Modeling of IoT devices in Business Processes: A Systematic Mapping Study

1st Victoria Torres
PROS Research Centre
Universitat Politècnica de València
Valencia, Spain
vtorres@pros.upv.es

2nd Estefanía Serral
LIRIS
KU Leuven
Leuven, Belgium
estefania.serralasensio@kuleuven.be

3rd Pedro Valderas
PROS Research Centre
Universitat Politècnica de València
Valencia, Spain
pvalderas@pros.upv.es

4th Vicente Pelechano
PROS Research Centre
Universitat Politècnica de València
Valencia, Spain
pele@pros.upv.es

5th Paul Grefen
School of Industrial Engineering
Eindhoven University of Technology
Eindhoven, Netherlands
p.w.p.j.grefen@tue.nl

***Abstract*—The Internet of Things (IoT) enables to connect the physical world to digital business processes (BP). By using the IoT, a BP can, e.g.: 1) take into account real-world data to take more informed business decisions, and 2) automate and/or improve BP tasks. To achieve these benefits, the integration of IoT and BPs needs to be successful. The first step to this end is to support the modeling of IoT-enhanced BPs. Although numerous researchers have studied this subject, it is unclear what is the current state of the art in terms of current modeling solutions and gaps. In this work, we carry out a Systematic Mapping Study (SMS) to find out how current solutions are modelling IoT into business processes. After studying 600 papers, we identified and analyzed in depth a total of 36 different solutions. In addition, we report on some important issues that should be addressed in the near future, such as, for instance the lack of standardization.**

***Index Terms*—Business process modeling; Internet of Things; IoT devices; IoT-enhanced BP; Systematic mapping study**

I. INTRODUCTION

Kevin Ashton, who first coined in 1999 the Internet of Things (IoT), envisioned a future where computers could "*see, hear, and smell the world for themselves*" [1]. Such computer empowerment would not just release human beings from capturing data from the real world but also release computers from their historical dependency on human beings and their limitations to acquire such data. Twenty years later, it is common to find devices and/or things supporting our daily activities both at the personal and professional side. In fact, the IoT device's connection capabilities and their ability to transmit data are revolutionizing the way we live and do business. Even though some of these IoT devices are smart ones capable to react individually upon some events, it is their combined usage what provides an added and innovative value to their users. Within this context, Business Process Management (BPM) appears as an essential component in leveraging the coordination and interaction of IoT devices, so that these can become active participants of future business processes (BPs). According to [2] a BP is defined as "*a set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business goal. Each business process is enacted by a single organization, but it may interact with business processes performed by other organizations*".

By embracing IoT devices a BP will be able to, e.g., 1) take into account real-world data to take more informed decisions, and 2) automate BP tasks and improve their execution([3], [4]). In this work we will refer to this type of BPs as *IoT-enhanced BPs* and we define it as *a BP that makes use of IoT technology to carry out the process tasks to achieve a specific goal*. In the literature this term is referred also as *IoT-aware BP* (e.g., [5], [6], [7], [8], [9], [10], [11], [12], [13]). However, in this work we prefer to use the term *IoT-enhanced BP* since we understand that BPs in this context are more than informed or alerted by existing IoT elements but magnified by the use of these elements, increasing as a result their value and quality.

As a first approach to merge the IoT and the BPM fields, in this work we focus on the design and analysis phase from the BPM lifecycle [2], specifically on the modeling task. We expect that the specificity of the topic being addressed will restrict the potential candidates studies for the analysis, allowing for an in-depth study of the selected proposals. This scenario favors the conduction of a systematic review instead of a mapping review where studies are analyzed more superficially [14]. As a result, we carry out a Systematic Mapping Study (SMS) where we carefully review the state of the art developed in this topic. Therefore, the major objective of this work is having an in-depth understanding of the current and common trends that exist to properly modeling IoT devices into BPs i.e. to clearly represent such new players within a BP model..

A. Research questions

In the literature we can find many definitions of the IoT term (e.g., [15], [16], [17], [18]). However, in a broad sense, the IoT is characterized by *a network of interconnected computing devices that are seamlessly integrated in so-called* things*, any real-world item (i.e., physical object, animal, person, etc.) which can be attached a computing device to*. Depending on its capabilities towards the associated real-world item, a computing device can be categorized as a *tag*, to identify the associated physical entity (e.g., product id), as a *sensor*, to provide data about the associated physical entity that is being monitored (e.g., temperature, ambient noise level, location, lighting, hearth rate, blood pressure, etc.), or as an *actuator*, to provide mechanisms that allow modifying the state of the associated physical entity (e.g., increasing/reducing the heat of a room, switching on/off room lighting, switching on/off garden irrigation, etc.).

Taking into account the important role that the IoT device concept play in the IoT domain, it needs to be somehow present in IoT-enhanced BP models. To overcome the challenge of introducing such concept at the modeling level, we also need to understand the used modeling strategies. Thus, we state the following two research questions:

RQ1. Which modeling strategies are provided to build IoT-enhanced BPs?

The generic-purpose constructs provided by common BP modeling languages such as Petri Nets, EPC, Yawl, BPEL, BPMN, UML Activity Diagram (UMLAD) may not be suitable to represent IoT-enhanced BPs. There are different ways to overcome this limitation, e.g., by extending existing BP languages with new constructs, by creating a new domain specific language (DSL), or by complementing BP models with other models to represent such specific aspects separately from the BP specification. Therefore, the objective of RQ1 is to identify the strategies used to design a modeling solution for the construction of IoT-enhanced BP models and also which BP languages are most preferred for implementing the chosen strategy.

RQ2. How IoT devices are represented at the modeling level?

Within the IoT domain we find a plethora of things and devices that play an active role for the achievement of a specific goal, for example by taking the responsibility of some of the tasks that make up a specific BP. Therefore, the objective of RQ2 is identifying how IoT devices can be represented when modeling IoT-enhanced BPs.

B. Structure of the paper

The remainder of the paper is organized as follows. Section II describes the research methodology applied to conduct the SMS. Section III answers the RQs by analyzing the set of primary studies resulting from the literature search. Section IV discusses the results from the SMS. Section V summarizes the state of the art, stressing the differences with our SMS. Finally, section VI presents our conclusions.

II. METHODOLOGY

To conduct the SMS we have followed the guidelines, procedures, and policies proposed by *Kitchenham* in [19]. Accordingly, we have defined a review protocol that starts with the specification of the research questions (cf. Section I-A). Then, a search string was defined to identify, as much as possible, all relevant literature (cf. Section II-A) from a selection of data sources (cf. Section II-B). As a result we obtained a list of studies that was evaluated by the authors, based on title and abstract, for inclusion in the set of candidate papers. Inclusion and exclusion criteria (cf. Section II-C) have been defined to assess each potential primary study. As a result of this stage, an initial set of potential primary studies was obtained. In addition, to reduce the probability of missing relevant studies, we have complemented the initial search with *backward* and *forward* snowballing [20].

A. Search string

The search string defined in this study has been elaborated based on keywords we derived from our own knowledge on the topic, i.e., we applied subjective search string definition ([21]). In addition, to broadly cover the scope of the SMS we have used a wide range of synonymous terms which have been connected through the OR logical connector. The final search string has been obtained after refining it iteratively with the goal of maximizing the number of relevant studies to be analysed in this SMS. This refinement has been performed with pilot searches with the search string based on a trial and error approach, excluding all those terms that do not contribute to retrieve any additional studies.

As a result, the search string applied during the SMS was the following:

((bpmn OR "uml activity" OR epc OR yawl OR "petri nets" OR bpel) OR (process OR workflow OR "service composition")) AND modeling AND (iot OR "internet of things" OR "cyber physical system" OR ubiquitous OR pervasive OR "smart system" OR "ambient intelligence" OR "context adaptive" OR "context aware")

To increase the probability of retrieved studies dealing with these terms, we applied the proposed search string to two meta-data fields, i.e. keywords and title. The automated search was performed with *Papers*[1], a reference management software that allows automating searches across multiple search engines.

B. Data source selection

The relevant studies for this SMS are those published in proceedings of the most relevant conferences, and workshops, and journals where the BPM and the IoT communities are

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[1] https://www.readcube.com/papers/

present. These include, among others, 1) journals such as Data & Knowledge Engineering, Computers in Industry, Personal and Ubiquitous Computing, Service Oriented Computing and Applications, Information Systems, Information and Software Technology, and 2) conferences and workshops such as the International Conference on Business Process Management (BPM), the International Conference on Service-Oriented Computing (ICSOC), the Advances in Grid and Pervasive Computing Conference (GPC), the Ubiquitous Computing and Ambient Intelligence Conference (UCAmI), the Embedded and Ubiquitous Computing Conference (EUC), Conference on Advanced Information Systems Engineering Conference(CAiSE), the Working Conference of Business Process Modeling, Development, and Support (BPMDS), the IEEE Enterprise Computer Conference (EDOC), the International Conference on Cooperative Information Systems (CoopIS), the Symposium on Applied Computing (SAC), the International Conference on Service Computing (SCC), the International Workshop on BP-Meet-IoT (BP-meet-IoT), the International Workshop on Business Process Modeling Notation (BPMN), and the IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE). All these journals, conferences, and workshops are registered in the following five electronic libraries, which have been used to conduct this SMS: SpringerLink, ScienceDirect, Scopus, Google Scholar, and Crossref Search.

With this selection of libraries we want to ensure a broad coverage, so we could retrieve the maximum number of candidate studies from a minimum number of libraries. As an additional data source, we considered the literature referenced by the retrieved studies and the literature that cited the retrieved studies; i.e., literature found by the application of backward and forward snowballing.

C. Inclusion and exclusion criteria

We defined several inclusion and exclusion criteria in order to follow a systematic approach to select the studies that must be considered as relevant. Therefore, all the studies meeting any of the exclusion criteria are eliminated from the analysis process. In particular, the following criteria were considered:

1) Inclusion criteria:

The study describes a modeling approach dealing with IoT-enhanced BPs.

2) Exclusion criteria:

a) The study is not focused on the modeling of IoT-enhanced BPs or merely mentioning modeling in a general manner.
b) The study does not include sufficient data to infer how IoT is taken into account in the BP model.
c) In case of several studies referring to the same modeling approach, all studies, except the latest and most complete version, are excluded.
d) The study is published in a non-peer reviewed publication (e.g., a preface, editorial, or technical report).
e) The study is not written in English.
f) The study is presented as a short paper of less than 5 pages.
g) The study is not electronically available or requires payment of access fees[2].

D. Study selection

We applied the proposed methodology through 5 stages. Data extraction was performed by the two first authors who collected such data in an Excel spread sheet. This sheet was reviewed by the remaining authors to check the decisions made over each study After stage 1, a total number of 600 studies were retrieved from the five electronic libraries selected. Then, in stage 2, after applying the items d-g identified in the exclusion criteria, a total of 534 studies were discarded, obtaining as a result a total of 66 potential studies. Afterwards, in stage 3, these potential studies were evaluated based on their title, abstract, and keywords in order to determine its relevance to the SMS according to the inclusion criteria and items a-c from the exclusion criteria. As a result, a set of 20 studies were selected. Then, from this selection we performed backward and forward snowballing to analyze the referenced literature (stage 4) and the literature that cited the primary studies (stage 5). This last stages resulted in the incorporation of 16 new studies, resulting in a total of 36 studies which are summarized in Table I. In addition to the reference to each study, this table shows, the name of the corresponding proposal, the publication year (Yr), the type of venue where the proposal has been published (i.e., journal (Jr.), conference (Cn.), and workshop (Wr.)) and finally the major research field to which the publication venue belongs to. In this case we have categorized the venues into three groups, i.e., IoT for venues where research is focused around IoT technology, BPM for venues where the topics are built around BPs and services, and IT for venues with a broader scope covering usually both fields.

III. RESULTS

According to the two RQs proposed in section I-A, here we present the major results obtained after analyzing the 36 primary studies selected for this SMS. As Table II shows, there is a clear increase of proposed approaches in the last five years (72,2% of the works have been published between 2015 and 2019). In addition, the type of venues selected to publish these studies include workshops, conferences, and journals. In this case, most of the studies (80,6%) have been published in conferences (41,7%) and journals (38,9%), revealing the maturity of the published works. Finally, the research areas of the selected venues include the BPM area (e.g., Information Systems journal (IS), BPM conference, BPMN workshop or CAiSE conference), the IoT area (e.g., ICNSC conference, DASC conference, ICNSC conference or the journal IEEE Transactions on industrial informatics), and also the IT area where more generic venues are considered such as the Journal of Universal Computer Science. In this case, as we may expect, most of

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[2] Note that this only applies to fees that are not covered by the subscriptions to any of the selected data sources.

Study ID	Proposal's name	Publication		
		Yr	**Type**	**Field**
Al-alshuhai2015 [22]	Context-aware AD	'15	Cn.	IoT
Albreshne2015 [23]	GPL4SRE	'15	Cn.	IoT
Appel2014 [24]	SPUs	'14	Jr.	BPM
Baresi2015 [25]	-	'15	Wr.	BPM
Bocciarelli2017 [26]	PyBPMN	'17	Cn.	IoT
Breitenbücher2015 [27]	SitME4BPEL	'15	Cn.	IT
Bucchiarone2009 [28]	APFoL	'09	Wr.	BPM
Caracaş2011 [29]	-	'11	Wr.	BPM
Cheng2019 [11]	-	'19	Jr.	IoT
Chiu2015 [9]	-	'15	Cn.	IoT
Dar2015 [30]	-	'15	Jr.	IoT
Domingos2014 [31]	-	'14	Jr.	IT
Domingos2017 [12]	-	'17	Jr.	IT
Dörndorfer2018 [32]	Context4BPMN	'18	Conf.	BPM
Friedow2018 [33]	-	'18	Cn.	BPM
Gao2011 [34]	-	'11	Wr.	BPM
Graja2016 [35]	BPMN4CPS	'16	Cn.	BPM
Kefalakis2011 [36]	APDL	'11	Jr.	IT
Kim2014 [37]	-	'14	Cn.	IoT
Kim2016 [38]	Process-aware IoT	'16	Jr.	IT
Lee2016 [39]	BPMN-MDM	'16	Jr.	IoT
Maamar2018 [40]	PoT	'18	Cn.	BPM
Mandal2017 [41]	-	'17	Cn.	BPM
Meyer2013 [42]	-	'13	Cn.	IT
Mottola2018 [43]	makeSense	'18	Jr.	IT
Petrasch2016 [44]	I4PML	'16	Cn.	BPM
Sasirekha2016 [45]	-	'16	Cn.	IoT
Schönig2018 [7]	-	'18	Cn.	BPM
Seiger2015 [46]	-	'15	Jr.	IT
Serral2015 [47]	CAPN	'15	Jr.	IoT
Sperner2011 [48]	-	'11	Wr.	BPM
Suri2017 [49]	IoT-BPO	'17	Cn.	BPM
Tu2018 [6]	IoTPM	'18	Jr.	IT
Wang2014 [50]	CWfMS	'14	Jr.	IoT
Wehlitz2017 [5]	-	'17	Wr.	BPM
Yousfi2019 [51]	UDABP	'19	Jr.	IT

TABLE I
SMS PRIMARY STUDIES

	Year		Venue type			Venue field		
	09-14	**15-19**	**Cn**	**Wr**	**Jn**	**BPM**	**IoT**	**IT**
#	10	26	15	7	14	15	11	10
%	27,8	72,2	41,7	19,4	38,9	41,7	30,6	27,8

TABLE II
SUMMARY OF PUBLICATION YEAR, VENUE TYPE AND VENUE AREA

the studies (72,3%) have been published in venues belonging to the more specific areas, i.e., BPM (41,7%) and IoT (30,6%).

A. Modeling strategies used (RQ1)

In this section we focus on the modeling strategies are used by the primary studies to model IoT-enhanced BPs. Based on the analysis we have categorized the studies into two main groups, one related to the studies that build their modeling proposal from the most well-known general purpose BP modeling languages, henceforth *Built-from-existing*, and a second one that relates to studies that build a new domain specific language (DSL), henceforth *Build-dsl*. While most of the studies (80,56%) fall within the *Built-from-existing* category (29 out of 36), just a small amount (19,44%) is classified within the *Build-dsl* category (7 out of 36). Tables III and IV gather the studies that fall into the *Built-from-existing* and *Build-dsl* categories respectively.

Study ID	BPMN	EPC	BPEL	UMLAD	PN
Al-alshuhai2015				↗	
Appel2014	↗	↗			
Baresi2015	≡				
Bocciarelli2017	↗				
Breitenbücher2015			↗		
Bucchiarone2009			↗		
Caracaş2011	≡				
Cheng2019	↗				
Chiu2015	↗				
Dar2015	≡				
Domingos2014			↗		
Domingos2017	≡				
Dörndorfer2018	↗				
Friedow2018	≡				
Gao2011	⊕				
Graja2016	↗				
Kim2014			↗		
Lee2016	↗				
Mandal2017	↗				
Meyer2013	↗				
Mottola2018	↗				
Petrasch2016	↗				
Sasirekha2016			≡		
Schönig2018	↗				
Serral2015					⊕
Sperner2011	↗				
Suri2017	↗				
Wehlitz2017	⊕				
Yousfi2019	↗				
Number of studies	22	1	5	1	1
% of studies	73,33	3,33	16,67	3,33	3,33

Legend: Extends(↗); As-is (≡); References (⊕)

TABLE III
PRIMARY STUDIES BELONGING TO THE *Built-from-existing* CATEGORY

Regarding the *Built-from-existing* category, the type of use proposals do over existing BP modeling languages vary. In particular, we have identified three different types of uses which we have catalogued as (1) *Extends*, to refer to those studies that propose enriching an existing modeling language with new concepts closer to the new requirements imposed by IoT systems, (2) *As-is*, to refer to the studies that propose using a specific modeling language in its original shape, with no changes or extensions, and (3) *References* to refer to those works that amplify the BP model by introducing new elements to linking it with another modeling artefact.

Table III classifies those primary studies falling within the *Built-from-existing* category. Note that Appel2014 extends two BP modeling languages (BPMN and EPC). For this reason we are counting this study twice in the analysis regarding the usage of existing BP modeling languages, having as a result 30 studies instead of 29. As this table shows 73,33% of the studies (22 out of 30) use BPMN, and only 26,67% (8 out of 30) use the remaining languages as follows 16,67% for BPEL, and 3,33% for EPC, UML Activity Diagram (AD), and PN respectively.

Regarding the studies that belong to the second category (*Build-dsl*), Table IV details the metamodeling language used

Study ID	n/s	Ecore	OWL	E-R	XML	ABNF
Albreshne2015	x					
Kefalakis2011					x	
Kim2016				x		
Maamar2018						x
Seiger2015		x				
Tu2018	x					
Wang2014			x			

TABLE IV

PRIMARY STUDIES BELONGING TO THE *Build-dsl* CATEGORY

in each case to build the proposed DSL. In many cases these proposals take concepts from existing languages to build their own metamodel such as Kefalakis2011 with XPDL [52], Seiger2015 with BPMN and EPC, and Maamar2018 with Storytelling [53].

However, not all the proposals rely just on a single modeling artefact to specify IoT-enhanced BPs. In fact, some primary studies apply the separation of concerns (SoC) design principle to design their modeling proposals. As a result different models targeted at different aspects are combined to properly specify such systems. In particular, the studies propose combining modeling artefacts as follows:

Albreshne2015 proposes combining the GPL4SRE, which is the modeling proposal based on BPEL4WS to describe BPs, with the ontology Ont4SRE to describe "smart objects". **Baresi2015** proposes the use of an extended Guard-Stage-Milestone (GSM) model to model and monitor the BP part that refers to goods that are moving from different organizations. These goods are turned into smart objects since these are equipped with software running, sensing data and communication capabilities. **Dörndorfer2018** proposes the sensor model (SenSoMod) to specify sensors, context and how these relate to each other. For example, by means of this model context data can be defined as an aggregation from data retrieved by different sensors. This aggregation is achieved through the *context description* element which is included in both, the BPMN extension (Context4BPMN) and also in the SenSoMod model and is used as a mechanisms to link both models. **Gao2011** proposes linking BPMN models with the Functional Model to import a sensor ontology and its instance data. **Sasirekha2016** proposes combining BPEL models with an ontology that defines IoT entities and that is integrated with the SSN ontology. **Serral2015** defines CAPN, an proposal that integrates CPN with ontologies to describe context. **Suri2017** proposes providing a semantic description of the BPMN models by means of an ontology that integrates concepts from the BP and the IoT domains. This integrated ontology is built from IoTBPO (an ontology defined from the IoT resources (Sensor, actuator y tag) included in the defined BPMN extension), BPMO [54], and IoT-Lite [55] ontologies. **Tu2018** combines three models specified at three different layers to represent separately the domain (IoTCM), the process (IoTPM), and objects (IoTOM). **Yousfi2019** combines their BPMN extended proposal (uBPMN) with a Decision Model where ubiquitous decisions, i.e., decisions taken based on an important amount of data (e.g., location, traffic status, gas level, etc.) are defined to improve the BP.

B. IoT device representation (RQ2)

According to our analysis, IoT devices (i.e., smart objects, physical entities, and devices) can be either represented in the BP model *explicitly*, i.e., by dedicating specific modeling elements to refer to such concepts or *implicitly*, i.e., by means of modeling elements that behave as bridges between the BP model and the physical entity or device. While 61,11% of the studies (22 out of 36) fall into the former category, 38,89% of the studies (14 out of 36) fall into the latter. Based on these two major categories we explain next how the different studies deal with such representation.

1) Explicit representation of IoT devices: During the analysis we identified that IoT devices are represented explicitly by means of the following mechanisms: a) by extending *data objects* (Do), b) by extending *resources* or *participants* which are represented graphically as *pools or lanes* (P/L), c) defining *new constructs* (Nc) in the metamodel, or d) by representing them in a *separated model* (Sm) that is linked to the BP specification. Table V categorizes the different studies according to these five mechanisms.

We have found 2 studies that extends data objects. **Lee2016** proposes to extend the Multipe-Domain Matrix (MDM) with BPMN modeling elements to describe elements and relationships between business processes. The activity DSM element from the matrix has been designed taking as reference the BPMN language and extending the data object element to represent smart objects. **Yousfi2019** extends the BPMN data object to represent explicitly smart objects. In addition, the BPMN activity and event elements are also extended to allow specifying IoT input technologies such as sensor, smart readers and so on. With this extension, activities and events can be specialized into one of the following subtypes: *Sensor*, *Reader*, *Image*, *Audio*, and *Collector*.

Regarding those that extend the *resource* or *participant*, 8 studies were found. **Al-alshuhai2015** extends a resource which is represented with swim-lanes. It proposes representing sensing devices by means of swim-lanes that they call *context source (CS) segments*. These lanes gather activities that represent actions (e.g., connect to the sensor, acquire a sensed measure, etc.) with the device. **Chiu2015** extends a resource which is represented with a lane. It allows representing physical entities (e.g., a room) as BPMN resources, represented graphically as swimlanes. In addition, sensing and actuation activities over those resources are represented following the Meyer et al. [10] proposal, i.e. by means of sensing and actuation tasks, which are tasks defined as an extension to the BPMN activity element. **Domingos2017** extends a participant which is represented with a pool. It proposes representing IoT devices as BPMN participants, i.e., as processes modeled in separated pools. Within each pool, BPMN script tasks are used to represent the interaction required with the corresponding device (e.g., switching on/off, measuring a particular property, etc.). **Kim2014** extends the BPEL *partnerLinks* element with a new participant, the *IoTService* to specify different types of devices (e.g., robots, smartphones, bio-mobile, and sensors). This new participant defines the *deviceType* element where the device id, type and model can be specified. **Meyer2013** extends a participant which is represented with a pool. This work represents physical entities by extending the BPMN metamodel with the *PhysicalEntity* concept. This new concept specializes the *ParticipantContainer* class which is also introduced in the metamodel as a superclass for the BPMN *Participant* class. The *PhysicalEntity* concept is represented graphically as an empty collapsed pool that interacts with process flow elements contained in a separated pool called *IoT Process*. The interaction with such entities is modeled through *Sensing Tasks*, representing information sent from the *Physical Entity* to the *IoT Process* and *Actuation Tasks*, representing information sent by the *IoT Process* to the *Physical Entity*. **Petrasch2016** represents IoT devices as BPMN partitions in the BP model. In addition, to represent the interaction with such devices, it proposes to extend the BPMN notation into *Sensing tasks* and *Actuating tasks*. These are depicted graphically with a differentiating icon placed on the top-left corner of the task. **Suri2017** extends the BPMN Resource element with the *ResourceExtension* to include IoT Devices (i.e., Sensor, Actuator, and Tag) and also their quality attributes (e.g., accuracy, response time, etc.) into the BP model. This extended element is represented graphically as a new element that is associated to BP tasks. **Wehlitz2017** extends a resource which is represented with a line. In particular, this work proposes to use BPMN swimlanes to represent device types which are represented at both, the type and instance level. While the type level description is used to represent similar devices of the same type (e.g., a temperature sensor), the instance level allows describing concrete devices in the model (e.g., the temperature sensor installed in the living room). This allows defining instance-independent BP models that can be reused at design time.

Other 7 studies propose new contructors. **Albreshne2015** includes in their proposed language (GPL4SRE) a section called *Smart Entities Declaration* where smart entities (e.g., a lamp, a room, etc.) can be explicitly declared. **Bocciarelli2017** extends the PyBPMN language (a BPMN extension to address performance and reliability analysis) to model resources, i.e., real entities that perform activities in the process from the I4.0 perspective. In particular, the PyCPS class is introduced as a BPMN Resource specialization to represent real entities participating in a BP. Then, a PyCPS class is made of a set of components which include sensors and actuators, represented by the PyCPS_Sensor and PyCPS_Actuator metaclasses respectively. **Bucchiarone2009** extends their proposed APFoL language to allow specifying by means of *context entities* those physical entities (e.g., boxes, warehouse, etc.) whose state is of interest to the process (e.g., if the box has been damaged or not). **Cheng2019** focuses on sensor networks providing a BPMN extension that includes: the *Sensor Device* class to determine the type of sensor being represented (e.g., a light sensor or a pressure sensor), the *Sensor Service* class to define the function provided by the sensor device, and the *Handler* class, to specify the technology used to access the sensor service (e.g., Restful, URL). Graphically, a sensor task is differentiated from an standard BPMN task with a sensor icon which is placed on the top-left corner of the task. In this case the *Sensor Device* has been included in the metamodel as an element that aggregates BPMN *Activities* and also *Handlers*. Finally, the *Sensor Services* concept is defined as a class that aggregates the BPMN *Performer* class. **Kim2016** differentiates in their proposed metamodel the *Things* concept into *Virtual Things*, i.e., smart objects, and *Physical Thing*, which can be refined into a person, sensor, actuator, device, service or other type of thing. **Maamar2018** defines things (either living or non-living) through the *Character* and *SelectedCharacter* elements included in the PoT's *scripts* (at design-time) and *scenes* (at run-time) respectively. In this case all things relevant for the scene are included either through an automatic or manual detection. **Sperner2011** proposes to extend the BPMN metamodel to represent physical entities and their interaction with devices (i.e., sensors and actuators). On the one hand physical entities are represented by the *PhysicalObject* new concept, which can be used to represent single objects but also a collection of objects. Graphically this new concept is represented as a rectangular box which includes three vertical bars at the bottom of its front face to denote collections. On the other hand, the BPMN *Task* element has been extended as *SensingTask*, to provide the process with data monitored from a physical entity, and *ActuatingTask*, to act upon a physical entity.

Finally, 5 studies propose a separate model to represent IoT devices. **Dörndorfer2018** proposes a separate model to specify sensors and its relation with context through the Sensor Model. This separated model is linked to BP model specified in Context4BPMN, an extension to BPMN to allow the creation of context-aware BPs. The type of sensors that can be specified in the Sensor Model include atomic (physical and virtual) and computed, obtained from the aggregation of multiple sensors. **Gao2011** proposes a separate model to enrich BPMN models with sensor and smart devices and their provided data by means of the Business Functional Model (BFM). The BFM define attribute-featured entities via a set of properties and their values, which are related in some cases to properties of the SSN ontology. **Sasirekha2016** represents IoT devices by means of an ontology. Such ontology is defined as the integration of a defined domain ontology and the SSN ontology. **Serral2015** represents devices in an ontology. Petri nets are used to model business processes and they are extended to include conditions over the context sensed by the specified devices. **Tu2018** proposes to build the so called IoT-aware Ontology Concept Model (IoTCM) to representing semantically the domain, in particular the involved *Objects*, *Resources*, and *Business Entities*. Then, the IoT-aware Process Model (IoTPM) is built by referencing those elements in the corresponding *IoT Process Steps* included in the model.

2) Implicit representation of IoT devices: Within this category we find the studies that represent IoT devices implicitly through their interaction. Accordingly, two different mechanisms are identified to achieve such interaction, i.e., through *tasks* and through *events*. Table V categorizes the different studies according to these two mechanisms.

There are 6 studies that are based on the task concept. **Breitenbücher2015** proposes, in the SitME modeling language, to attach real entities to *situation events* and *situational scopes*, two new types of events that get triggered when a specific situation occurs for the associated entity. However, when SitME is translated to BPEL, these new types of events are transformed into BPEL receive and invoke activities respectively. **Dar2015** proposes integrating smart objects into BPs through the use of BPMN script tasks. These tasks are in charge of collecting measured data from IoT devices and transmit it where need it. These tasks can be contained either in the *the Set Top Box (STB)* BP model part and in the *smart phone* BP model part, which are connected through messages to pass the measurement responsibility depending on the user location. **Domingos2014** introduces the concept of IoT aware processes where actions with devices are modelled through the invocation of web services. **Graja2016** represents the interaction with physical devices by extending BPMN service tasks. In particular, the extension includes *physical tasks*, tasks that are refined into actuator and sensor tasks, and *cyber tasks*, tasks that are executed by a piece of software, i.e., a web service, cloud service or embedded service. **Mottola2018** extends BPMN with the *WSN task* concept to represent interactions with the WSN. These tasks are differentiated graphically from standard BPMN tasks by including an antenna icon in their top-left corner. All these tasks are contained within a new type of pool, the WSN Pool, introduced in the notation to separate the business logic that is performed by the WSN from the logic performed by traditional IT systems. This new pool includes the same antenna icon to graphically differentiate it from an standard BPMN pool.

Other 8 studies are based on the concept of Event. **Schönig2018** proposes an architecture where BPs get notified after subscription on certain object's state changes. **Seiger2015** provides a solution based on tasks. It includes in its DSL the *Atomic Process Step* concept which is used to integrate services and devices into Processes. This concept specializes the *Process Step* concept which is the basic component for modeling processes. **Appel2014** introduces the Event Stream Processing Units (SPUs) abstract concept to integrate relevant environmental data into the process. SPUs encapsulate event stream processing in BP models. **Baresi2015** proposes to use the infrastructure deployed in the own smart objects to sense the environment and trigger events. This infrastructure includes the *trace generator* component which consists of a CEP engine that compares data streams with sentries (conditions expressed as Boolean formulas) defined in the process model to detect process events. The conditions that define when an event is triggered is specified in the *guards* and *milestones* defined in the extended GSM model. **Caracaş2011** makes use of the different types of events provided in BPMN (i.e., escalation, timer, and message events) to capture the reactive nature of the WSN applications. **Friedow2018** proposes to use the Bosch IoT Things service to define the connection between IoT devices and the BP by influencing the execution of BPs by the reception of events. **Kefalakis2011** associates different types of events that refer to physical objects to process activities which are called *Elementary Business Processes (EBProc)* in APDL. **Mandal2017** proposes a framework based on the processing of events, which are captured by BP tasks that are subscribed to it. **Wang2014** includes in their proposed architecture the *context provisioning platform (CPP)* which behaves as intermediary between sensors and BPs through the triggering of events that include high-level context data.

Table V summarizes the number of studies and percentages that fall into the two major categories, detailing also the modeling element or mechanism used to represent IoT devices.

IV. DISCUSSION

Regarding RQ1, we have learned that BPMN is by far the modeling language preferred by most of the analyzed studies (73,33%). Other BP languages used to a lesser extent are BPEL, EPC, Petri Nets, and UMLAD. This is not a surprise if we consider that BPMN is widely used standard that provides a graphical notation and extension capabilities, a key aspect for this research question. In fact, this capability has been used by most of the solutions to give support to the newly introduced concepts. On the other side, we see that very few proposals (19,44%) have proposed a new DSL. There is therefore a clear preference of extending existing languages over defining new ones.

From our study we can conclude that current trends to include physical devices into business processes are based on the extension of the BPMN meta-model. BPMN extension mechanisms are conservative with its meta-model, allowing that current editors and engines can work with extended versions. However, only core concepts of its meta-model can be interpreted. In order to interpret new concepts additional effort to adapt editors and engines is required. To do that, however, a standardization effort should be performed in order to adopt a unique solution.

Another important aspect that has been observed in some of the analyzed studies is the application of the separation of concerns (SoC) design principle. If BP models are extended or enriched with too much information we run the risk of making models no longer understandable. For this reason, specifying IoT devices separately from the BP model may also be a solution to keep BP models understandable for all the involved stakeholders.

Regarding RQ2, we have learned that IoT devices can be represented in the BP model either explicitly, i.e., by providing a specific construct to represent such element or implicitly, i.e., by means of another modeling element. When the representation is performed explicitly, the most natural way to represent such elements is by using or extending the participant or resource concept supported by BP modeling languages, which is graphically represented for example in BPMN as pools or lanes, but also with the definition of

Study ID	Explicit				Implicit	
	Do	P/L	Nc	Sm	Tk	Ev
Al-alshuhai2015		x				
Albreshne2015			x			
Appel2014						x
Baresi2015						x
Bocciarelli2017			x			
Breitenbücher2015					x	
Bucchiarone2009			x			
Caracaş2011						x
Cheng2019			x			
Chiu2015		x				
Dar2015					x	
Domingos2014					x	
Domingos2017		x				
Dörndorfer2018				x		
Friedow2018						x
Gao2011				x		
Graja2016					x	
Kefalakis2011						x
Kim2014		x				
Kim2016			x			
Lee2016	x					
Maamar2018			x			
Mandal2017						x
Meyer2013		x				
Mottola2018					x	
Petrasch2016		x				
Sasirekha2016				x		
Schönig2018						x
Seiger2015					x	
Serral2015				x		
Sperner2011			x			
Suri2017		x				
Tu2018				x		
Wang2014						x
Wehlitz2017		x				
Yousfi2019	x					
Number of studies	2	8	7	5	6	8
% of studies	5,6	22,2	19,4	13,9	16,7	22,2
Number of studies	22				14	
% of studies	61,11				38,89	

Legend:
Do: Data object; **P/L:** Pool/Lane;
Nc: New construct; **Sm:** Separated model;
Tk: Task; **Ev:** Event;

TABLE V
IoT DEVICE REPRESENTATION SUPPORT PROVIDED BY PRIMARY STUDIES

new modeling constructs. The analysis showed that 19,44% of the studies opted for each of these solutions. However, other mechanisms to achieve the explicit representation is by reusing/extending existing concepts such as *data objects*. Finally, externalizing these elements from the BP model is also a solution designed by some of the studies (13,89%). In this case, IoT devices are represented in detail in a separated model and linked afterwards to the BP model to reference them. Regarding the implicit representation, this is mainly achieved through the use of tasks and events, being this last element the most preferred by the analyzed studies (22,22%). In this case, instead of representing the IoT device itself, it is represented in terms of its interaction with the BP model. To this end, while the use of tasks allows representing synchronous interactions with the device when it is required by the BP, the use of events allows representing asynchronous interactions which are based on the occurrence of relevant situations of the device or environment.

Another very interesting finding relates to the abstraction level in which IoT devices are represented in a BP model. IoT scenarios operate in a very low abstraction level, being highly dependent on the device's technology. However, BP models should not be created based on the limitations imposed by such technology. Otherwise, changes in the underlying technology (which is constantly progressing) would require continuously revising and modifying the associated BP models. While Wehlitz2017 proposes to provide this abstraction by defining at the modeling level device types instead of instances to define technology independent models, other works have opted for the implementation of a middleware that makes the BPs independent of the device technology. This separation allows having BP model representations independent from the underlying technology and that can be reused in a different technological scenarios.

V. STATE OF THE ART

To the best of our knowledge, no systematic literature review focused on the topic addressed in this SMS has been performed so far in the literature. However, during the primary studies search process we found some papers that although they pursue a different goal, share some similarities with this SMS. These papers are [56], [57], and [58] and focus their analysis on Mobile Cloud Computing (MCC), Wireless Sensor Network (WSN) applications, and Mobile Devices respectively.

The work developed by Chang et al. [56] is focused on the analysis and evaluation of a selection of BPMS for IoT (BPMS4IoT) frameworks from the MCC perspective. The analysis is organized based on the three different phases that conform the BPMS4IoT lifecycle (re-design, implementation/configuration, and execution and adjustment). Focused on the re-design analysis, which is the one related to the modeling stage addressed in this SMS, this paper analyzes seven works that are also considered in our SMS. Besides the small number of studies considered in the analysis regarding the modelling of IoT elements, all of them provide solutions based on the BPMN modeling language.

The work developed by Teixeira et al. [58] presents, within the context of WSN applications, a systematic mapping study (SMS) on how to model and automate code generation by the application of model-driven and business process approaches. Among other aspects, the SMS discusses how WSN application requirements can be described in a BP representation. The major difference between this work and our SMS is the specific target of their analysis towards WSN-based IoT solutions. Teixera et al. limit their study to WSN applications and the model driven techniques that can be used to automatically generate code for the development of such applications.

Finally, the work developed by Dörndorfer2018 et al. [57] presents a study that identifies the impact that the use of a specific type of IoT device has on BPs and their lifecycle.

Specifically, the focus is put on the context and how can be represented by the corresponding modeling languages. The major difference with our SMS is that this work puts the focus around context in BPs that are supported by mobile devices. To this end it explores the impact that context has on the different phases of BPs.

VI. CONCLUSIONS

This work aims at providing a fundamental understanding of how to achieve the modeling of IoT-enhanced BPs. We performed a SMS that resulted in a total of 36 primary studies. These selected studies were analyzed according to two RQs which were focused on the specific aspects that deal with the integration of the IoT and the BPM at the modeling level. We identified the different strategies used to address the modeling of such BPs with to understand to which extent existing BP modeling languages could be used for such purpose and also how. Then, we looked more specifically at the mechanisms provided to introduce IoT devices into BP models.

Our future work will extends this SMS with additional research questions that analyze aspects such as the management of context in IoT-enhanced business processes, the validation performed by the different approaches, or the provided modelling tool support. In addition, it would be very interesting to study the different frameworks and architectures proposed in the literature to support a specific aspect found in many IoT scenarios, which is dealing with tons of data and events generated during BP execution.

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