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What's in a Smart Thing? Development of a Multi-layer Taxonomy

by

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Abstract

Digital technologies immerse in our private lives and force businesses to rethink existing work practices. Among the emerging digital technologies, the Internet of Things (IoT) is attributed disruptive potential, as it refers to the equipment of physical things with sensor and communication technologies and to the integration of these things into the networked society. Until today, the IoT is low on theoretical insights. Most notably, smart things, which constitute a vital building block of the IoT and the foundation of IoT-based business models, have been neglected by academic research. Taking a smart thing's perspective, our study aims to complement extant work on the IoT. We offer a multi-layer taxonomy of smart things that comprises ten dimensions structured along the architectural layers of existing IoT stacks (i.e., the thing itself, interaction, data, and services). To evaluate our taxonomy, we used a sample of 50 real-life smart things from the B2C context.

Keywords: Internet of Things, Digital Technologies, Smart Things, Taxonomy

Introduction

Digitalization, which refers to the society's penetration with digital technologies as well as to the associated changes regarding the connection of individuals, businesses, and things (Bharadwaj et al. 2013; Gimpel and Röglinger 2015), substantially impacts our everyday lives. Among these emerging digital technologies, the Internet of Things (IoT) is regarded as one of the most disruptive ones (McKinsey Global Institute 2013). It ranges on the top of the Gardner Hype Cycle, having even overtaken Big Data as the most-hyped technology so far (Forbes 2014). The IoT bridges the gap between the physical and the digital world, equipping merely physical things with sensor and communication technology and integrating them into the networked society (Yoo 2010; Yoo et al. 2012; (Rosemann 2013). Smart things form the building block of the IoT (Borgia 2014; Kortuem et al. 2010). Over 50 billion smart things are estimated to be connected to the Internet by 2020 (Macaulay et al. 2015). Smart things do not only bear the potential of influencing our business and private lives in the future (Atzori et al. 2010). They have already penetrated many application domains. Examples range from smart home automation (e.g., remote accessible locks), smart mobility solutions (e.g., car sharing) to smart health concepts (e.g., safety watch and connected pillbox). Across all application domains, the IoT is attributed huge potential of up to $11 trillion per year in 2025 (McKinsey Global Institute 2015).

Since its introduction, the IoT has been discussed from various perspectives. The contributions by Atzori et al. 2010 (2010), Borgia (2014), or Laya et al. (2014), for instance, comprehensively address topics with respect to engineering challenges and technological requirements. From a business perspective, the IoT's impact on intra- and inter-organizational processes was examined for innovation management (e.g., Caputo et al. 2016), logistics, and supply chain management (e.g., Geerts and O'Leary 2014; Qin 2011). Boos et al. (2013), for instance, offer a framework for balancing control capabilities and accountabilities of human actors using IoT technologies in a supply chain context. Besides the technology-focused and business-to-business (B2B) perspectives, another stream focuses on the IoT's implications on the business-to-consumer (B2C) context. Kees et al. (2015) investigate interactions among smart things, customers, and businesses, complementing traditional B2C interactions with innovative business-to-thing (B2T) interactions. Porter and Heppelmann (2014) and Rosemann (2013) provide strategic insights into challenges and opportunities of IoT-based business models. Turber et al. (2014) and Dijkman et al. (2015) take the business model literature as starting point for developing business model frameworks geared toward IoT-based business environments. They conclude that rethinking a business model's value proposition is the key challenge for organizations to succeed in the IoT. Thereby, the increase in available data, accessible via smart things, is expected to play an essential role (Bucherer and Uckelmann 2011). It is the IoT's inherent characteristic of connecting physical products with the digital world that calls for changing extant business models (Fleisch et al. 2015). Although Fleisch et al. (2015) highlight the essential and changing role of physical products in the IoT, their work focuses on theoretical and practical guidance on the business model level. The individual smart thing, which is a vital building block of the IoT and a foundation of successful IoT-based business models, has not yet attracted substantial attention of academic research. A noteworthy exception is the work of Kortuem et al. (2010) who propose a classification of smart objects. Their work, however, builds on case studies from the B2B context and emphasizes a technological perspective. To entirely understand the transformative potential of smart things, technological considerations must be complemented by a business view (Porter and Heppelmann 2014). Thus, there is a research gap regarding insights into the characteristics of smart things as a vital building block of the IoT. Against this backdrop, we address the following research question: *How can smart things as a vital building block of the IoT be classified?*

In order to answer this research question, we propose a multi-layer taxonomy of smart things in line with the taxonomy development method by Nickerson et al. (2013). We examine smart things primarily from a business perspective, shedding light on selected technical characteristics as far as required for a profound understanding of smart things. When setting up our taxonomy, we deliberately abstract from application domains as we are interested in more general insights into essential characteristics of smart things that help classify and distinguish them. For structural guidance, we draw from extant architectural models referred to as IoT (technology) stacks (Fleisch et al. 2015; Porter and Heppelmann 2014; Yoo et al. 2010). As evaluation, we validated our taxonomy by classifying 50 real-life smart things from the B2C context.

We believe that addressing the research gap via a multi-layer taxonomy of smart things is valuable as such a taxonomy adds to the descriptive knowledge related to the IoT. With the IoT being an immature field low on theoretical insights, it benefits from descriptive knowledge that helps understand smart things as socio-material phenomenon. Thereby, our taxonomy aims to serve as foundation for sense-making research and theory-led design in the future.

Our study is structured as follows: First, we equip the reader with theoretical background regarding the IoT and existing IoT-related architectural frameworks. We then introduce the research method we applied for developing our taxonomy as per Nickerson et al. (2013). As the core of our work, we present our taxonomy of smart things with dimensions and characteristics as well as with justificatory knowledge and examples. As for evaluation, we check the taxonomy's practical applicability and usefulness, classifying a sample of 50 real-life smart things. We also derive preliminary insights into the functioning of smart things. We conclude with discussing limitations and pointing to opportunities for future research.

Theoretical Background

For a long time, there was a prevailing understanding that information technology (IT) is used in the work context only (e.g., enterprise resource planning systems, customer relationship management systems), in particular to improve organization's effectiveness and efficiency (Yoo 2010). Nowadays, however, boundaries between work and private lives are blurring. Yoo (2010) denotes the omnipresence of IT as ubiquitous computing technologies. Prerequisite for the penetration of our private lives are the continuous development of hardware (e.g., miniaturization of processors with increasing performance and power), cost-effective and reliable memory, and an improved broadband communication (Yoo 2010). As a result, everyday artifacts such as refrigerators and televisions become smart artifacts by being equipped with computing capabilities and the ability to connect with the Internet (Yoo et al. 2012). Today, the ideas of Yoo (2010) and Yoo et al. (2012) become manifest in the context of the IoT.

The IoT symbolizes a novel paradigm characterized by the combination of various information respectively digital technologies (e.g., sensing and tracking, Internet protocol, or pervasive computing) (Atzori et al. 2010; Borgia 2014; Yoo et al. 2012). Yoo et al. (2012) characterize the combination of formerly separate user experiences (e.g., quadruple play which combines broadband Internet, phone, TV services, and mobile Internet) as well as the combination of non-digital physical technologies with pervasive digital technologies to generate smart products as convergence. In the IoT, IT is inseparably implemented into physical products, leading to a fusion of the physical and the digital world (Porter and Heppelmann 2014). Consequently, everyday artifacts or physical things of all kinds are equipped with sensor, actor, and connectivity technologies transforming them into smart artifacts respectively smart things (Yoo 2010; Yoo et al. 2012). In line with the revolution of physical things, the IoT requires radically rethinking corporate IT architectures and advances them toward a so-called IoT stack. The latter enables utilizing smart things' expanded capabilities and tapping IoT's transformative business potential.

Although its underlying concept seems intuitive and has already been coined by Ashton in 1999, the IoT still struggles for an accepted definition. This lack of clarity can be partially attributed to the IoT's inherent characteristic of combining two different angles, namely the connectivity and the thing perspective (Atzori et al. 2010; Borgia 2014). In the literature, attempts to define the IoT differ in whether they adopt a thing-oriented or a connectivity-oriented perspective (Atzori et al. 2010). As for the connectivity perspective, the understanding ranges from smart things' general communication capabilities to the connectivity's technical implementation (Mattern and Flörkemeier 2010). For instance, Atzori et al. (2010) and Borgia (2014) provide an overview of enabling technologies and their role in the IoT. Nevertheless, most IoT definitions adopt a broad interpretation of connectivity and do not restrict themselves to a concrete technology. In fact, the distinction between wireless and wired technologies (O'Leary 2013) can be found more frequently as there are IoT definitions that include wired networks (e.g., Chui et al. 2010; McKinsey Global Institute 2013) as well as other definitions exclusively based on wireless communication technologies (e.g., Boos et al. 2013; Mattern and Flörkemeier 2010). Surprisingly, the term Internet itself is rarely used (e.g., Uckelmann et al. 2011) or deemed inappropriate (Porter and Heppelmann 2014) in IoT definitions.

The thing perspective lacks a common understanding either. To reduce the IoT's conceptual fuzziness, an in-depth analysis of the thing dimension is inevitable as things are a vital building block of the IoT (Borgia 2014; Kortuem et al. 2010). Everyday objects, such as cars, refrigerators, or thermostats, form the IoT's nucleus and showcase the IoT's great potential of impacting almost all aspects of private and business lives. Enriched with intelligence (Borgia 2014) – in the sense of "seamlessly integrated communication, sensing and computing capabilities" (Boos and Grote 2012, p. 3), physical things turn into smart things. These smart things combine physical, smart, and connectivity components in a single object (Porter and Heppelmann 2014). Further, the role of mobile devices (e.g., smartphones, tablets) and PCs is regarded inconsistently in the literature. While such devices are included by some definitions (e.g., Atzori et al. 2010; Sundmaeker et al. 2010), they are excluded by others (e.g., Gartner 2013; McKinsey Global Institute 2015; Uckelmann et al. 2011). One reason for this exclusion is that such devices do not exist independently from IT. In line with the second group of definitions, Mattern and Flörkemeier (2010) stress the role of mobile devices and PCs as intermediaries between smart thing, businesses, and users.

Based on this discussion, we define the IoT as the connectivity of physical objects, equipped with sensors and actuators, to the Internet via communication technology. This enables for interactions with and among smart things. PCs, tablets, or mobile phones do not represent smart things, but can act as an intermediaries (Kees et al. 2015).

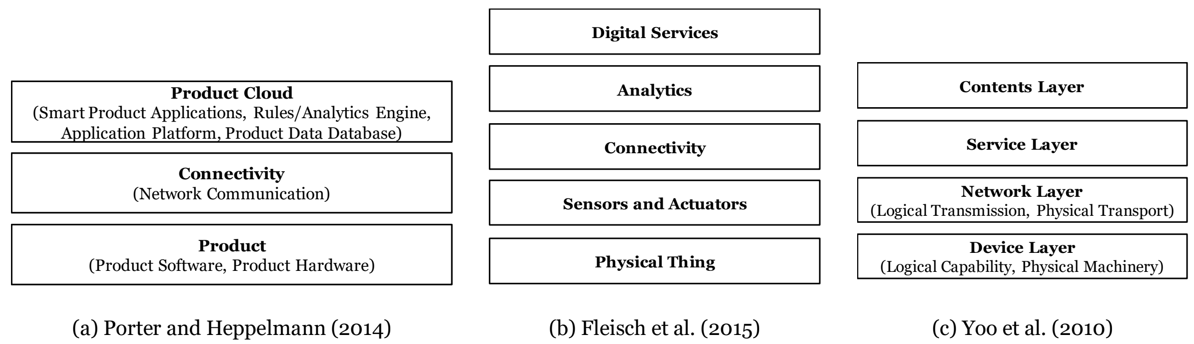

Figure 1. Existing IoT Stacks (Simplified Illustrations)

To tap the full potential of smart things, organizations must further develop their technology infrastructure. For that reason, academia and practitioners intensely discuss architecture models referred to as IoT stacks or IoT technology stacks (Figure 1). Porter and Heppelmann (2014) illustrate how smart things influence the strategic choice of organizations to achieve competitive advantage and which smart thing components influence corporate decision-making. They also propose a multi-layer technology stack. On the bottom-most layer, things are equipped with hardware and software components. The connectivity level allows for connecting things to the cloud layer, which bundles smart thing and analytics applications. The cloud layer also offers platform and database access. Orthogonally, the technology stack includes tools that cater for security issues and help establish gateways to external information sources. Fleisch et al. (2015) offer a similar concept with five layers. They focus on a smart thing's value creation and argue that IT is the key to extend a product's physical to a digital value offering. Although customer value only emerges on the top-most layer named digital services, the IoT stack requires an integrated approach. Fleisch et al. (2015) stress that considering the IoT stack's layers separately makes it hard to leverage the full potential of smart things and their service offerings. In contrast to both aforementioned IoT stacks, which are geared toward smart things in the IoT context, Yoo et al. (2010) introduce a more general layered architecture. Their model comprises four main layers, i.e., device, network, service, and content, which are comparable to the concepts proposed by Fleisch et al. (2015) as well as by Porter and Heppelmann (2014). Yoo et al. (2010) use this model as a starting point, refining it toward a layered modular architecture applicable to product innovation settings. Therefore, they emphasize the loose coupling of layers allowing for multiple combinations.

All IoT stacks and architecture models consider physical things equipped with hard- and software at the most fundamental layer. Further, physical things own a connectivity layer that enables data exchange with users or other things. The analytical layer collects, stores, and processes data from sensors and triggers. On top of these layers so far, it is possible to provide services like mobile applications in the service layer. The layered architecture underlying the IoT reflects characteristics of smart things as well as differences and advancements of smart things compared to physical products. Thus, IoT stacks support understanding the nature of smart things. They establish useful criteria for classifying smart things. For this reason, we use the layered architecture of IoT stacks for structuring the dimensions of our taxonomy of smart things.

Research Method

To answer our research question, we developed a taxonomy as a particular classification scheme. Often used interchangeably with the terms typology or framework, a taxonomy describes an empirically or conceptually derived system of groupings of objects (Nickerson et al. 2013). With a taxonomy at hand, researchers and practitioners are enabled to understand, analyze, and structure the knowledge within a distinct field (Nickerson et al. 2013). These attributes prove particularly beneficial if applied to the IoT – still being a complex, fuzzy, and immature field (Atzori et al. 2010). Thus, we found the method of taxonomy development appropriate for advancing the theoretical insights into smart things. As smart things will continue to be subject to rapid change and technological progress, the taxonomy further intends to offer guidance for determining where new smart things fit in among existent ones and to highlight gaps where new smart things should be developed (Nickerson et al. 2013).

When developing our taxonomy of smart things, we applied the method proposed by Nickerson et al. (2013). This method is based on and extends the approach by Bailey (1994) from the social sciences. Taxonomy development as per Nickerson et al. (2013) enables combining empirical-to-conceptual and conceptual-to-empirical approaches in an iterative manner. In sum, taxonomy development comprises the following steps: determination of a meta-characteristic, determination of objective and subjective ending conditions, choice of approach, conceptualization of dimensions and characteristics, examination of objects for the derived dimensions and characteristics, revision of the taxonomy, and testing of ending conditions. The taxonomy's purpose is reflected in its meta-characteristic, which must be fixed prior to the ending conditions. With the meta-characteristic and the ending conditions set, the conceptual-to-empirical or empirical-to-conceptual approach is chosen per iteration. Using the conceptual-to-empirical approach, the taxonomy's dimensions are conceptualized first, and characteristics are determined for each dimension. After that, real-life objects are mapped to the dimensions and characteristics, leading to an initial or revised taxonomy. In case the empirical-to-conceptual approach is chosen, real-life objects are identified first. These objects are screened for commonalities and differences, grouped into distinct dimensions and characteristics, leading again to an initial or a revised taxonomy. Both approaches are repeated until the ending conditions are met.

When developing our taxonomy of smart things, we conducted three iterations. The iterations are grounded on the following meta-characteristic, which aligns with our research question of classifying smart things: *Characteristics of smart things structured along the layers of existing IoT stacks*. In all iterations, we chose the conceptual-to-empirical approach, considering that the IoT is an immature field. We intended to derive a taxonomy that is valid in the longer term as well as expandable to emerging affordances of smart things. Compared to the empirical-to-conceptual approach, which builds on real-life objects to derive dimensions and characteristics, the conceptual-to-empirical one is more likely to achieve this goal.

We did not terminate the taxonomy development process until the following objective ending conditions according to Nickerson et al. (2013) were met: (1) Every characteristic is unique within its dimension (i.e., neither redundancy nor overlap among the characteristics), (2) every dimension is unique and not repeated (i.e., neither redundancy nor overlap among the dimensions), and (3) at least one object is classified under each characteristic of each dimension (i.e. no "empty" characteristic). Another ending condition was that the taxonomy should include dimensions whose characteristics are mutually exclusive and exhaustive. We catered for this condition by developing clear definitions for each characteristic and avoiding redundancies among them. Nevertheless, while examining real smart things, it became obvious that, in some cases, several characteristics per dimension apply. In our perspective, this does not violate the taxonomy properties as for each combination an own characteristic might be introduced, resulting in a mutually exclusive, but inflated set of characteristics. To increase the comprehensibility of our taxonomy, we indicate for each dimension whether its characteristics are mutually exclusive (ME) or non-exclusive (NE). We also indicate which dimensions are nominally or ordinally scaled. As for subjective ending conditions, the taxonomy development process ended after all authors agreed that the taxonomy was concise, robust, comprehensive, extendible, and explanatory.

As for the first iteration, a literature review on the IoT formed the starting point. In line with the proposed meta-characteristic, we conceived initial dimensions and related characteristics to capture distinct features of smart things. However, the resulting taxonomy was neither concise nor comprehensive. It included too many unstructured dimensions that partially overlapped and could not be matched to real-life objects. The taxonomy lacked clear guidance to tackle the multi-facetted nature of smart things. In the second iteration, we reviewed the dimensions with respect to existing IoT stacks and applied the related findings to enhance our taxonomy's structure. Existing IoT stacks helped understand smart things and structure the taxonomy. Based on that, we reassessed the taxonomy's dimensions and clustered them into layers. Thereby, the taxonomy's explanatory strength increased, which reflects its ability to provide useful explanations of the nature of smart things rather than describing every possible detail (Nickerson et al. 2013). Nevertheless, the taxonomy still did not meet the ending conditions. Although the dimensions benefited from a layered structure, the characteristics were beset with limitations. Thus, the third iteration focused on refining the characteristics, drawing from justificatory knowledge and theories (e.g., media richness theory, service-dominant logic) wherever reasonable and possible. The revised taxonomy complied with the authors' subjective as well as the objective ending conditions. We present the results of the third iteration below.

Beyond the real-life objects, which we used to test the versions of our taxonomy in each iteration, we finally intended to evaluate the taxonomy's usefulness by classifying a larger sample. We examined a sample of 50 real-life objects representing smart things from different IoT application domains in the B2C context. When compiling this sample, we included two sources: First, we used the results of our initial literature review to identify hints to smart things within the academic literature. Thereby, the works of Porter and Heppelmann (2014, 2015), Rosemann (2013), Atzori et al. (2010), and Borgia (2014) provided valuable overviews. To account for smart things from well-established companies as well as from start-ups, we additionally relied on the CrunchBase (2016) database. When preparing the test sample, we paid particular attention to include smart things from all current application domains in the B2C context (Borgia 2014). We selected the B2C context as it is expected to be most strongly affected by the IoT and as more information about smart things is publicly available compared to the B2B context (Kees et al. 2015).

When analyzing our sample, we classified the included smart things as well as their service offerings. Two co-authors classified each smart thing according to our taxonomy independently from each other. We only used publicly available information for the classification (e.g., homepages or press releases; see Appendix for details). We analyzed the taxonomy's reliability via hit ratios that measure inter-judge agreement within the author team (Nahm et al. 2002). We counted agreement among authors as 1 and disagreement as 0 per smart thing and dimension. In case of non-exclusive characteristics, agreement among authors was coded on a scale ranging from 0 to 1 to cater for partial agreement. In order to account for the taxonomy's layered structure, we determined dimension- and object-specific hit ratios. As for the application of our taxonomy, we calculated additional descriptive statistics. As for mutually exclusive characteristics, we calculated the absolute ratio that relates the number of occurrences per characteristic to the number of objects from the sample. For non-exclusive characteristics, we further determined the relative ratio that relates the number of occurrences per characteristic to the total number of occurrences per dimension. This procedure ensures comparability among dimensions irrespective of their mutually exclusive or non-exclusive nature. All results are presented in the evaluation and application section.

A Multi-Layer Taxonomy of Smart Things

We now present the dimensions and corresponding characteristics of our taxonomy. When developing the dimensions, we decided to adopt an individual smart thing's perspective in order to set a common ground for the entire taxonomy. This focus also allowed us to derive a detailed understanding of the nature of smart things, being a vital building block and a foundation of future business opportunities in the IoT (Borgia

2014; Kortuem et al. 2010). Overall, our taxonomy encompasses four layers and ten dimensions. As shown in Figure 2, the taxonomy's dimensions are structured along the typical layers of existing IoT stacks (Fleisch et al. 2015; Porter and Heppelmann 2014; Yoo et al. 2010). To facilitate the understanding of our taxonomy, Table 1 shows an overview of definitions and justificatory references for all dimensions and characteristics.

Starting on the local level of an individual thing, the thing layer includes two dimensions that refer to the thing's sensing and acting capabilities. After that, the interaction layer focuses on the intersection between an individual smart thing considered locally and its embedding into a broader, potentially global context. Consequently, the interaction layer includes four dimensions that relate to a thing's compatibility as well as to potential partners, directions, and multiplicity of a thing's interaction. Next, the data layer caters for the increased importance of data, which is attributed the potential of becoming one main value proposition of IoT-based business models in the future. The data layer comprises two dimensions that refer to potential data sources and variants of data usage. Although the taxonomy takes the perspective of an individual smart thing, it would fall short of a holistic view if things were considered independently of their service offering. Thus, the service layer captures smart things as enablers of digital services. The service layer includes two dimensions, referring to the services' main purpose and offline functionality. Below, we highlight the characteristics in italics and complement them by justificatory knowledge as well as illustrative examples.

The taxonomy's dimensions included are not orthogonal, i.e., the characteristics of each dimension cannot be arbitrarily combined with the characteristics of any other dimension. The sample of real smart things we used to evaluate the taxonomy corroborated that some combinations are very unlikely. For example, the characteristic 'unidirectional' of the 'direction' dimension is very unlikely to occur simultaneously with the 'many-to-many' characteristic of the 'multiplicity' dimension. If the dimensions were orthogonal, there would be 1.7 million possible realizations[1] of smart things. The number of possible realizations is calculated as follows: For dimensions with mutually exclusive characteristics, the number of characteristics must be considered. For dimensions with non-exclusive characteristics, the cardinality of the characteristics' power set minus 1 must be considered. This accounts for all combinations, despite the case where no characteristic is chosen. Finally, all dimension-specific parameters must be multiplied.

Thing Layer

Following the physical product at the bottom of the IoT stack, the *Thing layer* addresses a thing's *sensing* and *acting capabilities* (Porter and Heppelmann 2014). The respective dimensions assist in analyzing how a physical thing becomes a smart one. Also denoted as collection phase (Borgia 2014), the transformation of a merely physical thing into a smart thing equipped with sensors and actuators establishes the foundation for the remaining layers. As we primarily take a business-centered perspective for taxonomy development only complemented by technical characteristics if needed, the sensing capabilities dimension and the acting capabilities dimension take an information processing rather than a technical point of view. We thus refer to media richness theory introduced by Daft and Lengel (1986) as justificatory knowledge. In line with media richness theory, information processing is influenced by two contingencies: uncertainty and equivocality. Uncertainty refers to a structured problem and the absence of information on how to solve this problem. Uncertainty decreases with the amount of information that can be obtained. Equivocality refers to information ambiguousness or possible misinterpretation. In contrast to uncertainty, equivocality benefits little from larger amounts of information, but decreases when processing richer information. Information richness thus is "the ability of information to change understanding within a time interval" (Daft and Lengel 1986, p. 560). Both dimensions refer back to media richness theory.

Sensing Capabilities

Different technologies (e.g., sensor nodes integrated in wireless sensor networks) provide the physical thing with sensing capabilities (Atzori et al. 2010; Borgia 2014). Sensors transform a physical thing into a smart one. Sensors enable smart things collecting data ranging from the thing itself up to its physical environment

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[1] Possible number of realizations: $(2^3-1)\cdot 2\cdot (2^3-1)\cdot (2^4-1)\cdot 2\cdot (2^3-1)\cdot (2^3-1)\cdot 2\cdot (2^2-1)\cdot 2 = 1{,}728{,}720$

(Borgia 2014). When applying media richness theory to a smart thing's sensing capabilities, we assume the more and the richer data a smart thing can collect, the sounder the foundation for higher-level interactions. However, a smart thing's sensing capabilities are particularly determined by the richness of the information processed rather than by the quantity of sensors. With our taxonomy abstracting from technical specifications, we distinguish *lean* and *rich* sensing capabilities with respect to information richness. For instance, motion, position, and temperature sensors, as installed in the smart shower Eva Drop, represent simple sensor technologies and qualify a smart thing as lean regarding this dimension. The smart security camera Cocoon combines microphone and complex sub-sound sensor technologies. It thus belongs to those smart things featuring rich sensing capabilities. Another advanced sensor technology is found in Medtronic MiniMed glucose measuring where it is applied for implementing a customized smart health application.

						Dimension Properties	
	Dimension	**Characteristics**				**Scale**	**Exclusivity**
Service	Main Purpose	Thing-centric	Additional service	Ecosystem integration		Ordinal	NE
	Offline Functionality	Limited	None			Nominal	ME
Data	Data Usage	Transactional	Analytical (basic)	Analytical (extended)		Ordinal	NE
	Data Source	Thing state	Thing context	Thing usage	Cloud	Ordinal	NE
Interaction	Thing Compatibility	Proprietary	Open			Nominal	ME
	Partner	User(s)	Business(es)	Thing(s)		Nominal	NE
	Multiplicity	One-to-one	One-to-many	Many-to-many		Ordinal	NE
	Direction	Unidirectional	Bidirectional			Nominal	ME
Thing	Acting Capabilities	Own	Intermediary			Nominal	NE
	Sensing Capabilities	Lean	Rich			Ordinal	ME

ME: Mutually exclusive NE: Non-exclusive

Figure 2. Multi-layer Taxonomy of Smart Things

Acting Capabilities

A smart thing's acting capabilities complement its sensing capabilities. In our taxonomy, acting capabilities are conceptualized as the way in which a smart thing provides the output of information processing to its users (e.g., audible signal, vibration, text or voice message). Thus, this dimension does not overlap with the interaction layer as it exclusively focuses on a single smart thing's local level. When we validated the interim versions of our taxonomy, it became obvious that acting capabilities are partially integrated in a smart thing itself (e.g., Lively Safety Watch offers an own display for reporting medication reminders). In addition, smart things may rely on intermediaries (e.g., smartphones, tablets) as part of their acting capabilities (e.g., the smart lock Lockitron sends a notification to the user's smartphone in case the door was unlocked). Thus, our taxonomy distinguishes *own* and *intermediary* as characteristics of a smart thing's acting capabilities. As smart things can feature both characteristics, this dimension is non-exclusive.

Interaction Layer

The interaction layer marks the intersection of a smart thing's local perspective with the digital, potentially global world. The interaction layer is also referred to as transmission (Borgia 2014) or connectivity (Fleisch et al. 2015) layer. Embedded connectivity technologies grant access to a thing's sensing and acting capabilities (Fleisch et al. 2015; Porter and Heppelmann 2014) as well as to information exchange far beyond single smart things (Bucherer and Uckelmann 2011). In contrast to their technical requirements, the interactions of smart things have not been investigated exhaustively yet. One exception are Kees et al. (2015) who conceptualized business-to-thing interaction patterns in the IoT. Beyond these interaction patterns, we examine the interactions of smart things using four dimensions. These dimensions assist in answering the questions related to how a smart thing's interaction can be classified (*direction* and *multiplicity*) as well as with whom smart things interact (*partner* and *thing compatibility*).

Direction

A smart thing's interactions can be classified with respect to their direction. An interaction is *unidirectional* in case information flows only in one way between the interaction partners involved. For example, the smart tennis racket Babolat Play interacts unidirectionally with its users as it collects data and displays this data via an intermediary (i.e., the respective app). Therefore, users only receive information, but cannot trigger an interaction. By contrast, if two or more interaction partners are actively involved and if information may flow in all directions among these partners, an interaction is *bidirectional*. The fitness tracker FitBit Charge, for example, allows for bidirectional interactions. On the one hand, FitBit interacts with users by triggering a vibration alert. On the other, the user interacts with FitBit by pushing the wristband button.

Multiplicity

Regarding its multiplicity, a smart thing's interactions can take three non-exclusive forms: *one-to-one*, *one-to-many*, or *many-to-many* (Porter and Heppelmann 2014). Involving a single user, a single business, or a single thing at a distinct point in time, an interaction qualifies for a *one-to-one* interaction. If several smart things interact with the same partner (e.g., multiple smart cars being connected with the car manufacturer), a *one-to-many* interaction is established. Changing the perspective, the bike sharing service Hubway also features a one-to-many interaction. With the bike station managing many bikes simultaneously, it allows for interactions with several users. Thus, the bike station, representing a smart thing in this case, interacts with many users. Furthermore, a smart thing can participate in even more complex interaction patterns, giving rise to *many-to-many* interactions (Kees et al. 2015). The smart street lightning network approach Intellistreet is an example for many-to-many interactions, allowing for complex interactions among street lights, pedestrians, and civil services.

Partner

The interactions of a smart thing may involve various partners. In the IoT context, Bucherer and Uckelmann (2011) identified four different actors, i.e., consumer, thing, business, and (information) service provider. First, when examining a wearable or a fitness tracker, a smart thing particularly interacts with its consumer. We refer to consumers more generally as the *users* of a smart thing. Second, a smart thing can interact with other smart *things*, as in a smart home context where a smart meter has been installed. Interactions among smart home appliances and smart meters allow for synchronizing the appliances' usage with forecasted energy supply. When considering a car connected with a car repair shop in order to receive notifications for maintenance, an interaction takes place between a smart thing and a *business*. As the (information) service provider represents a specific form of business, our taxonomy does not contain a specific characteristic for service providers (Kees et al. 2015). Concluding, our taxonomy distinguishes three interaction partners, namely user, thing, and business. As demonstrated by Kees et al. (2015), a smart thing can be involved in an interaction with only one or several of these partners. Thus the partner dimension is non-exclusive.

Thing Compatibility

A smart thing's compatibility with other smart things or platforms and systems is a vital property in the IoT (Porter and Heppelmann 2015). Compatibility is crucial in the digital economy as the digital transformation is characterized by recombination rather than by displacement and replacement (Iansiti and Lakhani 2014). In line with these findings, Bärenfänger and Otto (2015) conclude that an organization's ability to develop hybrid modular products and services is of utmost importance in establishing digital business models. From a smart thing's perspective, the compatibility dimension includes two mutually exclusive characteristics: *proprietary* and *open*. A smart thing can disclose no or at best constrained compatibility properties limited to other products or services of the same provider (e.g., iCOMM water heater monitoring applies to a particular water heater product family only). When being compatible beyond the proprietary product and service portfolio, a smart thing's compatibility is classified as open (e.g., Nest Thermostat).

Data Layer

Data are radically reshaping how physical things can be integrated into value chains. For the first time, data created by internal operations and along a physical product's value chain are complemented by the product itself as a new data source (Porter and Heppelmann 2015; Qin et al. 2016). Justifiably, data are considered as a new source of value in the digital economy (Bharadwaj et al. 2013). Transferred to the IoT context, data is attributed the potential of becoming a smart thing's main value proposition (Bucherer and Uckelmann 2011; Iansiti and Lakhani 2014; Porter and Heppelmann 2015). Thereby, the amount and type of data captured as well as processed in smart things is not only influenced by cost and data security issues. Primarily, an organization's business strategy and intended service offerings are important when setting the data scene (Porter and Heppelmann 2015). Thus, the data layer reveals insights into the type of data being captured and processed by smart things (*source*) as well as its intended usage (*use*).

Dimension	**Definitions**	**Justificatory References**
Main Purpose	Thing-centric: The smart thing's services strongly relate to the physical product. Additional service: The smart thing's services go beyond the physical product. Ecosystem integration: The smart thing's services offer integration into a wider product system or into a system of systems.	Fleisch et al. (2015); Mattern and Flörkemeier (2010); Porter and Heppelmann (2014); Vargo and Lusch (2004)
Offline Functionality	Limited: The smart thing provides at least parts of its functionality without a connection. None: The smart thing provides no functionality without a connection.	
Data Usage	Transactional: The smart thing processes data of distinct transactions or interactions. Analytical (basic): The smart thing processes data for descriptive analytical purposes. Analytical (extended): The smart thing processes data for diagnostic, predictive, and/or prescriptive analytical purposes.	Borgia (2014); Kortuem et al. (2010); Qin et al. (2016); Porter and Heppelmann (2015)
Data Source	Thing state: The smart thing processes data about its local representation. Thing context: The smart thing processes data about its physical environment. Thing usage: The smart thing processes data about its usage by interaction partners. Cloud: The smart thing processes further external or enterprise data.	
Thing Compatibility	Proprietary: The smart thing is compatible with products of the same provider. Open: The smart thing is compatible with products of other providers.	Bucherer and Uckelmann (2011); Kees et al. (2015); Porter and Heppelmann (2014); Porter and Heppelmann (2015)
Interaction Partner	User(s): The smart thing interacts with one or more human partners. Business(es): The smart thing interacts with one or more businesses. Thing(s): The smart thing interacts with one or more other smart things.	
Interaction Multiplicity	One-to-one: The smart thing interacts with a single interaction partner. One-to-many: The smart thing interacts with many interaction partners (or vice versa). Many-to-many: Many smart things interact with many interaction partners.	
Interaction Direction	Unidirectional: Information flows in one direction between interaction partners. Bidirectional: Information flows in all directions between interaction partners.	
Acting Capabilities	Own: The smart thing interacts directly with its users. Intermediary: The smart thing relies on intermediaries to interact with its users.	Daft and Lengel (1986)
Sensing Capabilities	Lean: The smart thing collects little and/or simple data. Rich: The smart thing collects much and/or highly diverse data.	

Table 1. Definitions and Justificatory References

Source

As smart things become valuable new suppliers of data in the IoT context, this dimension examines different data sources a smart thing collects, stores, and processes. Our taxonomy distinguishes four characteristics: *thing state*, *thing context*, *thing usage*, and *cloud*. Thing state refers to the local representation of a smart thing and captures thing-related data such as the thing's identity, charging status, or operating status (Borgia 2014). In addition, the sensors integrated into a smart thing enable monitoring its physical environment, e.g., temperature or humidity (thing context) (Borgia 2014). Whereas thing context data still results from the local level of a smart thing, thing usage data refer to the output of the smart thing's interaction with interaction partners. Further, smart things might have access to a wider set of data, including external data (e.g., weather or energy prices) or enterprise data (e.g., service histories or warranty status) (Porter and Heppelmann 2015). In the digital world, these data are accessible via the cloud. As smart things offer data whose generation was neither economically reasonable nor technically impossible before, data are valuable by themselves (Fleisch et al. 2015). Nevertheless, data extensively increases in value when being integrated with other data, forming a so-called "data lake" (Porter and Heppelmann 2015). Thus the characteristics of this dimension are non-exclusive.

Usage

Data usage can be split in two primary types: *transactional* and *analytical*. Transactional data usage refers to the processing of distinct transactions or interactions. For example, the smart shower Eva Drop uses the collected data (i.e., current water temperature and a person's position in the shower) to adjust the water flow. Collected data can also be used for analytical purposes. Such analyses might be conducted in the sense of simple analytics in order to provide basic insights. Further, advanced analytics can be applied to generate profound insights (Porter and Heppelmann 2015). As for analytical data usage, Porter and Heppelmann (2015) mention four sub-types, namely descriptive, diagnostic, predictive, and prescriptive. Accounting for a smart thing's analytical data usage capabilities, we aim for a detailed distinction in our taxonomy. Thus, we split the analytical data usage characteristic in two characteristics, namely *analytical (basic)* and *analytical (extended)*. This distinction complies with a smart thing's maturity level (e.g., Kortuem et al. 2010; Porter and Heppelmann 2014; Rosemann 2013; Sundmaeker et al. 2010). A smart thing might be able to provide simple analytics to its users in terms of descriptive analytics, e.g., presenting a time line, history or summary of past transactions. Diagnostic, predictive, and prescriptive analytics, however, refer to the 'analytical (extended)' characteristic as these characteristics require advanced analytic capabilities, which may either be implemented in the smart thing itself or be accessible via the cloud.

Service Layer

In line with the architecture of existing IoT stacks, the service layer is the top-most layer of our taxonomy. It combines the underlying layers with the physical thing in order to provide service offerings (Fleisch et al. 2015). As smart things still are physical products that serve as enabler for additional services, the IoT fits the paradigm of servitization very well. Servitization refers to the increased service orientation of manufacturing companies (Kujala et al. 2010). The term was initially coined by Vandermerwe and Rada in 1988. To realize hybrid product/service combinations, organizations can draw from service-dominant logic as theoretical foundation (Vargo and Lusch 2004). Accordingly, services replace goods in their function as primary unit of exchange. Goods remain as a transmitter within service provision. Further, the role of the customer shifts from a recipient to a co-producer of services. Up to now, smart things have penetrated many application domains (e.g., Atzori et al. 2010; Borgia 2014; McKinsey Global Institute 2015). Future service offerings enabled by smart things are said to be "limited only by imagination" (Porter and Heppelmann 2015, p. 114). However, against the background of service-dominant logic, the dimensions included in this layer abstract from distinct application domains to analyze the service offerings of smart things more generally. Due to their importance in the IoT context, our taxonomy comprises a smart thing's *offline functionality* as well as the *main purpose* of a smart thing's service offerings as dimensions.

Offline Functionality

By definition, connectivity plays an important role for smart things. The related literature defines connectivity rather broadly in the IoT context, ranging from definitions that refer to a smart thing's general communication ability to technical definitions (e.g., Mattern and Flörkemeier 2010; O'Leary 2013). Rather than investigating distinct communication technologies, we focus on the degree to which a smart thing's functionality depends on a working connection. If a smart thing is able to provide parts of its functionality and services without a working connection, it meets the *limited* characteristic. For instance, the fitness tracker FitBit is able to track steps and show them on its display without a working connection. In contrast, a smart thing is classified as *none* if it requires a working connection for providing each part of its functionality. In this case, no offline functionality is available. For instance, the WeMo Insight Switch requires a working connection to offer its remote control of home appliances as well as the tracking of their energy usage.

Main Purpose

Abstracting from a smart thing's application domain and functionality, this dimension characterizes the main purpose of its service offering. To do so, it includes three characteristics, i.e., *thing-centric*, *additional service*, and *ecosystem integration*, being of non-exclusive nature. At the one end, the service provided by a smart thing strongly relates to the underlying physical product itself and solely differs from the original product by slightly enhanced functionality (thing-centric). In addition, smart things may extend their original functionality by additional services, possibly connection- and/or data-based, which ever more abstract from the basic functionality and purpose of the physical product (Fleisch et al. 2015). Apart from existing products being upgraded by the IoT, the IoT also yields devices that offer entirely new functionality as for example fitness trackers and wearables (Bitkom 2015). This group of smart things relates to the 'additional services' characteristic. At the other end of this dimension, a smart thing's main purpose can be reflected by its integration into a wider product system or system of systems (Porter and Heppelmann 2014). We refer to this kind of service offering as ecosystem integration. For example, smart home appliances offered by LG electronics or the smart thermostat Nest aim at integrating things into a network and platform allowing for further extending thing-to-thing interactions.

Evaluation and Application

Our taxonomy of smart things is primarily rooted in the extant IoT literature as we opted for the conceptual-to-empirical approach to taxonomy development (Nickerson et al. 2013). With our taxonomy at hand, we pursued two objectives: First, we intended to validate the taxonomy's practical applicability to classify smart things and whether it proves useful for this purpose (*evaluation*). Second, we strived for initial insights into the functioning of smart things in the B2C context (*application*).

For evaluation and application purposes, we used a sample of real-life smart things. Due to the taxonomy's complexity (i.e., ten dimensions and their characteristics must be assessed, some require deep insights into a smart thing's functioning), our sample consists of 50 smart things. To include smart things from all current application domains within the B2C context, we adopted the application domain structure proposed by Borgia (2014). Table 2 shows the sample structure grouped according to application domains.

To evaluate the taxonomy, two co-authors classified the smart things from our sample independently. They achieved dimension-specific hit ratios of at least 80%. Table 3 provides an overview. Moreover, 88% of the object-specific hit ratios exceeded 75% (see Appendix for details). This result corroborates our taxonomy's ability to foster in-depth insights into the nature of smart things. It furthermore shows that smart things can be classified regardless of their application domain. Nevertheless, the evaluation disclosed some of the taxonomy's limitations. For example, the amount of information varied among the classified objects as we only used publicly available information. Thus, the appropriate classification of some dimensions heavily depends on the amount of available information as well as on insights into the functioning of smart things.

Application Domain	Share in %
Individual Well-Being	18
Smart Health	16
Smart Home	44
Smart City	6
Smart Energy	4
Smart Mobility	12

Table 2. Sample Structure

Dimension	Hit Ratio in %	Dimension	Hit Ration in %
Sensing Capabilities	84	Thing Compatibility	84
Acting Capabilities	90	Data Source	80
Interaction Direction	80	Data Usage	83
Interaction Multiplicity	85	Offline Functionality	98
Interaction Partner	87	Main Purpose	92

Table 3. Dimension-specific Hit Ratios

To make the classification of smart things more transparent, we illustrate two examples: The smart security camera Nest Cam is an example of a highly developed smart thing (Figure 3). Using its own (e.g., speaker) and intermediary acting capabilities, Nest Cam engages in complex interactions with users and other smart things (e.g., Nest Thermostat). Further, rich sensing capabilities (e.g., microphone and video) enable the Nest Cam to collect vast amounts of different data. These data are used for transactional as well as analytical purposes. Nest Cam learns over time to differentiate normal behavior from situations that require sending alerts to users. Thus, the service range provided by Nest Cam is way broader than that of a traditional security camera. Compared to Nest Cam, the smart lock Lockitron is a simple smart thing (Figure 4). In addition to its fundamental purpose of being a door lock, Lockitron allows for opening doors without keys, using a smartphone. It provides users with an additional service. Lockitron includes solely lean sensing capabilities and only uses intermediaries (e.g., smartphone) for engaging with interaction partners. These simple capabilities are sufficient to fulfil Lockitron's main purpose. The collected data is foremost used to process door opening transactions. In addition, simple data analyses (e.g., tracking of time and person) are provided.

In addition to validating the taxonomy's usefulness for classifying smart things, the results revealed initial insights regarding the taxonomy's layers. Beyond the presentation of major highlights below, we are happy to provide detailed results upon request. Figure 5 shows an overview with the characteristics' relative ratio in round brackets and the absolute ratio in square brackets, respectively. Starting with the thing layer, it is remarkable that 72% of the classified smart things feature lean sensing capabilities. This result confirms our impression that the idea of smart things in their current state is about intelligently combining existing sensor technologies rather than equipping things with more sophisticated sensor technology. This opens up a new area for the future development of smart things. The assessment of the acting capabilities revealed that slightly more than half of the smart things in our sample provide own acting capabilities. Almost all investigated smart things rely on intermediaries (92%). Concluding, smartphones or tablets paired with a thing-related app currently are common practice in the IoT context.

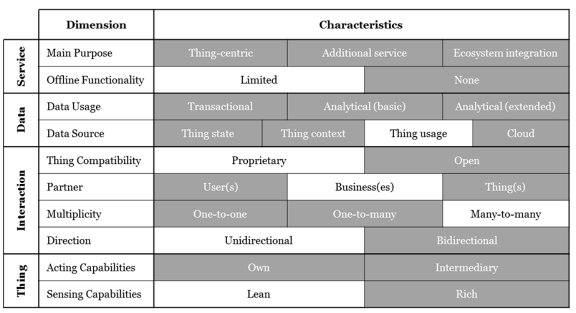

Figure 3. Classification 'Nest Cam'

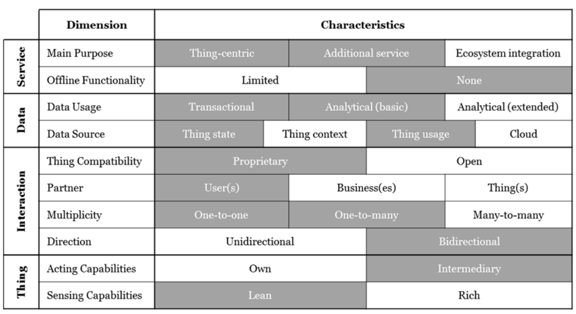

Figure 4. Classification 'Lockitron'

Layer	Dimension	Characteristics			
Service	Main Purpose	Thing-centric (19%)[26%]	Additional service (66%) [92%]	Ecosystem integration (15%) [22%]	
Service	Offline Functionality	Limited (21%)	None (79%)		
Data	Data Usage	Transactional (42%) [71%]	Analytical (basic) (43%) [73%]	Analytical (extended) (15%) [26%]	
Data	Data Source	Thing state (19%) [29%]	Thing context (33%) [51%]	Thing usage (39%) [59%]	Cloud (9%) [13%]
Interaction	Thing Compatibility	Proprietary (74%)	Open (26%)		
Interaction	Partner	User(s) (66%) [99%]	Business(es) (15%) [23%]	Thing(s) (19%) [28%]	
Interaction	Multiplicity	One-to-one (63%) [89%]	One-to-many (33%) [47%]	Many-to-many (4%) [5%]	
Interaction	Direction	Unidirectional (40%)	Bidirectional (60%)		
Thing	Acting Capabilities	Own (39%) [58%]	Intermediary (61%) [92%]		
Thing	Sensing Capabilities	Lean (72%)	Rich (28%)		

(...): relative ratio [...]: absolute ratio

Figure 5. Classification Results

On the interaction layer, 60% of the examined smart things enable a bidirectional interaction with at least one of their interaction partners. Regarding a smart thing's interaction multiplicity and partner, our sample stresses another interesting fact: less than one third (28%) of the investigated smart things participate in thing-to-thing and only 5% in many-to-many interactions. Against the background of the IoT, which strives for advancing interactions with and in particular among things, this result highlights an area that requires substantial further development. Further, to the current state, 74% of all examined smart things are limited regarding their compatibility. Although the compatibility has been identified as an essential characteristic of smart things in the IoT, solely 26% of all objects within the sample are compatible with the products and services of other providers.

As for the data layer, we were interested in insights into what data types smart things collect and process as well as which ways of data usage the service offerings of smart things are based on. Most examined smart things collect data related to the thing context and usage. Surprisingly, additional data that can be accessed via the cloud, was only leveraged by 13% of smart things from our sample. This finding confirms the picture sketched by the thing compatibility and interaction dimensions. It also complies with announcements of smart thing providers who intend to include more external data in their smart things' service offerings in the near future (e.g., Awair (2016)). Moreover, the usage of data for transactional (71%) and basic analytical (73%) purposes dominated our sample. In contrast, smart things that leverage data for extended analytical purposes are under-represented in our sample (26%). Enlarging a smart thing's data usage capabilities thus constitutes a rewarding area for future development.

Analyzing the results of the service layer, further conclusions can be drawn. In 92% of the sample, the smart thing's main purpose includes additional services to its customer. This high percentage might be explained by the fact that there is a considerable share of smart things that newly emerged in the IoT. For instance, wearables or smart gadgets (e.g., Awair or Breathometer) that primarily focus on analytical purposes substantiate their functionality by the emergence of the IoT and did not exist as physical products before. With only 22%, the integration of smart things into digital ecosystems is fairly under-represented in our sample. This finding highlights another worthwhile field for the further development of smart things. With regard to a smart thing's offline functionality, our analysis revealed that only in one fifth of our sample (21%) some functionality works without connectivity. The remaining 79% need a working connection.

Taking a cross-dimension perspective, applying our taxonomy to a sample of 50 real-life smart things from the B2C context revealed interesting initial findings. Whereas individual smart things are already equipped with sensing, acting, and connectivity components, the IoT's major value proposition has not yet been exploited to its full extent. Reasons are limitations particularly with respect to thing compatibility, thing-to-thing interaction, and ecosystem integration. Further, the uptake of advanced analytics gets stuck as smart things mostly treat data in a transactional or basic analytical manner. Moreover, smart things and related service offerings make hardly use of data from thing clouds. Although we compiled our sample of smart things carefully with respect to comparability (i.e., the distribution of smart things across application domains in the B2C context), we do not claim our findings to be representative in a statistical sense. To ensure representativity, a larger sample needs to be compiled and analyzed in the future. A larger sample should include application domains beyond the B2C context, e.g., smart factories or digital supply chains. In these domains, the findings may be completely different than in the B2C context investigated here.

Conclusion and Outlook

Though being intensely discussed by practitioners and researchers alike, the IoT is a fuzzy concept. It has been examined from a technological and an engineering perspective as well as from a managerial and a business model perspective. Surprisingly, smart things, which are a vital building block of the IoT and serve as a starting point for advanced IoT topics, lack an in-depth examination. Be it our business or private lives, smart things have already immersed many application domains. Smart things enforce to radically rethink current work practices and bear the potential of reshaping interactions among businesses and customers. With this study, we aimed to contribute to better understand the IoT by taking a smart thing's perspective, addressing the question how smart things can be classified. In line with Nickerson et al. (2013), we proposed a multi-layer taxonomy of smart things. Each dimension of this taxonomy highlights a distinct feature of smart things, contrasting them from merely physical products. The layers that structure the dimensions of our taxonomy draw from extant IoT stacks, allowing smart things to be assessed regarding their sensing and acting, interaction, and data capabilities as well as their service offerings. To demonstrate its usefulness and applicability, we used the taxonomy to classify 50 real-life smart things from the B2C context.

Though being perceived as having an immense transformative potential, the IoT remains low on theoretical insights. Thus, our taxonomy extends extant findings on smart things and adds to the descriptive knowledge related to the IoT. Our study is the first to focus on smart things as a vital building block of the IoT. To answer the question how smart things can be classified, we also drew from established theories (e.g., media richness theory and service-dominant logic) and transferred them into the IoT domain for the first time.

From a managerial standpoint, our taxonomy serves as a tool for different players within the IoT ecosystem. Adopting a smart thing producer's perspective, our taxonomy assists in classifying currently offered smart things. The taxonomy's layers ensure that dimensions relevant for smart things can be considered entirely and systematically. Our taxonomy also allows for comparing own smart things with those of competitors, providing feedback for advancing the range of proprietary smart things. Taking the perspective of a smart service provider, our taxonomy helps identify how to embed smart things into IoT-based business models. First, the taxonomy's lower layers convey insights into the sensing and acting capabilities of smart things and provide a foundation for potential services. With newly accessible data being a key value proposition in the IoT, the data layer helps determine opportunities for data-driven services. Different combinations of smart things and services are then examined in the top-most layer. Despite its limited representativity, the application of our taxonomy to a sample of 50 real-life smart things from the B2C context showcases that the IoT's major value proposition has not yet been exploited to its full extent due to limitations regarding thing compatibility, thing-to-thing interaction, ecosystem integration, and extended data analytics.

Although our study offers initial theoretical and managerial implications, there is room for improvement to be addressed in future research. First of all, the IoT is a dynamically evolving field. Thus, innumerable smart things with novel functionality will arise throughout the next years. By selecting the conceptual-to-empirical approach of Nickerson et al.'s (2013) taxonomy development method, we accounted for this circumstance and prepared our taxonomy for being applicable in the longer term. Some characteristics that were hardly present in our sample (e.g., extended analytical data usage, the cloud as possible data source, and ecosystem integration as service purpose) already point to areas where smart things might emerge in the future. To account for upcoming smart things, our taxonomy should be continuously re-evaluated and adjusted. Due to its complexity, our taxonomy's evaluation and application are currently limited to a sample of 50 smart things. Thus, the taxonomy's validity will benefit from classifying more real-world smart things from different contexts, industries, and application domains. Such a larger sample, which might be gathered using big data analytics or Web mining, would allow for detailed analyses. It would, for instance, enable discovering typical combinations of jointly occurring characteristics. Complemented by appropriate data analysis methods (e.g., cluster analysis), a larger sample would also enable identifying higher-order constructs such as smart thing archetypes. Such archetypes have the potential to reduce the number of possible realizations to a manageable amount, a property that would guide sense-making research and theory-led design. Due to its emerging nature, the IoT remains an interesting topic for IS research. We thus hope that our work is useful and provides fellow researchers with valuable insights into the nature of smart things.

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Appendix

No.	Object	Sensing Capabilities	Acting Capabilities	Interaction Direction	Interaction Multiplicity	Interaction Partner	Thing Compatibility	Data Source	Data Usage	Offline Functionality	Main Purpose	Hit Ratio (Object)
1	Eva Drop	1.00	1.00	0.00	1.00	0.67	1.00	0.75	0.67	1.00	1.00	**81%**
2	Hapifork	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	0.67	**93%**
3	Lockitron	1.00	1.00	0.00	0.67	1.00	1.00	0.75	0.67	1.00	0.67	**78%**
4	Cocoon	0.00	1.00	1.00	0.67	1.00	1.00	0.25	0.33	1.00	0.67	**69%**
5	FitBit Charge	1.00	1.00	1.00	1.00	0.67	0.00	0.75	0.67	1.00	1.00	**81%**
6	FitBit Aria	1.00	1.00	0.00	0.67	0.67	1.00	1.00	1.00	1.00	1.00	**83%**
7	Babolat Play	1.00	1.00	1.00	1.00	1.00	1.00	0.75	1.00	1.00	0.67	**94%**
8	Babolat Pop	1.00	1.00	1.00	1.00	1.00	0.00	0.75	1.00	1.00	1.00	**88%**
9	WeMo Insight Switch	1.00	1.00	1.00	0.67	0.67	0.00	0.75	1.00	1.00	1.00	**81%**
10	iCOMM Water Heater	1.00	1.00	1.00	0.33	0.67	1.00	0.50	0.67	1.00	1.00	**82%**
11	Iota	1.00	1.00	0.00	0.33	1.00	1.00	0.75	0.67	1.00	1.00	**78%**
12	Hubway	1.00	1.00	0.00	0.33	1.00	1.00	0.50	1.00	0.00	1.00	**68%**
13	Jawbone Up3	0.00	0.50	1.00	1.00	1.00	1.00	0.75	0.67	1.00	1.00	**79%**
14	Haiku	1.00	1.00	1.00	1.00	1.00	1.00	0.75	1.00	1.00	0.67	**94%**
15	Dropcam	1.00	1.00	1.00	0.67	1.00	0.00	0.50	1.00	1.00	0.67	**78%**
16	Minut	1.00	1.00	1.00	1.00	0.67	0.00	1.00	0.67	1.00	1.00	**83%**
17	Kevo	0.00	1.00	1.00	0.67	0.67	1.00	0.75	0.67	1.00	1.00	**78%**
18	Ladera Labs	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	**95%**
19	Leeo	1.00	0.50	0.00	0.67	0.67	1.00	1.00	1.00	1.00	1.00	**78%**
20	LG Electronics	1.00	1.00	1.00	0.67	0.33	1.00	0.50	0.33	1.00	0.67	**75%**
21	Lively Pillbox	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**100%**
22	Lively Safety Watch	0.00	1.00	1.00	0.67	1.00	1.00	1.00	0.67	1.00	1.00	**83%**
23	Luna Matress	1.00	1.00	1.00	0.67	1.00	1.00	0.75	0.67	1.00	1.00	**91%**
24	Intellistreet	1.00	1.00	1.00	1.00	0.67	1.00	0.50	1.00	1.00	0.67	**88%**
25	Issy Grid Smart Meter	1.00	1.00	1.00	1.00	1.00	1.00	0.75	1.00	1.00	1.00	**98%**
26	Withings Smart Scale	0.00	1.00	0.00	0.67	1.00	1.00	0.75	1.00	1.00	0.67	**71%**
27	Nike Fuel	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**100%**
28	Tile	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**95%**
29	TrackR Bravo	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**95%**
30	TrackR Atlas	1.00	1.00	0.00	1.00	0.67	1.00	1.00	0.67	1.00	1.00	**83%**
31	DriveNow	1.00	1.00	1.00	0.67	1.00	1.00	1.00	1.00	1.00	1.00	**97%**
32	Smoove	1.00	0.50	1.00	0.67	1.00	1.00	0.75	1.00	1.00	1.00	**89%**
33	ShieldRadar	0.00	1.00	1.00	0.67	0.33	1.00	0.50	0.67	1.00	1.00	**72%**
34	Philipps Hue	1.00	1.00	1.00	0.33	0.67	1.00	0.75	1.00	1.00	0.67	**84%**
35	Medtronic MiniMed	1.00	0.00	0.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	**77%**
36	Nest Thermostat	1.00	1.00	1.00	1.00	0.33	1.00	0.75	0.33	1.00	1.00	**84%**
37	GM Car	1.00	1.00	1.00	1.00	1.00	0.00	0.75	1.00	1.00	1.00	**88%**
38	Recycling Bin	0.00	1.00	1.00	1.00	0.67	0.00	0.75	1.00	1.00	0.67	**71%**

39	Shokabell	1.00	1.00	1.00	1.00	1.00	1.00	0.75	0.67	1.00	1.00	**94%**
40	Skylock	1.00	0.50	1.00	0.67	1.00	1.00	0.50	1.00	1.00	1.00	**87%**
41	Qmedic	1.00	0.50	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	**92%**
42	Mimo Body	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	**97%**
43	CliniCloud	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.67	**87%**
44	Awair	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**100%**
45	Breathometer	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**100%**
46	Ecovent	1.00	1.00	0.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	**87%**
47	InteliSocket	1.00	1.00	1.00	1.00	0.67	1.00	1.00	1.00	1.00	1.00	**97%**
48	Ecobee	1.00	1.00	1.00	1.00	0.67	0.00	0.75	0.67	1.00	1.00	**81%**
49	Curb	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	**97%**
50	Drop Scale	1.00	0.50	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	**90%**
	Hit Ratio (Dimension)	**84%**	**90%**	**80%**	**85%**	**87%**	**84%**	**80%**	**83%**	**98%**	**92%**	**86%**

Table A-1. Inter-judge Agreement, Dimension- and Object-specific Hit Ratios

No.	**URL**	**No.**	**URL**
1	http://evadrop.com/	**26**	http://www.withings.com/us/en/products/smart-body-analyzer
2	https://www.hapi.com/product/hapifork	**27**	http://www.nike.com/us/en_us/c/nikeplus-fuel
3	https://lockitron.com/	**28**	https://www.thetileapp.com/how-it-works
4	http://cocoon.life/	**29**	https://www.thetrackr.com/
5	https://www.fitbit.com/de/charge	**30**	https://www.thetrackr.com/atlas/new
6	https://www.fitbit.com/de/aria	**31**	https://de.drive-now.com/en/#!/howto
7	https://en.babolatplay.com/play	**32**	http://www.smoovebikeshare.com/howitworks.html
8	http://en.babolatplay.com/pop	**33**	http://www.alltrafficsolutions.com/products/shield-radar-speed-displays/
9	http://www.belkin.com/de/F7C029-Belkin/p/P-F7C029/	**34**	http://www2.meethue.com/de-DE
10	http://www.aosmithconnect.com/index.html	**35**	http://www.professional.medtronicdiabetes.com/personal-cgm
11	http://www.iotatracker.com/howitworks	**36**	https://nest.com/thermostat/meet-nest-thermostat/
12	http://www.thehubway.com/how-it-works	**37**	https://www.smartbin.com/
13	https://jawbone.com/store/buy/up3	**38**	https://www.onstar.com/us/en/services/connections.html
14	https://www.haikuhome.com/why-haiku-home	**39**	www.shokabell.com
15	https://nest.com/camera/meet-nest-cam/?dropcam=true	**40**	skylock.cc
16	https://minut.com/	**41**	http://www.qmedichealth.com/
17	https://mykevo.com/	**42**	http://mimobaby.com/
18	http://www.laderalabs.com/products	**43**	clinicloud.com
19	https://shop.leeo.com/pages/about-leeo-smart-alert	**44**	https://getawair.com/
20	http://www.lg.com/us/discover/smartthinq/thinq	**45**	https://www.breathometer.com/
21	http://www.mylively.com/how-it-works	**46**	https://www.ecoventsystems.com/
22	http://www.mylively.com/how-it-works	**47**	http://ibisnetworks.com/
23	https://www.eightsleep.com/	**48**	https://www.ecobee.com/
24	http://www.illuminatingconcepts.com/intellistreets/	**49**	http://energycurb.com/
25	http://www.issy.com/en/home/issy-a-smart-city/issygrid	**50**	https://www.getdrop.com/product

Table A-2. Publicly Available Information Consulted for Classification

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