Modelling Notations for IoT-Aware Business Processes: a Systematic Literature Review

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Abstract. The term *IoT-aware business processes* refers to the interplay of business processes and Internet of Things concepts. Several studies have been carried out on such a topic, so a better awareness of the current state of knowledge can be beneficial. In particular, in a given application domain, this can help the choice of the most suitable modelling approach. This paper reports on the results of a systematic literature review with the aim of developing a map on modelling notations for IoT-aware business processes. It includes 48 research works from the main computer science digital libraries. We first present a description of the systematic literature review protocol we applied, then we report a list of available notations, discussing their main characteristics. A focus has been devoted to modelling tools and application scenarios. Finally, we provide a discussion on the capability of the identified modelling notations to represent requirements of scenarios enriched by IoT adequately.

1 Introduction

Disruptive innovation introduced by the large adoption of Internet of Things in several sectors (e.g., smart agriculture, smart industry, smart environment) received much attention in recent years. This is mainly due to the capability of the Internet of Things to fill the gap between the physical and the digital world, enhancing physical objects with electronic devices. As a side effect, we also observe that complex business processes need to be adapted when electronic devices support foreseen activities. As underlined by the *Business Processes Meet the Internet-of Things* group, and as reported in the manifesto entitled "*The Internet-of-Things Meets Business Process Management: Mutual Benefits and Challenges*" [24], novel research challenges have to be considered [47].

To face such challenges the research community looks for a suitable modelling language to be used as a lingua franca both for documenting and engineering pre-defined models and for representing models discovered by mining logs of IoT systems. Much effort has been devoted to this topic. However, a better understanding of the current state of knowledge can be helpful to select the most suitable approach to a considered purpose.

This paper reports on the results of a Systematic Literature Review (SLR)[1] to organize and synthesize the knowledge about the available notations for mod-

[1] All the details of our SLR are available at http://pros.unicam.it/BP-meet-IoT-2020

elling IoT-aware business processes. We conducted an SLR to present a fair evaluation of the research works on this topic by using a trustworthy, rigorous, and auditable methodology [25].

The paper is organized following the phases of the SLR. Sec. 2 reports on the planning phase. Sec. 3 describes the conducting phase providing some insights on the retrieved research works. Sec. 4 answers to the research questions, while Sec. 5 compares our work with related surveys on the topic. Finally, Sec. 6 provides some conclusive remarks.

2 Planning the Systematic Literature Review

This section illustrates the steps done to plan the SLR, such as the definition of research questions, the search query, and the inclusion/exclusion criteria.

Research Questions. During the planning of our study, we defined one main research question (RQ) and two secondary research questions (SRQ1 and SRQ2). Answers for the secondary research questions are based on scientific works retrieved for answering the main research question.

RQ. Which are the notations used to model IoT-aware business processes? The objective of this question is to gather a list of the available notations that can be used to model business processes integrating IoT concepts. The main characteristics of each notation will be explained with a focus on the actual graphical representation.

SRQ1. Which are the available tools supporting the IoT-aware business process modelling? The objective of this question is to gather a list of available modelling tools that allow designing graphical representations of business processes including IoT concepts. This aims at investigating the possibility of using the notations in practice.

SRQ2. Which are the target application domains for modelling IoT-aware business processes? The objective of this question is to identify which application domains have been already considered in the literature as a target for modelling IoT-aware scenarios. This aims at understanding whether there are domains that will benefit more than others from the integration of IoT concepts in a modelling notation.

Search Query. After defining the research questions, we carefully planned a search query to find suitable works to answer the research questions. The definition of the query has been based on consolidated recommendations as reported in [4]. In particular, the search query was generated by terms related to three different areas: business process, IoT, modelling. It is worth clarifying that among the terms chosen for the query in the IoT area we have also included Cyber Physical System (CPS). This choice is motivated by a NIST research [21], which confirms that the terms IoT and CPS are interchangeably used. The resulting search query is reported in Table 1.

We applied such a query over five main digital libraries: IEEE Xplore, ACM Digital Library, Scopus, Science Direct, and Web of Science. We queried the mentioned digital libraries to search the terms of the query into title, abstract,

Table 1. Search Query.

(BPM **OR** "business process management" **OR** "business process") **AND** (IoT **OR** "Internet of Things" **OR** "Cyber Physical Systems" **OR** CPS **OR** Smart **OR** WSN **OR** "Wireless Sensor Network") **AND** (model **OR** behavior **OR** model driven)

and keywords. Also, since the combination of business process and IoT concepts is relatively recent, we restricted the query to the last nine years, thus considering all the research works published between January 2011 and September 2019 (when the retrieval process took place). We were confident, anyway, that those paper returned by the query would have referenced possibly relevant research works published before 2011, and then included, if relevant, as result of the snowballing step. Our choice about the time frame is also supported by [21], where 2011 is considered as the starting point for the research activity in the IoT area.

Inclusion/Exclusion Criteria. As part of the protocol implementation, a set of inclusion/exclusion criteria has been defined to guarantee the selection of only relevant research works. We defined two criteria for inclusion: *IC.1* - the research work is a primary study; *IC.2* - the research work proposes or uses a graphical notation to model IoT-aware business processes. We also considered two criteria for exclusion: *EC.1* - the research work is not written in the English Language; *EC.2* - the research work does not propose and does not refer to any notation to model IoT-aware business processes.

3 Conducting the Systematic Literature Review

This section describes how we performed the review. In particular, we provide details related to the identification and selection activities of the research works, and we report the categories used to classify them.

Identification and Selection of the Research Works. From the application of the search query over the digital libraries, we identified 1321 research works potentially relevant for the research topic. The selection steps we applied are illustrated in Fig. 1. Through a careful analysis of the title and abstract of these research works, we identified 92 relevant works. After the removal of 53 duplicates, the remaining 39 research works were read and analyzed for a final selection. The final number of research works obtained by applying the search query, and after having analyzed them, is 23.

To improve the accuracy of our review, we also applied *Snowballing* [23]. It consists of analysing all the research works that mention or are mentioned

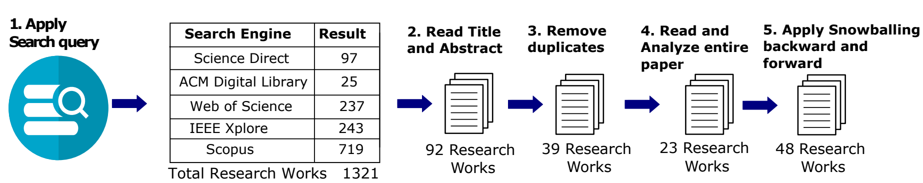

Fig. 1. Research works retrieval process

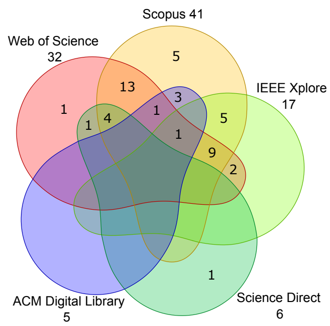

Fig. 2. Research works distribution in digital libraries

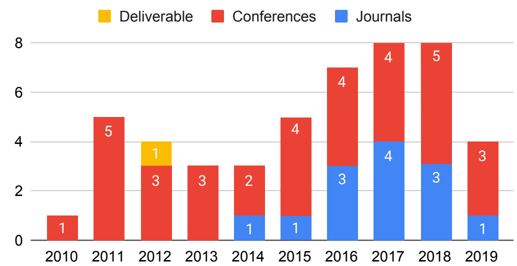

Fig. 3. Research works publication venue per year

by the research works already selected. The snowballing allows finding research works potentially relevant for our study that have not been found with the query technique previously used. We used both *backward* and *forward* snowballing: we analysed in the first case, all the referenced research works, while in the second case, all the works that refer to those we selected. This step was not limited to the considered time frame, to have a comprehensive picture on related research, possibly including also contributions antecedent 2011. With the first execution of the snowballing, we found 15 new research works; we stopped at the fourth iteration of the snowballing. The entire snowballing procedure added 25 research works to the 23 selected with the search query for a total of 48 relevant research works retrieved.

Fig. 2 reports how many research works out of the total 48 can be found querying each digital library. From this analysis, we can say that Scopus and Web of Science appear to be the most suitable digital libraries for such a topic. They include 41 (85%) and 32 (67%) of the total 48 research works, respectively. The results for the other digital libraries are IEEE Xplore 17 (35%), Science Direct 7 (14.5%), ACM Digital Library 5 (10.4%). It is worth mentioning that 2 works (one conference research works and a deliverable) (4.2%) could not be found searching in those libraries.

Fig. 3 reports a diagram showing a classification of the different venues from which the research works were selected during the literature review, grouped by year of publication. The majority of the works have been presented at Conferences 34 (70.8%) or published in Journals 13 (27.1%). Among the selected works, we also found a Deliverable (2.1%) worth to be considered, since it was referenced by several of the reviewed scientific works. Moreover, from 2010 to 2019 there has always been at least one contribution related to the analysed topic, with a peak of 8 papers in 2018. This testifies that the research community has been active on the selected research topic and that the interest seems to increase in recent years. As we can see, more than 50% of the works have been published from 2016 and 2019. It is worth noticing a possible decrease in interest in 2019. However, this could be because, at the time of the search, some of the research works published (or under publication) in late 2019 were not indexed, yet.

Data Extraction and Synthesis. To retrieve the necessary data to answer the research questions, we defined the structure of Table 2 to guide the extraction of data out of the retrieved research works. It presents the following columns: *Source* reports the reference to the research work; *Modelling Notation* reports the name of the modelling notation used/proposed or the name of the authors if no name has been assigned to the notation; *Modelling Tool* refers to the tool used to design a process model; *Notation Usage* tells whether the notation is used just to design a business process model related to an IoT application scenario or whether it is also used to guide the implementation and execution of such a process; *Application Domain* refers to the domain of the process represented by the modelling notation. To categorize the application domains we referred to the well-known classification proposed in [2], which groups IoT domains in: healthcare, environmental, smart city, commercial, industrial, and general aspects.

4 Results of the Systematic Literature Review

This section illustrates the data we extracted to answer our research questions.

Answer to RQ. To answer to research question RQ - *Which are the notations used to model IoT-aware business processes?* - we grouped the notation that emerged from the literature in three classes: Not-BPMN, BPMN, and BPMN extension. As it can be seen in Table 2, only 4 (8.3%) out of the 48 identified research works presented a notation to model IoT-aware business processes that are not related to BPMN; 14 (29.2%) of the identified research works make usage of the BPMN 2.0 notation as it is; 30 (62.5%) of the identified research works propose or use an extension of BPMN 2.0. Some of those works make usage of BPMN only for the design of business process models (D), others propose entire architectures and frameworks based on BPMN and related tools so to enable the execution phase (E).

Not-BPMN. All approaches that do not use BPMN focus on the design phase except for [46] in which the authors propose Context-Adaptive Petri-Net (CAPN) a tool-supported formalism to construct Petri nets that are context-adaptive. In [49] the authors use CAPN for acquiring IoT-awareness in an industrial application. In [17] the authors use Cooperative Task Language (CoTaL), a subject-oriented and task-based approach for specifying activities in smart scenarios. In [16] the authors use Subject-Oriented Business Process Management (S-BPM), a modelling paradigm using a standard semantics of natural language with subjects, predicates, and objects to describe business processes of a smart environment; the Subject Behavior Diagram is generated for each subject involved in the business process to define its interactions with other subjects in the process.

BPMN. This category refers to all the research works that perceive BPMN, as it is, adequate in capturing process specifications of IoT scenarios; this means that they represent IoT aspects by means of the standard BPMN elements. In the following, we first report the research works that make use of BPMN mainly

	Source	Modelling Notation	Modelling Tool	Notation Usage	Application Domain
Not-BPMN	[46]	CAPN	CPN Tools	E	Healthcare
	[49]	CAPN	Not specified	D	Industrial
	[17]	CoTaL	CoTaSE	D	Smart city
	[56]	S-BPM	Metasonic Build	D	Commercial
BPMN 2.0	[6]	BPMN 2.0	Oryx	D	Commercial
	[7]	BPMN 2.0	Oryx	D	Smart city
	[15]	BPMN 2.0	Not specified	D	Commercial
	[12]	BPMN 2.0	Eclipse Modeler	D	Smart city
	[48]	BPMN 2.0	Signavio	D	Commercial
	[29]	BPMN 2.0	Not specified	E	Environmental
	[14]	BPMN 2.0	jBPM	E	Environmental
	[30]	BPMN 2.0	Not specified	E	Smart city
	[18]	BPMN 2.0	bpmn.io	E	Smart city
	[31]	BPMN 2.0	Not specified	E	Commercial
	[45]	BPMN 2.0	Camunda	E	Industrial
	[37]	BPMN 2.0	Camunda	E	Industrial
	[57]	BPMN 2.0	Not specified	E	Smart city
	[41]	BPMN 2.0	Bonita	E	Healthcare
BPMN Extensions	[35]	IAPM	Not specified	D	Commercial
	[32]	IAPM	Activiti	D	Commercial
	[34]	IAPM	Signavio	D	Commercial
	[42]	IAPM	Signavio	D	General aspects
	[28]	IAPM	Not specified	D	Commercial
	[33]	IAPM	Not specified	D	General aspects
	[13]	IAPM	Not specified	D	General aspects
	[10]	IAPM	Not specified	D	Smart city
	[38]	IAPM	MagicDraw	D	Smart city
	[39]	I4PML	MagicDraw	D	Industrial
	[53]	IoT-BPO	Signavio Core C.	D	Commercial
	[52]	IoT-BPO	Signavio Core C.	D	Commercial
	[59]	uBPMN	Not specified	D	Industrial
	[58]	uBPMN	Not specified	D	Commercial
	[60]	uBPMN	Not specified	D	Commercial
	[20]	BPMN4CPS	Not specified	D	Healthcare
	[27]	BPMN-MDM	Not specified	D	Smart city
	[50]	Sperner et al.	Not specified	D	Not defined
	[40]	BPMN-E2	ARIS	D	Industrial
	[19]	Gao et al.	Not specified	D	Industrial
	[11]	Cheng et al.	jBPM	D	Environmental
	[26]	Kozel T.	Not specified	D	Commercial
	[43]	Sang et al.	Activiti	D	Healthcare
	[44]	Schonig S et al.	Not specified	D	Industrial
	[22]	Grefen P. et al.	Not specified	D	Industrial
	[8]	BPMN4WSN	Signavio Core C.	D	Smart city
	[55]	BPMN4WSN	Signavio Core C.	E	Smart city
	[51]	BPMN4WSN	Signavio Core C.	E	Smart city
	[36]	BPMN4WSN	Signavio Core C.	E	Smart city
	[1]	SPU	Not specified	E	Commercial

Table 2. SLR Extracted Data (D = Design, E = Execution).

in the design phase of a model [6,7,15,12,48], then we refer to the ones also considering to model execution [14,29,30,18,31,45,37,57,41].

In [6] the authors use BPMN to capture IoT scenarios and propose to transform such models into code to be executed on a sensor network. In [15] the authors represent, by means of BPMN annotations attached to a pool, conditions that must always be valid within an IoT process. In [12] the authors propose a way to adapt an already available IoT platform to the needs of the BPM approach and analyse the difficulties that arise therein using BPMN in the design phase. In [48] the authors propose a framework to connect the IoT infrastructure to the context-aware BPM ecosystem using IoT-integrated ontologies and IoT-enhanced decision models, which enable the capabilities of IoT to make business processes modelled via BPMN and the involved decision making aware of the dynamic context. In [14] and [29] the authors directly focus on IoT and business processes, proposing first to use BPMN to model IoT scenarios, then to transform the models into an intermediate language, such as Callas Byte Code, to describe WSN systems, and finally to execute such code on the IoT devices. In [30] the authors use BPMN as a starting point to model IoT scenarios managed by BPM Systems, proposing an architecture for decentralised device-to-device business process execution over mobile nodes. In [18] the authors presented a contribution that allows to coordinate the devices used in an IoT application by means of a business process engine with the design of BPMN models for the process logic. In [31] the authors focus on monitoring the compliance of the execution of multi-party business processes. They exploit the IoT paradigm by instructing smart objects. The scenario is modelled in BPMN, then translated into a set of artifact-centric process models, rendered in another notation called Extended-GSM. In [45] the authors introduce an integrated approach for IoT-aware business process execution that exploits IoT for BPM with a particular focus on the management of IoT data. In [37] the authors use BPMN for and controlling the maintenance procedure in a scenario of an industrial cyber-physical production environment. In [57] the authors propose an architecture for a smart home service. Home business processes are analyzed and classified, and then a BPMN-based home business process method is presented. In [41] the authors propose a model based on BPM paradigm, and IT principles to model and enhance the process of a specific scenario.

BPMN Extensions. In this category are reported all the research works presenting extensions to the BPMN notation for better representing IoT aspects in a designed model. We can see that in some cases the same BPMN extension is used (i.e., IAPM [35], uBPMN [59], BPMN4WSN [8]) and in turn extended (see, e.g., [32,58,51]). Looking at the various extensions proposed to the BPMN notation, we observed that none of them presents a completely new element, but they present characterizations of already available ones[2]. Several BPMN elements have been extended, such as Activities, Events, Data Objects, Pool/Lanes, and Gateways. IoT concepts like Sensing and Actuating are often represented using tasks: *Actuator task* is a physical task performed by an IoT device, while *Sensing task* indicates the retrieval of data from the physical world by a sensor. Data produced by IoT devices are represented using *Smart data objects* or *Stream Data objects*; they represent, either an input or an output, the data flow generally produced by IoT devices. Also, the *mobility* aspect, which characterizes some IoT devices, is represented using location markers added to Events or Pools/Lanes. Besides, it is worth noticing that only a few of the research works proposing a BPMN extension also provide approaches to execute the model designed with such a notation.

Answer to SRQ1 and SRQ2. For answering the research question ***SRQ1*** - *Which are the available tools supporting the IoT-aware business process mod-*

[2] For more details see the Graphical BPMN extension sheet available at `http://pros.unicam.it/BP-meet-IoT-2020`

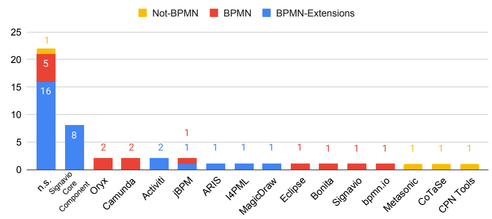

Fig. 4. Tools for modelling IoT-aware business processes.

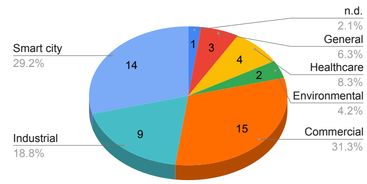

Fig. 5. Application Domain of IoT-aware business processes.

elling? - we can refer to column *Modelling Tool* of Table 2. For presentation purpose, we collected those data in the form of diagram reported in Fig. 4. We can see that 22 of the research works (45.8%) do not refer to any modelling tool that can be used to model IoT-aware business processes; 3 research works (6.25%) do not use BPMN and refer to dedicated tools; 9 research works (18.75%) make use of the BPMN notation without extending it but referring to standard modelling editors; 14 research works (29.2%) present a BPMN extension developed by adding new elements to the ones available in existing modelling editors. It results that for what concerns BPMN extensions for modelling IoT aspects, many of the proposed notations are limited to the conceptualization of an extension and do not provide any editor for actually being used. Usually, those that provide an editor refer to custom extensions of already available editors, which in many cases are not made available or are deprecated.

Column *Application Domain* in Table 2 permits to answer the research question ***SRQ2*** - *Which are the target application domains for the modelling of IoT-aware business processes?* For presentation purpose, we collected those data in a form of chart reported in Fig. 5. The application domains referred by the retrieved research works are: commercial (31.3%); smart city (29.2%); industrial (18.8%); healthcare (8.3%); general aspects (6.3%); environmental (4.2%). Only one of the research works (2.1%) does not refer to any application domain.

5 Related Work

While scouting the literature for retrieving scientific contributions concerning the modelling of IoT-aware business processes, we found some research works that, while being different, share the spirit of our work.

IBM provided a report [5] targeting the modelling of IoT-aware business processes. It gives, not in the form of a systematic literature review, an overview of some BPMN extensions used to incorporate IoT aspects in business process models. They describe extensions published in the period 2010-2018, which result in being a subset of those we retrieved from our study. In [9] the authors provide, not in the form of a systematic literature review, an analysis of existing BPMSs for IoT frameworks and identify the limitations, and their drawbacks based on a Mobile Cloud Computing perspective. They also provide a summary of some of the BPMN extensions used to incorporate IoT aspects in business process models. These extensions are a subset of those we retrieved from our study published in the period 2012-2016. The authors of [54] performed a systematic mapping study that investigates the modelling and automatic code generation initiatives for wireless sensor network applications based on the IEEE 802.15.4 standard. Even though this work presents a significant amount of retrieved research works, it differs from ours on the query, which is kept more general, also including terms referring to Model Driven Engineering. Besides, their contribution focuses on aspects linked to the technology used by the various approaches, the kind of supported middleware, the proposed service-oriented architecture. However, while limiting the notation comparison on the support for aspects linked to WSN (e.g. energy consumption), they miss some less specific notations, which we retrieved, and that target IoT in general. Moreover, the modelling notations that they identified have been published in the period 2005-2015, so not including more recent works. In [3], the authors provide a survey, not in the form of a systematic literature review, on domain-specific BPMN extensions. Their work is, therefore, more general and less precise on the topic of modelling IoT-aware business processes, resulting in a subset of the notations we identified. Their research only covers the period 2007-2014.

6 Concluding Remarks

In this paper, we performed an SLR on modelling notations for IoT-aware business processes using the Kitchenham guidelines. We organize the work in sections reflecting the followed SLR protocol: *planning* (Sec. 2), *conducting* (Sec. 3), and *reporting* (Sec. 4). We selected and analyzed 48 research works. The results confirmed the increasing relevance of the considered topic, witnessed by the increase in the number of the published research works on the subject till 2018.

Answering our research questions, we recognized that modelling notations for IoT-aware business processes result to be a hot topic from the BP-meet-IoT community. However, during our study, we observed the lack of a notation suitable to support all the IoT related requirements (reported in [35]) that are typically used by the community as a reference point for comparing IoT-aware business process notations. In this regard, while analyzing the various contributions, we synthesized an overview of the IoT requirements supported by the emerged notations. In Table 3 we present as columns the IoT requirements and as rows the identified notations (note that we group research works referring to the same notation). The comparison shows that almost all extensions integrate the *RQ1. Entity Based Concept* requirement. Other requirements, such as *RQ2. Distributed Execution*, *RQ3. Interactions*, *RQ4. Distributed Data*, *RQ6. Abstraction*, *RQ9. Flexibility - Event based*, and *RQ11. Real Time* are met by most of the proposed extensions. Other requirements, such as *RQ5. Scalability*, *RQ7. Availability - Mobility*, *RQ8. Fault Tolerance* and the *RQ10. Uncertainty of information* are requirements not met by existing extensions. This is because these requirements refer to data management, and most extensions avoid dealing with data. As a final consideration, we can see that none of the identified notations fully meets the IoT requirements.

Source	RQ1	RQ2	RQ3	RQ4	RQ5	RQ6	RQ7	RQ8	RQ9	RQ10	RQ11
[46] [49]		✓		✓	Partly	✓	✓	Partly	✓	Partly	✓
[17]	Partly	✓	✓			✓	Partly		✓		✓
[56]	Partly	✓	✓	✓	Partly	✓	✓	✓	✓	Partly	✓
[6] [7] [15] [12] [48] [29] [14] [30] [18] [31] [45] [37] [57] [41]	Partly	Partly		Partly	Partly	✓		Partly	✓		✓
[35] [32] [34] [42] [28] [33] [13] [10] [38]	✓	✓	✓	✓	Partly	✓	✓	Partly	✓	Partly	✓
[39]	✓		✓	✓		✓					✓
[53] [52]	Partly	✓				✓			✓		✓
[59] [58] [60]	✓		✓	✓		✓			✓		✓
[20]	✓		✓			✓					✓
[27]	✓		✓	✓		✓					✓
[50]	✓		✓			✓					✓
[40]		✓				✓					✓
[19]	✓			✓		✓					✓
[11]	✓		✓			✓					✓
[26]						✓	✓		✓		✓
[43]	✓		✓			✓			✓	✓	✓
[44]	✓		✓			✓			✓		✓
[22]		✓		✓		✓	✓				✓
[8] [55] [51] [36]	✓	✓	✓			✓					✓
[1]	✓	✓	✓			✓					✓

Table 3. IoT-aware extension language requirements comparison.

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