide unaccompanied by the other factors. On the whole, we intend to better characterize the current state of research regarding the ecosystem construct in the emerging IoT phenomena. Using our selection logic, we have created a sample of 70 relevant articles. We believe that the evaluation of the articles reveals at least four major research avenues (Adner 2016): *(1) How is collaboration designed in the IoT ecosystem? (2) What are governance and regulation mechanisms appropriate for the IoT? (3) How to capture value in the IoT ecosystem?* (4) *How is the coordination within the cyber physical IoT ecosystem managed.* Our first results indicate that a range of different research streams contribute to the identification of the four research directions. For example, the third research gap on value creation in IoT clearly results from the streams Innovation and Entrepreneurship as well as Management where the business model lens is leveraged for exploring the logic of value creation in the emerging IoT phenomenon. After an in-depth analysis of the results, we aim to advise future researchers to mitigate these research gaps.

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