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Abstract

The Internet of Things (IoT) is a relatively new concept that combines ubiquitous and pervasive computing, sensing and communication technologies, and embedded devices to form a system where the real and digital worlds meet and are continuously in interdependent communication. In this context, IoT acts as an intelligent Service Supply Chain linking objects, information, and people through computer, smart object and sensor networks. This Service Supply Chain creates numerous business design challenges. This article addresses these challenges by providing a cohesive typology matrix to explain the IoT Service Supply Chain. This matrix has been developed through a systematic literature review of 78 academic papers, identifies the key contributors and influences at each stage of the Service Supply Chain and their inter-relationships, to facilitate the rectification of business design and integration challenges that may emerge at the different stages of the sequence.

Keywords – Internet of Things (IoT), IoT Ecosystem, Service Supply Chain, IoT Reference Model, IoT Architecture, Business Ecosystem, Business Design, IoT Typology, Literature Review, IoT Matrix

1. Introduction

In recent years, the growth of the Internet of Things (IoT) has led to predictions that it will change every aspect of our lives in a way previous Industrial Revolutions have not done so. By connecting networks of physical objects or ‘things’ embedded with electronics, software, sensors, and network connectivity. These objects can continuously collect and exchange data ‘any-time,’ ‘any-where’ and for ‘any-thing’ (Whitmore et al., 2015). Creating opportunities for direct integration between the physical world and computer/internet-based systems, resulting in improved efficiency, accuracy and economic benefits. In this sense, the IoT goes beyond the original vision of the internet and World Wide Web by connecting and integrating the physical world with the information space, which will create many practical improvements from increasing convenience to more predictive and efficient business operations.

In simple terms, the IoT is about connecting any device to the Internet, and/or to each other in order to gather data and present it in a way that is relevant to a user. The *smart object* is the building block of the IoT, as it provides seamless, ubiquitous sensing, data analytics and information representation, and *cloud computing* acts as the IoT’s unifying framework by using any path or network and any service in a heterogeneous environment (Fleisch 2010, Atzori et al. 2010, Borgia 2014, Gubbi et al. 2014, Bai and Rabara 2015). Central features of the IoT are *connectivity* and *interoperability* between smart objects, which enable a user to interpret the collected data in a meaningful way. From a business design perspective, the IoT acts as a *service supply chain – which we call the IoT service supply chain* - through which a smart object gathers, processes, and exchanges data in the context of its operating environment, and presents it in a way that is useful to a user, typically through a smart object application – an *app*. In the context of this article, *business design* refers to the process through which an IoT service provider determines a need, through to the development, delivery and ongoing support of a product and/or service that satisfies that need. It is a combination of research, design and business modelling that enables businesses to create and deliver value and competitive advantage to interested stakeholders (Sundberg 2017; Frank et al., 2019). This is achieved through the IoT service supply chains ability to increase transparency; enable enhanced efficiency, flexibility and quality; and new business models (Kiel et al., 2017) within and across business ecosystems - the *affiliation ecosystem* or the *structural ecosystem* of firms.

With a real paradigm, shift in the IoT, from proprietary and non-interoperable solutions towards more open and interoperable business ecosystems, the need for a standardised reference architecture typology has intensified. In recent years, there have been attempts by various industry bodies to develop a standardised architecture that enables interoperability, simplifies development and eases the implementation of IoT technologies (Atzori et al. 2010, Alhamedi 2014, Lu et al., 2018, Weyreich and Ebert 2016). Despite this, these architectures generally focus on the application, technology or specific types of communication media, or are proprietary models based on fragmented software implementations for specific systems and use cases from an 'internet-oriented' or a 'things-oriented' perspective. This fragmentation means that there is no complete or standardised architecture typology addressing the business design challenges that emerge within and between each layer of the IoT service supply chain (Atzori et al., 2010; Lu et al., 2018; Nicolescu et al., 2018). This is a pressing issue as the IoT becomes increasingly pervasive in every aspect of our personal and business lives. Consequently, a lack of an integrated business approach to the IoT service supply chain can restrict its successful adoption and integration in a manner that results in appropriate business design responses. The justification for this research is therefore, that 'there is a pressing need for a 'standardised IoT service supply chain architecture typology, which describes/addresses the business design challenges that business ecosystems encounter when they adopt and integrate the IoT into their business activities.

To address these issues, we perform a systematic literature review of academic papers drawn from the field of business management and related academic disciplines, including computer science, organisational and operations management; published between 2010 and 2020. This enables us to identify, select and critically appraise disparate streams of work on the IoT service supply chain and its architecture(s) in an integrated way, so to identify, examine and shed new light on 'the key issues that need to be factored in when businesses adopt and integrate IoT in their operations,' and to develop a typology for a standard IoT service supply chain architecture (Dahmus et al., 1999, Geum et al., 2011, Oh et al., 2015, Persson and Åhlström 2006, Ulrich 1995). By accounting for the characteristics of the individual layers of the IoT service supply chain, and their interactions from a systems theory perspective, we can describe the properties of the system itself rather its individual parts in isolation. Developing a typology in this way academia and practitioners will be able to envisage and evaluate the IoT as part of a comprehensive integrated service supply chain, rather than focusing purely on technology or application related issues. In so doing, we address the business design issues that may emerge at the different stages of the sequence, in a standardised format. This is important because, by having a clear picture of the key issues that must be addressed within each layer and supporting gateway of the IoT service supply chain, business ecosystem firms can be aware and adapt their systems according to a situation. Business ecosystems can also clearly visualise how the IoT service supply chain impacts upon their existing business design and model(s), and make necessary changes in order to maximise and capture the value it creates, and put measures in place to minimise the impact of any potential negative consequences.

The remainder of this paper is structured as follows: Section 2 presents the theoretical background on the IoT, the IoT service supply chain and its associated business design challenges and IoT ecosystem. Section 3 describes the research methodology employed in our study, and in Section 4 we present our results and conceptual framework for the IoT service supply chain architecture. In section 5 we discuss the consequences of our review and the conceptual framework for practice and academia, and in Section we provide our concluding remarks.

2. Theoretical Background

2.1 The IoT

To describe how the IoT service supply chain is transforming nearly every aspect of lives, we must first examine the definition of the IoT itself. Since its inception, the IoT has meant different things to different people. Consequently, there are multiple descriptions of the IoT, which makes it difficult to gain an understanding of what it really means. The term IoT has been around for approximately 20 years, having first appeared in 1999, when Kevin Ashton presented the term while he was working on a project at the Massachusetts Institute of Technology's AutoID lab to explore ways to improve business performance through linking RFID technology information to the internet (Gubbi et al., 2013, Borgia 2014). However, it was only in 2005, when the International Telecommunication Union (ITU) published its first report on the subject, that the term IoT was coined. The ITU view the IoT as a new dimension to the world of information and communication technologies moving 'from anytime, anywhere connectivity for anyone,' to connectivity for 'anything.' In this scenario connections multiply and create an entirely new dynamic network of networks – an Internet of Things (Borgia 2014).'

From 2005 onwards, the number of definitions and related activities has increased significantly across multiple paradigms. Atzori et al. (2010) define the IoT as 'a conceptual framework that leverages on the availability of heterogeneous devices and interconnection solutions, as well as augmented physical objects providing a shared information base on a global scale, to support the design of applications involving at the same virtual level, for people and representations of objects.' This is realised in three paradigms – internet-oriented (middleware), things-oriented (sensors) and semantics-oriented (knowledge). Building upon this definition, Borgia (2014) describes the IoT as an interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, thereby developing a common operating picture for enabling innovative applications. This enables devices, machines and humans to connect with each other to create databased services to support day-to-day living (Lee and Lee 2015). In the IoT, 'the things' refers to tags, sensors and smart phones, which are used to collect measurement data from, and share information processes with, end-use locations. Another central concept connected with the IoT is 'the cloud,' which refers to a model for on-demand access to a shared pool of configurable online resources, such as massive, flexible data storage that enables real-time data streaming and analytic services (Díaz et al., 2016). The IoT opens doors to new findings, applications, benefits and risks (Fleisch 2010), and has the potential to revolutionise a broad range of applications in basically all domains of our social and business lives, from education and health to farming and the aeronautic industry (Nicolescu et al., 2018).

2.2 Business design challenges to the IoT service supply chain

From a business perspective, the IoT service supply chain inevitably increases the complexity of service offerings by challenging value-network actors to assess their businesses as ecosystems and to emphasise co-creation. The potential for value co-creation drives businesses to join IoT ecosystems, regardless of the expenditure and investment requirements. This is because they want to engage in dynamic business environments and create new ways of innovating offerings (Papert and Pflaum 2017). Despite this, technical specifications and reference architectures for IoT service supply chains are currently far from being complete and standardised, and are often heterogeneous with respect to their degree of openness and closure and the level of decentralisation (Nicolescu et al., 2018). This makes it difficult for business ecosystems to fully understand and evaluate the benefits and risks associated with IoT service supply chain from a business design perspective. As well as having access to a well-defined IoT service supply chain architecture typology, which can be applied beyond a specific business activity, application, technology or specific types of communication media. This greatly restricts the integration of the IoT service supply chain, and willingness of business ecosystems to use it to innovate their business design.

Recognising these challenges, there have been attempts in recent years by various industry bodies to develop a standardised architecture that enables interoperability, simplifies development and eases the implementation of IoT technologies (see Section 4), which have had varying degrees of success. In this paper, we address these issues by identifying the key business design challenges at each layer of the IoT service supply chain applying an adapted the Open Systems Interconnections reference model (OSI RM) 7-Layer architecture (Figure 1).

Figure 1. The OSI RM IoT architecture model (Rouse, 2019)

This architecture model can be described as an IoT service supply chain as each layer is connected to and serves the layer above it and, in turn, serves and is served by the layer below it. So, in a message between users, there will be a flow of data down through the layers in the source computer, across the network, and then up through the layers in the receiving computer. Only the application layer, at the top of the stack, does not provide services to a higher-level layer (Rouse, 2019). According to the OSI RM the layers of the IoT service supply are the:

(1) Physical/Sensor layer - Transports data using electrical, mechanical or procedural interfaces.
(2) Data Acquisition layer - The protocol layer in a program that handles the moving of data into and out of a physical link in a network.
(3) Network layer - Primary function is to move data into and through other networks by packaging data with correct network address information, selecting the appropriate network routes and forwarding the packaged data up the stack to the transport layer.
(4) Transport layer - Is responsible for transferring data across a network and provides error-checking mechanisms and data flow controls. It determines how much data to send, where it gets sent and at what rate.
(5) Session layer - Sets up, coordinates and terminates conversations between applications. Its services include authentication and reconnection after an interruption
(6) Presentation layer - Translates or formats data for the application layer based on the semantics or syntax that the application accepts. This layer is also able to handle the encryption and decryption that the application layer requires.

(7) Application layer - Enables the user (human or software) to interact with the application or network whenever the user elects to read messages, transfer files or perform other network-related activities (*ibid*).

Applying these definitions of the IoT service supply chain, business design challenges are approached by dividing the integration problem and the intended solution structure into a detailed system of products, services, processes and data to understand the structure and parts of the solution, and to understand how the IoT technology can be used to improve the system. In the literature, this construct is referred to as a product–service system , according to which a firm's product and service portfolio is mapped as a modular, interconnected system to support the structure of an integrated solution (Dahmus et al., 1999, Geum et al., 2011, Ulrich 1995). The key principle of the system is its functional structure, as the system divides its products and services into service functions that describe what the products and services do, rather than what they are (Ulrich, 1995). One product or service may enable one or several service functions, and, conversely, one service function can be enabled by several products and services (Dahmus et al., 1999, Geum et al., 2011, Oh et al., 2015, Persson and Åhlström 2006, Ulrich 1995). It is, therefore, necessary to identify the systemic service functions in a solution's design in order to optimise the value of the solution. A straightforward analysis of the importance of a service function, for example, might recommend the removal of non-value-creating service functions from the product and service portfolio, but, given the systemic interconnections between the service functions, removing a piece of the system may weaken the value of the entire system (Persson and Åhlström 2006, Pynnönen et al., 2011).

3. Methodology used for literature review of the IoT service supply chain

3.1 Research approach

The purpose of this literature review is to identify pre-existing architectures for the IoT service supply chain, to determine the key contributors and influencers and their interrelationships at each layer of the IoT service supply chain. In so doing, we make recommendations for how to rectify the key business design challenges that may emerge at the different stages of the sequence, in a standardised format.

Specifically, we conducted a systematic literature review as it allowed us to answer our specific research question through the production of a critical overview and synthesis of previous primary research studies on IoT architectures. This was done using an explicit, methodological approach to identify 'themes' or 'constructs' that lie in or across previous research on the phenomena (Shachak and Reis 2009). This approach was suitable as it provided a rigorous and well-defined approach to review relevant literature in the research area in a transparent, inclusive, explanatory, replicable and heuristic way (Denyer and Tranfield 2009, Barratt et al., 2010; Yan et al., 2018). It has also been found to be more objective and suitable for studying new and emerging trends (Mishra et al., 2016). This is particularly relevant in our development of a standardised IoT service supply chain architecture typology, as there is limited primary academic data on business design challenges associated with these phenomena.

3.2 Article sampling and timeframe

To generate a better understanding of the current thinking on the IoT architectures and frameworks, and to design our own conceptual framework/typology that can be applied across multiple scenarios, a review of academic papers was conducted. Figure 2 illustrates the processes that were used when we conducted the review, and the remainder of this section describes the review process in more detail.

Figure 2. Sampling process used in the literature review.

A literature search for peer reviewed academic papers written between 2010 and 2020 using the Scopus database was conducted to identify data relevant to our research question. The Scopus database was chosen for this process as it is one of the largest multidisciplinary (i.e., including social science and engineering studies) abstract and citation databases of peer-reviewed literature, which covers research from both major and minor publishers, including Elsevier, Emerald, Springer, and Wiley. Additionally, this database covers peer-reviewed multidisciplinary research studies therefore, it was certain to find many academic works related to the IoT service supply architectures. As our research phenomena are an interdisciplinary field straddling multiple disciplines, material was selected from the fields of business and operations management, and related areas including economics, information systems, operations research and organisation theory. This enabled us to identify, select and critically appraise disparate streams of work on the IoT service supply chain architectures from a business and operations management perspective, in an integrated way. As we analysed the results from these searches and the reference lists of the selected papers, additional works from outside of these fields were added to our literature review if they were relevant to our research. This allowed us to identify a broader range of academic papers than if we had narrowed our search criteria. It also reduced the risk of us overlooking literature relevant to our study (Webster and Watson, 2002). Papers published before 2010, were omitted from our as the IoT only emerged as a technology with significant disruptive potential in the early 2010's (Nicolescu et al., 2018), and as a consequence there was limited research on the phenomena prior to this year (Figure 3). Finally, selected papers were restricted to those written in English language, as this is the primary working language of the researchers (Pautasso 2013; Okoli 2015).

Figure 3. Number of paper's published in the English language on the Internet of Things in all academic categories 1999-2020 (Source: Web of Science, 2020).

In our search of the database, was based on Boolean logic which uses words that connect search terms or key words together to broaden or narrow the results retrieved, using the operators *OR, AND, NOT*. The OR operator searches for either of two terms in a document, AND searches for both terms in a document and NOT searches for documents without a specific term (Denyer and Tranfield 2009, p. 684). In this article, AND logic was used for the keywords 'Internet of Things' and 'IoT' in different combinations with the terms 'architecture,' 'ecosystem,' 'framework,' 'service' and 'supply chain.' The search was restricted to these terms and did not include other terms associated with the IoT, such as 'Industry 4.0,' 'Industrial Internet of Things,' 'Internet of Everything' or 'Web of Things,' to narrow our search results to our key research phenomena, the IoT. This also limited the complexity of the research topic and reduce misinterpretation that could arise from the between each of these expressions, such as the different digital technologies/concepts and applications they encapsulate.

After the first round of the database searches, we found 921 academic papers were identified on ScienceDirect. Supplementing the first round of our literature review, we undertook a forward search using the 'Web of Science' database to expand our search using an alternate comprehensive publisher-independent global citation database. This enabled us to identify and capture as many pertinent papers as possible. By applying this methodology, we were able to accumulate a relatively complete consensus of relevant literature on the research phenomenon (Webster and Watson, 2002).

Once this data gathering was completed, purposeful critical case sampling was used, to select the chosen papers. This technique is particularly useful in exploratory qualitative research, where a small number of cases can be decisive in explaining the phenomenon of interest, as was the case in this research. In this selection phase we examined the title, abstract and keywords, of each article to evaluate whether inclusion was warranted based on if they contained the keywords according to the search logic in Section 3.2, and they provided a detailed enough description of the phenomena being studied to find significant information that would allow us to answer our research question. Following this sampling review a total of 78 academic papers were identified as relevant to our research. These papers were read in full by one of the researchers and coded into relevant thematic nodes presented in Section 3.3. The results of analysis and synthesis of these literatures form the results and discussion points presented in the following sections of this paper.

3.3 Coding and analysis approach

A mixed coding logic was used in this research, whereby the researchers' manually designed a predetermined (deductive) code structure at the beginning of the analysis, in the course of internal discussions and based on a consideration of both the keywords listed in the 78 selected papers, and the researchers' knowledge of the phenomena. Additional codes were added as previously unconsidered, but relevant; themes emerged from the literature analysis itself (Bandara et al., 2011). The papers were read in full, analysed and relevant data was extracted using NVivo software, and both key and sub themes were identified. For each of the coding categories, we created nodes in NVivo and then selected relevant text excerpts and placed them into one or more categories/node themes (Figure 4) (Saldana 2012, pp. 1-31; Bandara et al., 2011).

Figure 4. High-level overview of key coding node themes used in NVivo software analysis.

As the purpose of this research was descriptive and inductive, and so was not conducive to the use of inferential statistics, we used a qualitative approach to identify key themes and to identify potential measures to address business design challenges. We then extracted the relevant information from the list of papers to serve as the raw material for the narrative synthesis of the studies. The outcome of this synthesis forms the foundation of the theoretical grounding, conceptual framework and the justification of our research. NVivo enabled us to map all the identified information based on our coding structure, and to explore the relationships in and across the data we collected (Okoli 2015).

4 Results

To explain the IoT service supply chain architecture and to develop a standardised typology, we began by examining existing IoT architectures, including the Open Systems Interconnection Reference Model (OSI RM), the ITU Reference Model, the Architectural Reference Model (IoT ARM), the IoT Reference Architecture developed by the WSO2 Company, the Korean IoT Reference Model, the Chinese IoT Reference Model and the Cisco IoT Reference Model (Table 1). These reference models are typically broken down into various 'layers' of abstraction based on the overarching idea that data is generated by multiple kinds of devices, processed in different ways, transmitted to different locations, and acted upon by applications (Cisco 2014). For example, the OSI RM divides different data-processing activities into four areas: devices, networks, big data and services (see Figure 5).

Table 1. Examples of Proposed IoT References Models and Reference Architectures.

Figure 5. Formalising the OSI RM IoT reference model in the context of the IoT service supply chain.

From a technical perspective of the IoT service supply chain, we can find five main categories where activity occurs: within measurement/control/identification devices, middleware interfaces, cloud computing, IoT application software programs and other operating information used to present the processed data (Lee and Lee 2015). The emphasis on integration in this definition of the IoT service supply chain also generates a list of cloud service components, cloud platforms, cloud infrastructures and IoT middleware (Díaz et al., 2016). Based on the previously described overviews of the IoT, it can be concluded that the IoT architecture should provide clear definitions and descriptions that can be applied accurately to all elements and functions of the IoT systems and applications. This reference model:

- **Simplifies:** It helps break down complex systems so that each part is more understandable.
- **Clarifies:** It provides additional information to identify levels of the IoT and to establish common terminology.
- **Identifies:** It identifies where specific types of processing is optimised across different parts of the system.
- **Standardises:** It provides a first step in enabling vendors to create the IoT products that work with each other.
- **Organises:** It makes the IoT real and approachable, instead of simply conceptual (Cisco 2014).

It does this by converting measurement data into context-related knowledge to address business design challenges. The IoT service supply chain architecture framework can therefore be an important first step towards standardising the concept and terminology surrounding the IoT; and provide a baseline for understanding its requirements and potential.

4.1 Existing architectures of the IoT service supply chain

Architecture is the cornerstone of all technologies, business processes and relationships and is therefore not only a key issue, but also a foundation for the development of the IoT service supply chain. Architectures are needed to represent, organise and structure the IoT in a way that enables it to function effectively (Whitmore et al., 2015). Without a well-integrated architecture that is applicable across different domains, devices, systems and network devices, much important content cannot be determined (Ning and Wang 2011, Tsai et al., 2014). While many businesses begin their IoT journeys with great expectations, many fail to realise the transformational and financial opportunities the IoT can offer due to a failure to develop appropriate architectures. The characteristic vagueness of architecture design in the IoT negatively affects its development and adoption, as well as its associated technologies and services. Current architectures often employ a 'silo' or 'stove' approach whereby each application has a proprietary ICT infrastructure and dedicated devices, and the focus is on the application, technology or specific types of communication media. rather than the given business design challenge. For example, data integrity, data management, data mining, energy awareness, interoperability, object naming schemes, privacy and security are common technological themes that emerge in the papers that were examined in this review (Atzori et al., 2010, Tsai et al., 2014, Lee and Lee 2015, Yaqoob et al. 2017). Reoccurring application themes include transport and logistics, healthcare, smart environments (home, office and plant) and environmental monitoring (Atzori et al., 2010, Xiaocong and Jiadong 2010, Jia et al., 2012, Khan et al., 2012, Gubbi et al., 2013, Hsieh and Lai 2014, Lee and Lee 2015, Nia and Jha 2016).

As the adoption of the IoT has broadened, the International Standards Organisation JTC1/WG10 group has identified more than 25 reference architectures/frameworks developed by prominent vendors, industry consortia and academic or standardisation bodies. This proliferation is not a surprise, given that there have most likely been just as many enterprise architectures developed for traditional information technology strategies to articulate and engineer technological responses to business needs over the years, if not more. This has led to a situation in which there is not yet a universally accepted IoT architectural framework that can integrate the various functionalities necessary to realise the full potential of the IoT (Lopez et al., 2014, Minoli et al., 2017).

From the existing architectures that have been identified through our research the most discussed IoT architecture is the three-layer model, which is composed of the perception, network and application layers (Wu et al., 2010, Yun and Yuxin 2010, Domingo 2012, Jia et al., 2012, Ning and Hu. 2012, Sun et al., 2012, Tsai et al., 2014, Ju et al., 2016, Nia and Jha 2016). The perception layer refers to the first step from the physical world to the information space and describes the procedures for sensing the physical environment, collecting real-time physical data and reconstructing a general perception of the physical environment. The network layer refers to the virtual platform and mechanisms for the receipt, dissemination and sharing of information. This layer primarily focuses on internet technology and wireless network technologies. The application layer refers to the integration, analysis, mining, storage and application of data, including public and industry technology. While the terminology used by academics to describe these layers varies, the terms refer to the same essential processes. These IoT layers are realised in three supporting archetypes: (1) hardware, which is made up of sensors, actuators and embedded communication hardware; (2) network, which includes transmitting and processing of the data collected by hardware; and (3) presentation, which includes novel, easy-to-understand visualisation and interpretation tools that can be widely accessed on different platforms and can be designed for different applications. Although this type of delineation is required due to the interdisciplinary nature of the IoT, the usefulness of the IoT is only realisable in an application domain in which the three paradigms intersect (Atzori et al., 2010, Xiaocong and Jidong 2010, Borgia 2014, Tsai et al., 2014, Ju et al., 2016, Yaqoob et al., 2017). In addition, there are technologies that are common throughout the three layers, including cloud computing, architecture technology and safety technology.

The five-layer architecture is an alternative to the three-layer architecture and has been proposed to facilitate interactions between the different sections of an enterprise by dividing complex systems into simplified applications that consist of an ecosystem of simple and well-defined components. The five-layer architecture adds the access gateway layer and the middleware layer to the three-layer architecture of the IoT. Unlike the three-layer architecture of the IoT, which uses only the network layer to connect the perception and application layers, the five-layer architecture of the IoT combines the access gateway layer with the network layer to manage the communications in the IoT environment and to transmit messages between the objects and systems. The middleware layer is another layer of the five-layer architecture of the IoT that provides a more flexible association interface between the hardware and applications. The top layer of the five-layer architecture is the application layer, defined similarly to the three-layer architecture in that it provides easy-to-understand visualisation and interpretation tools that can be widely accessed on different platforms and can be designed for different applications (Tsai, Lai and Vasilakos 2014, Gaitan et al., 2015, Lee and Lee 2015). The most recognised five-layer architectures are the reference architecture proposed by the WSO2 Company (Cavalcante, et al., 2015; Fremantle, 2015; Torkaman and Seyyedi, 2016) and the IoT-A ARM proposed by the European Lighthouse Integrated Project and co-funded by the European Commission as part of the Seventh Framework Programme (2007–2013) (Alhamedi, 2014, Gaitan, et al., 2015; Khan et al., 2012, Torkaman and Seyyedi, 2016; Weyrich and Ebert, 2016) .

In addition to these commonly recognised architectures, several academics have proposed a four-layer architecture that follows the Service Oriented Architecture (SOA) approach by building upon the three-layer concept but adding a service layer between the networking and application layers (Atzori et al., 2010, Georgakopoulos et al., 2015, Lan et al., 2014, Xu and Shancang., 2014). Xu and Shancang (2014) discuss a simplified four-layer SOA for the IoT, whose infrastructural architecture focuses more on providing services than on networking and is a result of a perceived demand to integrate heterogeneous systems and devices to create and manage services that satisfy users' needs. The adoption of the SOA principles allows for deconstructing complex and monolithic systems into applications that consist of an ecosystem of simple and well-defined components. This facilitates the interaction between the parts of an enterprise and reduces the time necessary for the enterprise to adapt itself to the changes imposed by market evolution. An SOA approach also allows for software and hardware reuse, because it does not impose a specific technology for the service implementation.

4.2 Proposed Conceptual Typology for the IoT Service Supply Chain

While different IoT service supply chain architectures exist, they principally focus on describing the different architectural layers of the chosen architectures in a particular industry, business process or application, or are proprietary models (Vishwakarma et al., 2019), bring along the risk of fragmentation and a lack of adoption of adequate standards (Miorandi et al., 2012), and fail to address the business design challenges that may occur within each layer. This is a critical oversight, as many business ecosystems are encountering issues such as how, when and where to apply IoT and its integrated technologies to create value. Designing an IoT service supply often overwhelms an implementing business ecosystem due to the pace, range and complexity of the technology. This often leads it to hastily designing business strategies that adopt a single tactic that focuses on the technology, thereby overlooking the critical business design issue such as user service experience, which is often the key to business success, especially when it comes to the IoT. The varying architectures that may be used to support the IoT service supply chain also highlight the importance of the issue of a standardised typology (Whitmore et al., 2015).

Applying the findings from the literature review, key challenges were identified and synthesised to produce a typology matrix for the IoT service supply chain (Table 2) in the context of the OSI RM seven-layer model shown in Figure 5. This model was chosen for three reasons: (1) the seven-layer model, provides a more nuanced breakdown of the IoT service supply chain. Importantly, it accounts for the 'application layer' which provides the interface by which end-users can interact with a device and query for interesting data. (2) It provides an interface to the 'Business Aggregation' and 'Analytics/Presentation' Layer's. These layer's host powerful technologies that can process, store and transform complex and enormous datasets into meaningful outputs. These are essential in helping business ecosystems make informed business design choices. (3) Finally, the OSI RM was developed by representatives of major computer and telecommunication companies beginning in 1983 - originally as a common reference model that others could then use to develop detailed interfaces, which, in turn, could become standards governing the transmission of data packets. It was subsequently officially adopted as an international standard by the International Organization for Standardization (ISO) in 1984. It, therefore, provides a well-established and recognised architecture developed by companies vested in developing an architecture that can be applied in a business context. It also has the benefit of being approved by an international standard-setting body composed of representatives from various national standards organisations, making it a widely accepted architecture for. Considering these points on the one hand and sticking to the simplicity of the architecture on the other hand, the seven-layer architecture is the most applicable model for emerging IoT service supply chain (Rouse, 2019), from which we can base the development of our typology.

The development of our typology included several stages:

1. The initial selection of the research phenomena and development of the research question by the researchers in internal discussions.
2. Identification of relevant academic articles papers from peer-reviewed business journals, based on the sampling criteria and methodology described in Section 3.2
3. Manual design of a coding scheme (Section 3.3) based on a consideration of the title, abstracts and keywords of the 78 selected papers and the researchers' knowledge of the phenomena.
4. In-depth review of the selected papers for salient information deemed relevant to answering the research question, according to the coding schema. A certain amount of recoding and reclassification of coded data into new categories was undertaken as knowledge of the phenomena developed.
5. Development of a typology based on the outcomes of the literature review. Categorisation of results is presented in Table 2 according to (1) their presentation in the sample papers and (2) the researchers' understanding of the phenomena and interpretation of the existing research literature.

In this typology matrix, we address the construct gaps and/or challenges that may appear in redesigning or reinventing business models when applying the IoT and its associated digital technologies to create and deliver new value (Johnson et al., 2008, Gassmann et al., 2014). This is presented in the form of intellectual 'bins' from a data, product and process angle and from a systems theory perspective (Baxter and Jack 2008).

Table 2. IoT Service Supply Chain Typology Matrix.

The increasing digitalisation and interconnectedness of our world is rapidly changing user expectations of the technologies that deliver services. The IoT changes the perceived and tangible value of products and solutions, and it is impossible to develop business design and resulting business model(s), without identifying and factoring in a clear user proposition (Johnson et al., 2008). In the following section we discuss the key business design issues presented in our typology matrix (Table 2), and implications business ecosystems and design when integrating the IoT service supply chain.

5 Discussion – consequences of review and proposed architectural framework

The IoT is increasingly embedding itself into the fabric of business DNA with IoT service supply chains continuously operating internally and externally to business ecosystem boundaries. The success of a business driven by the IoT depends on its ability to be adaptive, responsive and align with business requirements. This is creating a need for a clear standardised architecture typology in order to enable business ecosystems to realise interoperability among diverse resources, and facilitate effective business design which accounts for the role that the IoT service supply chain plays in enabling them to fulfil objectives and value propositions set out in their business model(s). By taking a systems theory perspective we can better understand and describe the IoT service supply chain layers and typology, which can help academics and practitioners gain a better insight into the real meaning and functionality of the IoT service supply chain layers. In our typology matrix we identify several key requirements that need to be factored in when performing business design in the context of the IoT service supply chain. These include common factors, such as usable security and privacy protocols, robust connectivity, integration and interoperability, big-data management and system simplicity, which are must for all the business design strategies. Concrete use cases and compelling value propositions can also improve business ecosystems firms understanding and decision making when it comes to the IoT service supply chain, as it enables them to contextualise how it can deliver more efficient and new value streams, against business objectives set out in business plans. It can also improve the coordination of core business activities, such as supply management, product-service tracking and monitoring, help determine and describe the utility to stakeholders, etc; through improved oversight of how the IoT service supply chain layers relate and interact with one another 'anytime', 'anywhere' for 'anything.' Key IoT service supply chain challenges when it comes to business design include:

- *A business ecosystem mentality* – In the IoT service supply chain, IoT ecosystems are conceptualised as interfaces that serve to mediate transactions between different sides, such as networks of buyers and sellers or complementors and users. This mediating function enables parties to interact and create value (Karhu and Ritala 2020). This also makes it possible to integrate a third-party provider's (complementors') hardware and digital services. Meaning that business ecosystem members do not need to implement all the related IoT service supply system layers themselves.

- *Cooperation* – to achieve a coordinated business ecosystem mentality requires cooperation throughout the entire business ecosystem. This emphasises the need for openness, cross-company cooperativeness, trust, and compatible technologies. Additionally, there is a need for close involvement of customers and suppliers into value creation (Kiel et al., 2017). This underlines the importance of an integrated IoT service supply chain approach. This enables them to continuously adapt, develop and improve its functionality.
- *Organisational transformation* – key to this is top management buy-in, involvement, and persuasion of internal company stakeholders. As well as, the creation of an adaptable and flexible corporate culture and hierarchical structure (Kiel et al., 2017). Appropriate human and financial resources; and the development of suitable business models for IoT.
- *Technological integration and* r*eliability in terms of the proper working of the system(s) based on its specification* – based on appropriate hardware and software levels, which enable an increase in the success rate of the IoT service supply chain delivery.
- *Continuous high-performance levels* - meaning that the IoT service supply system needs to be continuously monitored, developed, evaluated and improved to meet rapidly changing user requirements at an affordable cost. Maintaining compatibility across the IoT layers also needs to be managed to enhance connectivity speed and to ensure service delivery.
- *Security and privacy protocols* - are critical requirements for the IoT service supply chain due to the inherent heterogeneity of the internet connected objects and the ability to monitor and control physical objects. Management and protection of the large amounts of data collected by IoT technologies is a critical issue for business design. Particularly ensuring that stringent and appropriate measures are put in place to reduce the risk of malicious attempts to access or manipulate data across the whole IoT ecosystem.

The urgency and speed of adoption of IoT service supply chain technologies, and the ultimate size of the market for these solutions, varies by industrial sector. Our proposed typology matrix can help business ecosystems in this process by adopting of a systematic and integrated approach to business design, which takes account of the interdependence between each layer of the IoT service supply chain. Specifically, the IoT service supply chain should do three things. Firstly, it should be able to read data streams from sensors directly or fetch data from databases. Secondly, it should analysis data in a logical way using functions/operators that process data streams in a transparent and scalable manner on cloud infrastructures. Thirdly, it should present relevant outcomes in a meaningful way. This will enable firms to provide a seamless user experience which will then contribute to an increase in revenue through different business ecosystems through the application of IoT orientated business models, which are based on activities that focus on creating, delivering, and capturing value through the delivery a service function rather than the traditional ownership orientated models. It also enables business ecosystems to create more value through personalised tailoring of product-services based on better multi-tiered interactive communication, and large amounts of unique data gathered throughout the IoT service supply chain layers. This is particularly important as users become increasingly tech-savvy and demand personalised experiences from the beginning to end of a product-service lifecycle (from design to consumption and retirement or recycling).

The combination of new data - that was previously unavailable - gathered in the different layers of the IoT service supply chain, also allows business ecosystem firms to overcome challenges including overstocking, downtime delivery delays and stock outs, that are common attributes of more traditional supply chains. It can also enable them to optimise maintenance schedules and output, monitor critical processes, and better understand and serve consumers (Kiel et al., 2017); ‘any-time,’ ‘any-where’ for any-thing.’ Finally, IoT technologies are evolving rapidly therefore architecture and typology need to be reviewed regularly to match future the IoT challenges and ensure that business design addresses them.

6 Conclusion and future research directions

The motivation for this study was to formulate a standard framework matrix for IoT business design to reduce the total monetary and time costs of devices, development and deployment. The proposed framework provides an illustration of the layers of the IoT service supply chain, by applying the OSI RM framework as a template, and the considerations at each layer of its architecture from the business developer and user perspectives.

By adopting a systems theory approach to our research, we contribute to the limited theoretical business and organisation academic works in the area of the IoT service supply chain. Our framework matrix provides researchers with a comprehensive description of the distinct layers of the IoT service supply chain. As well as an overview of how they interact with each other and their environment(s), to deliver value. It also provides a starting point for future IoT systems theory research, particularly from an empirical perspective, where real life case studies will enable an understanding of how IoT service supply chains are operating in real-life.
This paper also benefits practitioners and managers, by proposing a unified typology matrix that identifies the key issues that must be addressed within each layer and supporting gateway of the IoT service supply chain, in order to capture value for all their interested stakeholders. This new knowledge in decision support when integrating the IoT into their systems by having a clear picture the key issues that must be addressed within each layer and supporting gateway of the IoT service supply chain and adapt their systems according to the situation.

To extend the understanding of issues discussed in this article, future research should focus on providing primary empirical evidence of how a standardised IoT architecture can be applied across multiple business sectors and scenarios, such as supply management, smart living and healthcare. Industry standards tend to be sector specific; however, with the increasing cross-boundary nature of the modern economy, fuelled by innovations such as the IoT, better understanding of how standards can be applied across multiple divergent fields is important information. Further research on how new models or adaptions to existing business models can better address issues created by these factors, and how to create value and new business streams without constantly reinventing the wheel, would also be valuable contributions to the existing research on business model innovation.

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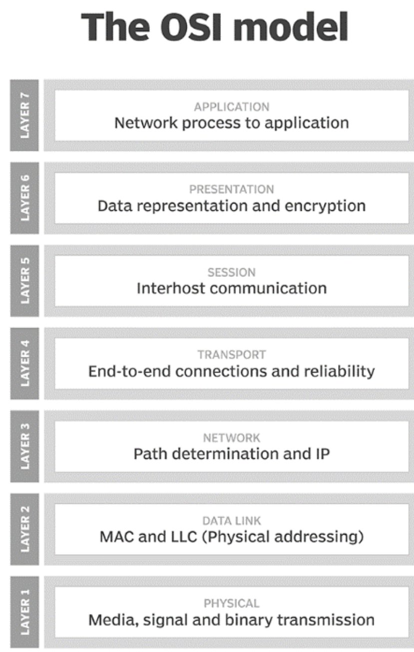
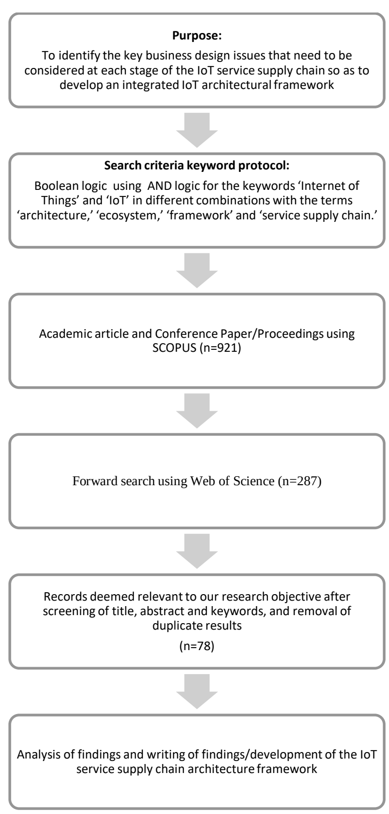
Table 1. Examples of Proposed IoT References Models and Reference Architectures.

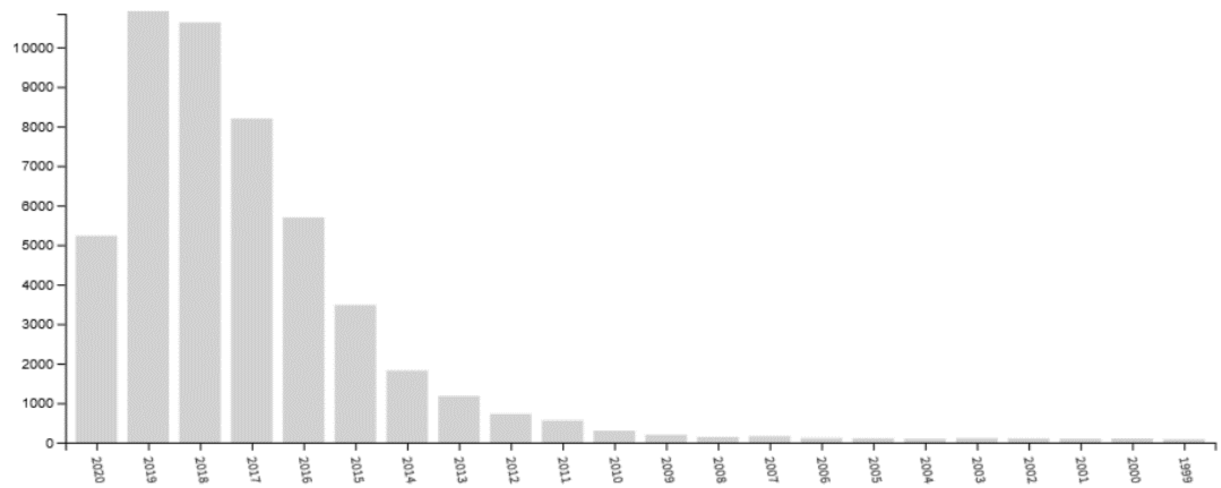
IoT Reference Model	**Reference Architecture Type**	**Reference Architecture Layers**	**Source**
Open Systems Interconnections reference model (OSI RM)	7 Layer	(1) Physical/Sensor layer (2) Data Acquisition layer (3) Network layer (4) Transport layer (5) Session layer (6) Presentation layer (7) Application layer	(Alhamedi 2014) (Rouse 2019)
International Telecommunication Union (ITU)	4 Layer	(1) Application layer (2) Service and application support layer (3) Network layer (4) Device layer	(Torkaman and Seyyedi 2016)
IoT-A project supported by the European Commission within the Seventh Framework Program (FP7)	3 Layer	(1) Functional layer (2) Information layer (3) Deployment layer	(Alhamedi 2014) (Gaitan, Gaitan and Ungurean 2015) (Khan, Khan, Zaheer and Khan 2012); (Torkaman and Seyyedi 2016); (Weyrich and Ebert, 2016)
Chinese Architectural Reference Model	3 Layer	(1) Sensing layer (2) Network and service layer (3) Application layer	(Chen et al. 2014) (Torkaman and Seyyedi 2016)
WS02 Architectural Reference Model	7 Layer	(1) Device layer (2) Communications layer (3) Aggregation/Bus layer (4) Event Processing and Analytics layer: (5) Aggregation/Bus layer, (6) Device Management layer (7) Identity and Access Management layer	(Cavalcante et al. 2015); (Torkaman and Seyyedi, 2016) (Freemantle, 2015)
CISCO IoT Reference Model	7 Layer	(1) Physical Devices and Controllers layer (2) Connectivity layer (3) Edge Computing layer (4) Data Accumulation layer (5) Data Abstraction layer (6) Application; Reporting, analytics and control layer (7) Collaboration and processes layer	(Cisco, 2014) (Nia and Jha, 2016)

Table 2. IoT Service Supply Chain Typology Matrix

	Service design issues			Integration issues		
Supply chain stage (IOT-architecture layer)	Data	Product	Process	Data	Product	Process
1. Devices						
1.1 Sensors "Universe of Things"	Real-time, logical, and relevant	Reliable, smart, common functionality	Anytime, anywhere, and anyplace	Secure, confidential, and integrity	Unique identifier, interoperability	Autonomy
1.2 Data Acquisition "Embedded Systems"	Logical & relevant	Intelligent, self-configurable, and scalable	Direct or indirect link to network and gateway to next layer	Customisable communication schemes enabling flow control	Fusion between device(s) and WSN protocols	Context and environment awareness
2. Networks						
2.1 Local Networks "Connectivity"	Diffusion and processing of end-to-end data in a reliable or unreliable way	Reliable roaming infrastructure and control schemas; cross-functional protocols, proxies, and gateways	Backbone networks and resource admin. Autonomous local fog and global cloud capability	Clustering and filtration of data collection according to user-defined criteria	Dynamic and integrated. Ability to handle spontaneous additions and departures	Logical address schemas, data packaging, manipulation, and delivery
2.2 Data Aggregation	Integrated adaptation and accretion of data flows from devices to back-end apps	Intelligent and self-managing	Smart identification and filtration according to defined criterion	Converts data of relevance to later stage from data in motion to data at rest via selective filtering and storage	Common functionalities utilisable by different IoT applications	Ubiquitous computation and independent decisions based on outcomes
3. Big Data						
3.1 Data Storage/ Centralisation	Normalisation, de-normalisation, scalable, indexing, and consolidating of complex data into meaningful formats, security, and privacy	Data, software, and control server components that handle data flows efficiently and securely during its life cycle	Retrieve, process, and compute data and automatic decision making connected to service-oriented issues	Retrieval, assimilation and processing of data from multiple sources	Represents relevant data in an IoT system in terms of static information structures	Processes and assimilates all service-oriented issues
3.2 Data Analytics	Smart object network structure repository	Processed in an automatic and smart way to deliver pervasive and spontaneous services	Intelligent analysis and decision making using smart computing and cloud technologies	Conversion of data into logical structures recognisable to information technology infrastructure components	Software cooperates with data accrual and abstraction levels	Stores, analyses, and processes data from the network layer using proxies to map data logically
4. Services						
4.1 Application	Inclusive applications management based on processed data in previous layers	Transforms data into content accessible through the user interface	Flexibility to make it easier to develop the platform as the service supply chain evolves	Multiple app assimilation at the back end; simplifying the management and linkage of "things"	Common interface, intelligent operation, and configuration to specification	Exporting all the systems' functionalities to the end-user


The OSI model
LAYER 7
APPLICATION
Network process to application
LAYER 6
PRESENTATION
Data representation and encryption
LAYER 5
SESSION
Interhost communication
LAYER 4
TRANSPORT
End-to-end connections and reliability
LAYER 3
NETWORK
Path determination and IP
LAYER 2
DATA LINK
MAC and LLC (Physical addressing)
LAYER 1
PHYSICAL
Media, signal and binary transmission


Purpose:
To identify the key business design issues that need to be considered at each stage of the IoT service supply chain so as to develop an integrated IoT architectural framework
Search criteria keyword protocol:
Boolean logic using AND logic for the keywords 'Internet of Things' and 'IoT' in different combinations with the terms 'architecture,' 'ecosystem,' 'framework' and 'service supply chain.'
Academic article and Conference Paper/Proceedings using SCOPUS (n=921)
Forward search using Web of Science (n=287)
Records deemed relevant to our research objective after screening of title, abstract and keywords, and removal of duplicate results
(n=78)
Analysis of findings and writing of findings/development of the IoT service supply chain architecture framework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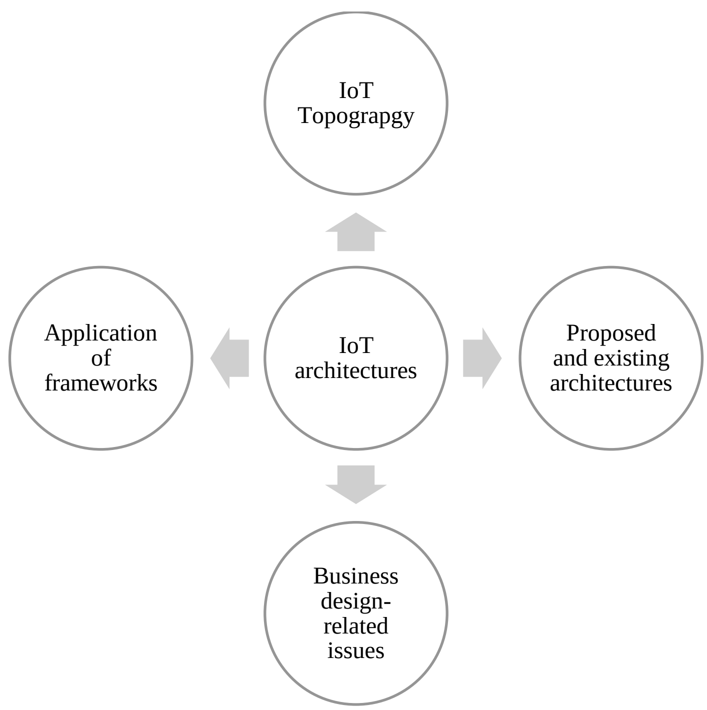
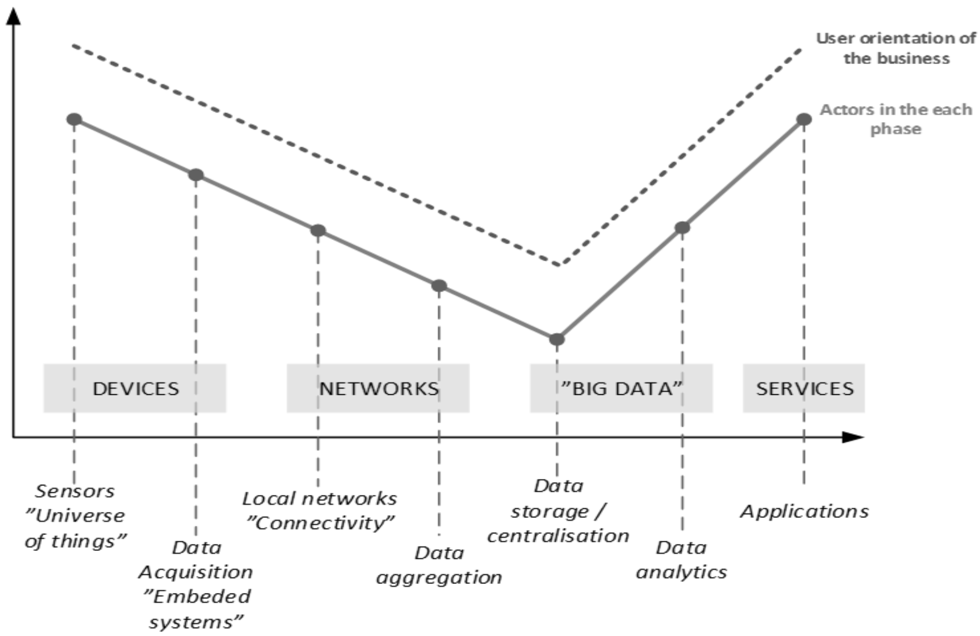

IoT Topograpgy
Application of frameworks
IoT architectures
Proposed and existing architectures
Business design-related issues


User orientation of the business
Actors in the each phase
DEVICES
NETWORKS
"BIG DATA"
SERVICES
Sensors "Universe of things"
Data Acquisition "Embeded systems"
Local networks "Connectivity"
Data aggregation
Data storage / centralisation
Data analytics
Applications