A systematic literature review on BPMN extensions

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Abstract

Despite the existence of several languages, BPMN has become the leading standard for business process modelling thanks to its expressiveness and semantic richness. However, BPMN is generic and still suffers from some limitations, which has prompted researchers to extend it, either for dealing with processes of specific domains like healthcare and manufacturing or for improving the language itself in terms of flexibility, variability, complexity, etc. This paper presents a systematic literature review that we conducted in order to determine the current state of the art of BPMN extensions. After the search and filtering of papers, 49 extensions were retained to be thoroughly examined and compared according to a set of criteria including objective, targeted domain, conformity to the extension mechanism, demonstration, implementation, etc. Based on the obtained results, we identified several gaps and suggested recommendations to fill them and advance the research field of extending BPMN.

Keywords: BPMN extension, Systematic literature review, Business process modelling, Modelling languages, Domain-specific business processes, Domain-specific modelling languages, OMG recommendations, MOF meta-model, XML Schema

1. Introduction

Given today's fiercely competitive and highly dynamic market, most modern companies are adopting a business process management (BPM) strategy, which ensures a continuous improvement of business processes (BPs) and their adaptation to change. BPM includes several activities such as automation, execution, and monitoring of BPs, but the modelling activity remains the most crucial one. Indeed, it allows specifying the way of carrying out BPs, which has a direct influence on the quality of a company's deliverables and thus on customer satisfaction. In addition, the errors and defects must be identified at the modelling phase where correction is cheaper. In fact, modelling is the first phase in the BP lifecycle and the cost of corrections increases exponentially over the lifecycle. Furthermore, BP models serve as a basis for knowledge sharing, quality of service, regulatory compliance, and stakeholder collaboration (Moreno-Montes de Oca et al., 2015).

Despite the existence of several modelling languages, Business Process Model and Notation (BPMN) has become the de-facto standard for BP modelling (Arevalo et al., 2016) (Yousfi et al., 2016) (Braun & Esswein, 2014). In fact, BPMN is defined by the Object Management Group (OMG) and specified as ISO standard (ISO/IEC 19510:2013). The BPMN language is widely used for its expressiveness, simplicity and semantic richness. Moreover, it is supported by a wide range of tools like Activiti, jBPM, and Bizagi. However, BPMN becomes limited in supporting specific domains or non-functional properties since it provides generic elements and focuses only on the functional requirements of BPs.

In order to overcome this shortcoming and expand the use cases of BPMN, the OMG has introduced an extension mechanism allowing users to integrate new elements and provide valid BPMN extensions (OMG, 2013). Indeed, unlike the UML language that provides an extension mechanism by

specialization (through UML profiles), the BPMN language allows extension by addition, which consists of attaching new domain-specific elements to the predefined elements of the language (OMG, 2013).

Furthermore, BP designers prefer extending BPMN and reusing its kernel to take advantage of its benefits (e.g., standardization, tool support) instead of developing a domain-specific modelling language (DSML) from the scratch, which is very costly and time-consuming (Braun and Esswein, 2014). Accordingly, a large and growing number of BPMN extensions are proposed in the literature targeting various objectives such as the representation of domain-specific BPs (e.g., healthcare, IoT, manufacturing) or the improvement of the BPMN language itself (e.g., flexibility, complexity, variability).

In this paper, we rely on guidelines depicted in (Kitchenham, 2007) to conduct a systematic literature review (SLR) that aims to determine the current state of the art of BPMN extensions and identify the gaps that should be filled in this research area. An SLR is distinguished from other types of literature review primarily by a comprehensive literature search and specification of research questions that should be addressed (Kitchenham, 2007). To the best of our knowledge, (Braun & Esswein, 2014) is the only existing literature review that focuses on work extending the BPMN language. In fact, the authors have classified 30 extensions published between 2007 and 2014. However, the BPMN extension mechanism was introduced in 2011 and therefore previously published extensions cannot be judged on their conformance.

Our SLR complements that of (Braun & Esswein, 2014) in terms of both literature and criteria. Indeed, after the search and filtering of papers, 49 BPMN extensions published after the last extension treated in (Braun & Esswein, 2014) are retained for in-depth examination and comparison. To achieve this, we have established a set of criteria such as objective, target domain, representation format, conformance, implementation, evaluation, etc. Our study also aims to see how the characteristics of BPMN extensions have evolved over the past few years by comparing our results with those of (Braun & Esswein, 2014).

The remainder of this paper is organized as follows. Section 2 overviews BP modelling techniques and in particular the BPMN language as well as its extension mechanism. Section 3 describes the methodology followed to conduct our SLR. In section 4, BPMN extensions are analysed and the obtained results are reported. Some related work are tackled in Section 5. Finally, Section 6 concludes this paper and provides directions for future work.

2. Background

In this section, we first highlight some process modelling techniques, and then we give an overview of the BPMN language as well as its extension mechanism.

2.1. Business process modelling techniques

Among the techniques that have been used for BP modelling, we can highlight flow diagrams, Petri nets, event driven process chain (EPC), and role activity diagrams. There are also some languages such as Business Process Modelling Language (BPML) that have appeared but soon discarded due to the lack of market acceptance. So far, UML and BPMN are the main standards.

It is worth mentioning that BPMN was not set for competing with existing BP languages like UML Activity Diagrams, BPEL, YAWL, and XPDL, but rather for complementing them. In fact, BPMN has been intended as an alternative language to be used by business analysts without technical knowledge, whereas UML was designed for software engineers, YAWL and BPEL provide respectively graphical and XML-based notations for executable processes, and XPDL was intended as a portable exchange format.

2.2. Overview of the BPMN language

The Business Process Model and Notation (BPMN) is a standard language for modelling BPs that is widely used in both academia and industry (Braun et al., 2016). BPMN is defined by the Object Management Group (OMG) and specified as ISO standard. BPMN in its latest release provides five basic categories of elements: flow objects, data, connecting objects, swimlanes, and artefacts (OMG, 2013). Based on the list of the core BPMN elements depicted in (OMG, 2013, p.26), we have created a meta-model (see figure 1) in which we structure BPMN elements according to their category.

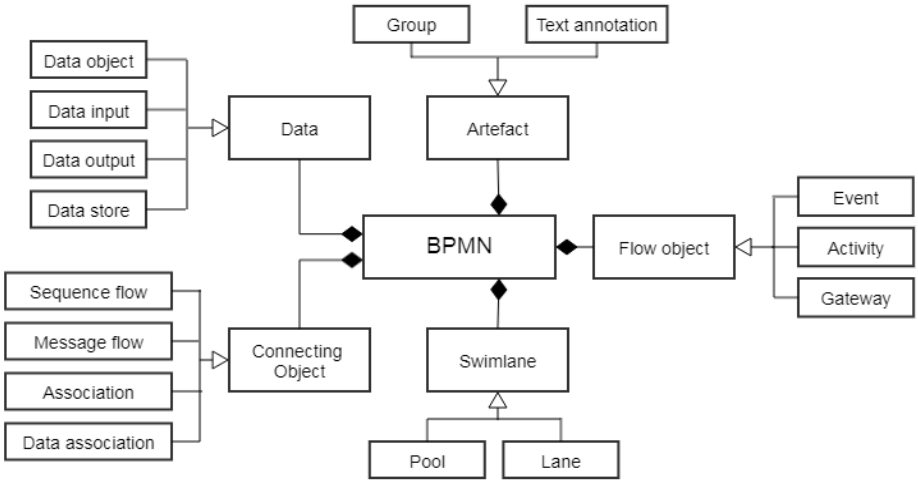

Figure 1. Structuring BPMN elements according to their category

BPMN is distinguished by a semantic richness, great expressiveness and ease of interpretation, thus reducing the risk of erroneous knowledge transfer (OMG, 2013). In addition, BPMN is supported by a wide range of modelling tools (e.g. Activiti, BPMN2 Modeler, Bizagi) and its models can be easily converted into executable languages (e.g., BPEL) (Pillat et al., 2015).

2.3. BPMN extension mechanism

BPMN 2.0.2 provides an extension mechanism that allows representing additional concepts and attaching them to its original elements in order to represent characteristics of a particular domain (e.g., health care, quality management, security, etc.). Extending BPMN and reusing its kernel allow taking advantage of its benefits (e.g., standardization, tool support) and avoiding expensive development of a domain-specific modelling language (DSML) from the scratch (Braun and Esswein, 2014).

For the specification of valid extensions, there are two representations defined in the official documentation of BPMN 2.0.2 (OMG, 2013). The first one is the meta-model represented in figure 2 and that is specified using the OMG's Meta Object Facility (MOF). This extension mechanism consists of four main elements (OMG, 2013):

1. Extension
2. ExtensionDefinition
3. ExtensionAttributeDefinition
4. ExtensionAttributeValue

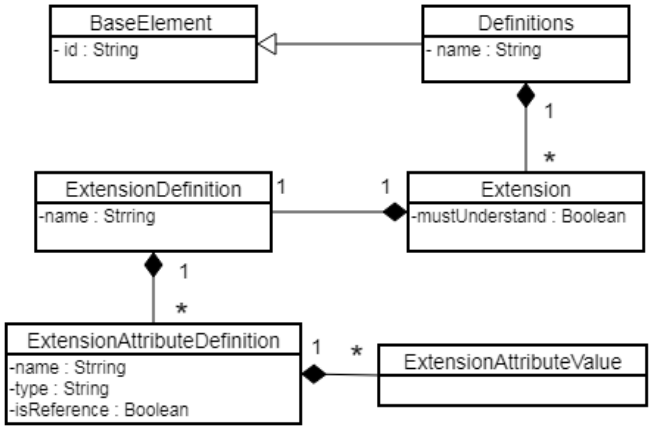

Figure 2. Extension class diagram (OMG, 2013)

Each BPMN element which subclasses the BPMN BaseElement can be extended by additional attributes. ExtensionDefinition groups new attributes under a new concept name and can be created independently of any BPMN definition. However, in order to use this meta-class to represent an extension, it must be associated with the meta-class Extension that binds an ExtensionDefinition and its attributes to the definition of a specific BPMN model (meta-class Definitions) (OMG, 2013).

An Extension Definition consists of several ExtensionAttributeDefinitions, which define the list of new attributes that can be attached to any BPMN element. The values of new attributes are stored in ExtensionAttributeValue meta-class (OMG, 2013). The mustUnderstand attribute indicates whether the semantics defined by the extension definition must be understood in order to process the BPMN model correctly. The default value is false. As for isReference attribute, it indicates if the attribute value will be referenced or contained (OMG, 2013).

The second format for representing valid BPMN extensions is a set of domain-specific elements represented in XML Schema that is saved into a BPMN file (i.e., a file with BPMN extension). The XML Schema representation specifies the interchange format for BPMN models (Pillat et al., 2015) and can support the definition of complex extensions that can be processed by BPMN tools. Nonetheless, the MOF-based extension mechanism has a limited capability. For instance, it does not define the type structures of the new attributes (OMG, 2013; Pillat et al., 2015).

The authors of (Stroppi et al., 2011) consider that the weak point in the BPMN extension mechanism is the lack of methodological guides for developing BPMN extensions. To fill this gap, they propose a procedure based on Model-Driven Architecture (MDA) for the methodical development of valid BPMN extensions. This method consists of four main steps (Stroppi et al., 2011):

1. Design of a Conceptual Domain Model of the Extension (CDME) using UML.
2. Definition of BPMN+X model describing an extension in terms of the BPMN extension mechanism. In this step, CDME elements are typed as 'BPMN concept' or 'Extension concept' using UML stereotypes.
3. Transformation of the BPMN+X model into an XML Schema Extension Definition Model.
4. Transformation of the XML Schema Extension Definition Model into an XML Schema Extension Definition Document.

In contrast, the Stroppi method has been criticized by (Braun & Schlieter, 2014) for the lack of domain requirement analysis. In addition, it does not consider whether a domain concept needs to be integrated as a new element or BPMN is semantically sufficient to support it. Therefore, (Braun & Schlieter, 2014) have extended the Stroppi method by a deep analysis of domain requirements and a comparison of domain-specific concepts with BPMN basic concepts. After defining the BPMN language

and its extension mechanism, we will present in the following section the methodology followed to conduct the literature review.

3. Methodology

A Systematic Literature Review (SLR) is a specific type of literature reviews that is characterized by (Kitchenham, 2007):

- A specification of research questions that should be addressed
- A comprehensive and unbiased search for the relevant literature
- An explicit definition of inclusion and exclusion criteria

One of the main reasons for undertaking an SLR is to summarize and evaluate existing work in a given research area, identify their gaps, and suggest work to address them (Kitchenham, 2007). Based on the guidelines depicted in (Kitchenham, 2007), we conducted our SLR in several stages:

1. Formulating the research questions
2. Extracting and filtering papers
3. Defining evaluation and comparison criteria
4. Presenting and discussing the obtained results

The remainder of this section describes the details of each stage.

3.1. Formulating the research questions

The specification of research questions (RQs) is the most important part of any SLR as they guide authors throughout the review process (Kitchenham, 2007). The RQs that should be addressed in our SLR are formulated as follows:

RQ1: What are the areas and goals targeted by BPMN extensions these last years?

RQ2: What are the formats used for the representation of BPMN extensions?

RQ3: Do the proposed extensions comply with the extension mechanism specified by the OMG?

RQ4: How are BPMN extensions demonstrated, implemented, and evaluated?

3.2. Extracting and filtering papers

To retrieve papers proposing BPMN extensions, we constructed our search string firstly by combining the main terms ‘BPMN’ and ‘Extension’. To make the search as comprehensive as possible and do not forget any BPMN extension, we replaced the term 'BPMN' with 'Modelling Language' and the term 'extension' was replaced by several derived words (e.g., 'Extending') or belonging to the same semantic field (e.g., ‘Enhancement’). The final search string is structured as follows:

Search string = (“BPMN” OR “Modelling language” AND “Exten*” OR “Enhanc*” OR “Expan*” OR “Customiz*” OR “Adapt”).

We resorted to several databases and search engines like Web of Science, Scopus, ScienceDirect, Emerald, SpringerLink, ACM, DBLP, Google Scholar, AIS Digital Library, IEEE Xplore Digital Library, INSPEC, etc. Besides, each found article was used for a backward search through its related work section.

Our SLR targets all BPMN extensions published over the timespan of November 6, 2014 to December 24, 2018 in journals, conference/workshop proceedings, and book chapters. For this, we filtered the obtained papers according to the following exclusion criteria:

- Papers that extend other modelling languages (e.g., UML, EPC) or execution languages like BPEL.
- Papers published before November 2014 whether or not they are treated in (classif Braun, 2014).
- Papers that are not published in journals, conference/workshop proceedings, and book chapters such as master and doctoral theses.
- Papers that do not propose a new BPMN extension.
- Papers written in a language other than English.
- Papers that describe the same BPMN extension in the same way.

We have found several papers in the literature that deal with similar BPMN extensions. For work where the extension is represented and implemented in the same way, only the most recent publication is retained. For example, the papers (Ben Hassen et al., 2017a), (Ben Hassen et al., 2017c), and (Ben Hassen et al., 2017b) present similar extensions in terms of objective, representation and implementation. Thus, only (Ben Hassen et al., 2017a) was selected. On the other hand, if the extensions are presented or implemented differently, they will both be considered as we did with (Yousfi et al., 2015) and (Yousfi et al., 2016) that share the same domain but the extensions are represented differently.

Filtering has greatly reduced the number of papers. In fact, after the paper collection, we obtained a total of 93 papers. Next, we discarded papers that were published before November 5, 2014 (including extensions treated in (Classif Braun, 2014)), duplicate/similar papers and those in which we did not find an extension of the BPMN language. However, we have kept the papers that propose an extension of BPMN whether it is primary or secondary contribution. Accordingly, a set of 49 papers were retained for an in-depth examination in our SLR. In figure 3, we used the BPMN language to model the main steps of paper extraction and filtering process.

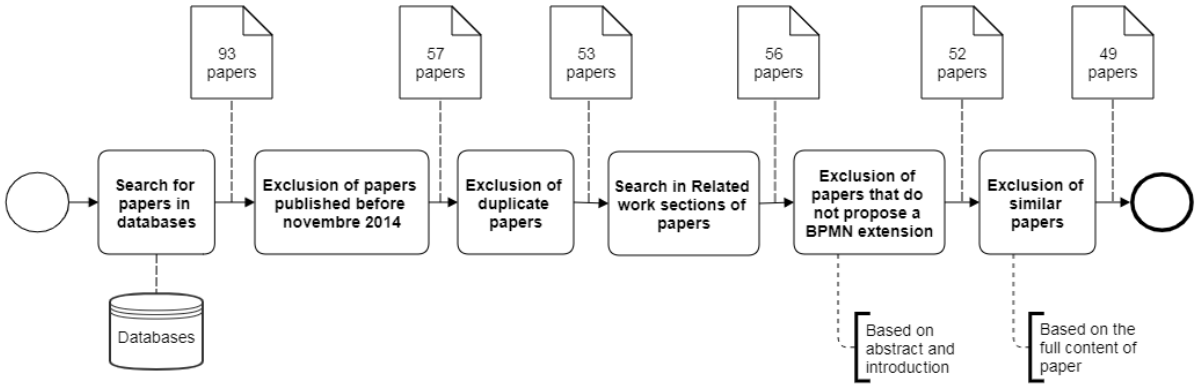

Figure 3. Process of paper extraction and filtering

3.3. Defining evaluation and comparison criteria

In order to evaluate and compare the BPMN extensions, we have defined the following criteria:

- **Publication type**: indicates if the extension has been published in a journal, a conference/workshop proceeding, or a book chapter.
- **Aim**: indicates the reason for which the extension was proposed or the problem that it solves.
- **Category**: we have defined two categories to classify the BPMN extensions according to their purpose. The first category 'Domain-specific BP' is for extensions intended to represent or handle the processes of a particular domain such as healthcare, manufacturing, Internet of Things (IoT), etc. The second category 'BP improvement' encompasses extensions that aim to improve the BPMN language (e.g., expressiveness, complexity, flexibility, variability), extensions that specify BP requirements in terms of different criteria (e.g., cost, performance

, security, compliance, quality) and extensions that contribute to BPM activities (e.g., simulation, execution, monitoring, process mining). The extensions of the second category are independent of a specific domain (i.e., they can be used in any domain).

- **BPMN version**: specifies the extended version of the BPMN language (e.g., 1.2, 2.0, 2.0.2)
- **Extension name**: indicates whether a name has been assigned to the proposed extension.
- **Main domain**: Designates the main domain targeted by an extension knowing that some extensions deal with multiple domains (e.g., security in healthcare processes) but only the main domain is considered.
- **Demonstration**: indicates whether an extension has been demonstrated through an illustrative example and whether the provided example is concrete or abstract.
- **Implementation**: mentions whether a BPMN extension has been implemented either by integrating it into a modelling tool (e.g., plugin, code injection) or by developing a new tool.
- **Evaluation**: specifies for each extension whether it has been evaluated and which method is used for the evaluation (e.g., experimentation, use of metrics, comparison with other extensions, comparison with the BPMN language itself).
- **Conformity**: determines whether a BPMN extension complies with the OMG's recommendations. An extension is considered conform if it is represented through a meta-model or an XML schema defined in the official documentation of the BPMN language. We also consider that the methods of (Stroppi et al., 2011) and (Braun & Schlieter, 2014) are conform because they are based on the MOF-meta model by specifying the correspondences to its meta-classes through stereotypes.
- **Representation**: mentions which of the three formats (Meta-model, XML Schema, and graphical elements) are used for the representation of the proposed extension.
- **Affected BPMN elements**: lists the BPMN elements that have been affected by the extension. A BPMN element is considered affected if it is reused, customized, or extended.

3.4. Presentation and discussion of the results

This last step is devoted to the presentation, interpretation, and analysis of the results obtained after a deep examination of each paper. For this, we begin by classifying, comparing, and assessing all BPMN extensions in tables according to the criteria defined in the previous stage. Then we give some statistics using graphs like pie charts and histograms. Finally, we interpret the obtained results and we provide explanations.

4. Results of the review

In table 1, we define for each BPMN extension the publication type ('J' for journal, 'C' for conference or workshop and 'Ch' for chapter), the main purpose of the extension as well as the category ('Imp' 'for BP improvement and 'DS' for domain-specific BP).

Table 1. Comparison of BPMN extensions according to their publication type, aim, and category

BPMN extension	Publication type	Extension aim	Category
(Anseeuw & al., 2015)	C	Support modelling and monitoring of decentralized BPs	DS
(Arevalo et al., 2016)	J	Integrate time aspects within BP models such as temporal dependencies between activities and deadlines	Imp
(Ben Hassen et al., 2017a)	J	Include crucial knowledge created and mobilized by sensitive BPs	Imp

(Ben said et al., 2017)	C	Deal with the flexibility of Inter-organizational BPs modelled through a version-based approach	Imp
(Betke & Seifert, 2017)	C	Specify the requirements of disaster response processes	DS
(Bocciarelli et al., 2017a)	C	Represent cyber-physical systems as resources supporting BP execution	DS
(Bocciarelli & al., 2017b)	C	Define structures of data exchanged during the execution of BP collaborations	Imp
(Bocciarelli et al., 2016)	C	Enable the dynamic allocation of resources to BP tasks	Imp
(Braun & Esswein, 2015)	C	Reduce BPMN complexity by providing appropriate views on BP models	Imp
(Braun et al., 2015)	C	Model healthcare processes that involve different stakeholders such as physicians and nurses	DS
(Braun et al., 2016)	C	Represent resources and documents used in clinical pathways	DS
(Cartelli et al., 2016)	C	Represent resources and external factors that may affect the process execution under a cost-sensitive perspective	Imp
(Carvalho et al., 2018)	C	Provide an aspect-oriented BP modelling notation to enhance the readability and simplicity of BPMN models	Imp
(Chergui & Benslimane, 2018)	C	Specify cyber security requirements and improve the system's security analysis	DS
(Chiu & Wang, 2015)	C	Introduce new types of events to take into account IoT aspects in process modelling	DS
(D'Ambrogio et al., 2016)	C	Annotate BP models with performance requirements and simulations results	Imp
(De Giacomo et al., 2015)	C	Add declarative constructs to BPMN for providing a hybrid process modelling	Imp
(Domingos et al., 2016)	Ch	Register reliability informations to reduce the failure rate of IoT-aware BPMN healthcare processes	DS
(Dorndorfer & Seel, 2017)	C	Enable the modelling of mobile context informations and their influence on sensitive BPs	DS
(Dukaric & Juric, 2018)	J	Orchestrate Cloud-specific workflow activities in BP engines	DS
(Graja et al., 2016) implemented in (Graja et al., 2017)	C	Enable designers to accurately model concepts of cyber-physical systems like sensors and actuators	DS
(Jankovic et al., 2015)	J	Allow a formal modelling of informations used and generated in cross-organizational BPs	DS
(Laue & Mueller, 2016)	C	Allow simulation of processes according to different scenarios	Imp
(Maines et al., 2016)	C	Specify accurately all cyber security requirements across the third dimension	Imp
(Mandal et al., 2017)	C	Propose a model for event handling based on explicit subscriptions and event buffering	Imp
(Martinho & Domingos, 2014)	J	Specify information quality and resource cost in IoT-aware processes	DS
(Martinho et al., 2015)	J	Ensure a controlled flexibility by defining where and how a BP can be changed	Imp
(Mazzola et al., 2017)	C	Employ an on-demand fault compensation mechanism through a Cloud-based execution	Imp
(Merino et al., 2016)	C	Define probe-oriented features to convey more informations about activities in a machine-understandable format	Imp
(Meyer et al., 2015)	C	Integrate IoT technologies and concepts within BP models	DS
(Neumann et al., 2016)	C	Model intraoperative surgical workflow in integrated operating rooms	DS

(Onggo et al., 2017)	J	Support the modelling of complex healthcare processes that require an explicit representation of queues and data-driven decision points	DS
(Polderdijk et al., 2018)	C	Visualize and analyse human physical risks (e.g. heavy lifting) in manufacturing processes	DS
(Pufahl & Weske, 2016)	C	Integrate batch processing into BPMN by synchronizing the execution of a several process instances	Imp
(Pullonen & al., 2017)	C	Secure processes by indicating the risks of private data leaks	Imp
(Ramos-Merino & al., 2018)	J	Describe in a machine-understandable way a set of variables to be monitored during BP execution	Imp
(Ramos-Merino & al., 2018)	J	Deal with the problem of ambiguities in representing hospital protocols	DS
(Rekik & al., 2016)	C	Specify BP requirements in order to outsource them to the best Cloud providers	Imp
(Respicio & Domingos, 2015)	J	Enrich BPMN with reliability informations to analyse alternatives at design time	Imp
(Salles et al., 2018)	J	Embody non-functional requirements and organizational goals through business level agreements (BLAs)	Imp
(Salnitri et al., 2017)	J	Express security aspects like integrity, accountability, and auditability	Imp
(Sang & Zhou, 2015)	C	Specify security requirements within healthcare processes	DS
(Tranquillini et al., 2015)	J	Program crowdsourcing in which multiple workers must coordinate to perform a composite task	DS
(Vogel et al., 2018)	C	Document and model smart glasses-based processes	DS
(Yahya et al., 2015)	C	Integrate web 2.0 features and technologies in social BPs	DS
(Yahya et al., 2018)	Ch	Enrich BP models with social aspects by considering web 2.0 features (collaboration, knowledge sharing, etc.)	DS
(Yousfi et al., 2015)	J	Represent BPs that use technologies of ubiquitous computing like sensors and smart readers	DS
(Yousfi et al., 2016)	J	Enable BPMN to represent accurately ubiquitous processes.	DS
(Zerbato etl al., 2015)	C	Add the time dimension in the modelling of healthcare processes related data	DS

Figures 4 and 5 represent the distribution of BPMN extensions by publication type and category, respectively.

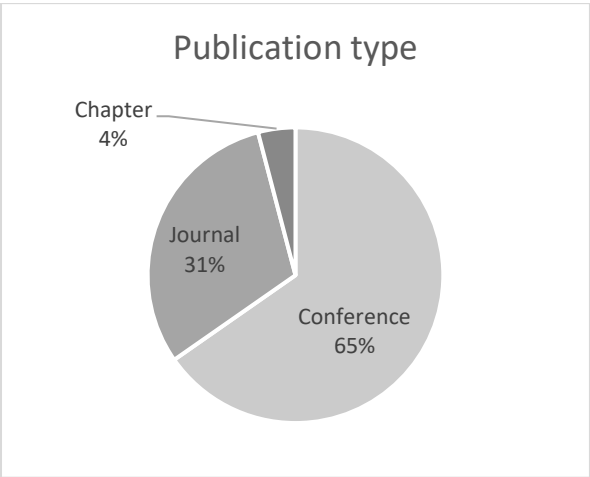

Figure 4. Distribution of BPMN extensions according to the type of publication

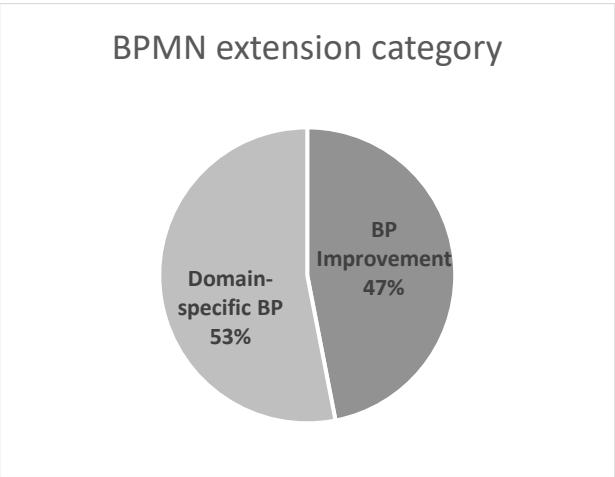

Figure 5. Distribution of BPMN extensions according to their category

We notice that the majority of extensions are published in conferences. We can explain this by the fact that BPMN extensions are not consistent enough in terms of contribution to be submitted to journals. There is also the lack of maturity in this research area since BPMN is a relatively recent language (standardized by the OMG in 2006) compared to other languages like UML, which was standardized by the OMG in 1997. On the other hand, the distribution by category is balanced since some researchers are interested in the processes of a particular field while others aim to improve BPMN language or contribute to BPM activities.

In table 2, the BPMN extensions are compared according to their name, main domain, demonstration, implementation, and evaluation.

Table 2. Comparison of BPMN extensions according to their name, domain, demonstration, implementation, and evaluation

BPMN extension	Extension name	Main domain	Illustrative example	Implementation	Evaluation
(Anseeuw & al., 2015)	/	Monitoring	Abstract example	No	No
(Arevalo et al., 2016)	/	Time dimension	Event management of an organization	No	Comparison with other approaches
(Ben Hassen et al., 2017a)	BPMN4KM	Knowledge management	Care of disabled children	BPMN2 Modeler	No
(Ben said et al., 2017)	BPMN4V	Flexibility	Radiological examination	BPMN2 Modeler	No
(Betke & Seifert, 2017)	/	Disaster response management	No	No	No
(Bocciarelli et al., 2017a)	/	Cyber physical systems	3D printing	No	No
(Bocciarelli & al., 2017b)	/	Data exchange	Production of hardware components	No	No
(Bocciarelli et al., 2016)	PyBPMN	BP resources	Delivery of hard copy contracts	No	No
(Braun & Esswein, 2015)	/	Complexity	Stroke diagnosis	No	No
(Braun et al., 2015)	/	Healthcare	Wisdom tooth treatment	No	Comparison with a DSML
(Braun et al., 2016)	BPMN4CP	Healthcare	Stroke care	No	no
(Cartelli et al., 2016)	BPSIM	Simulation	Releasing a construction permit	New tool	no
(Carvalho et al., 2017)	AO-BPM	Complexity	University administrative services	Draw.io	Comparison with BPMN
(Chergui & Benslimane, 2018)	/	Security	Patient admission in a hospital	No	Experiments with students
(Chiu & Wang, 2015)	/	IoT	Temperature control	No	No
(D'Ambrogio et al., 2016)	PyBPMN	Performance	Abstract example	BPMN2 Modeler	No
(De Giacomo et al., 2015)	BPMN-D	Variability	Purchase order process	No	no
(Domingos et al., 2016)	relyBPMN	Healthcare	Ambient assisted living healthcare	No	Reliability calculation

(Dorndorfer & Seel, 2017)	Context4BPMN	Mobile devices	Inspection and control of employees	No	no
(Dukaric & Juric, 2018)	/	Cloud computing	Abstract axample	New tool	Measuring complexity using various metrics
(Graja et al., 2016) implemented in (Graja et al., 2017)	BPMN4CPS	Cyber-physical systems	Ambulance drone system	BPMN2 Modeler	no
(Jankovic et al., 2015)	/	BP resources	Collaborative shipping process	No	No
(Laue & Mueller, 2016)	BPSIM	Simulation	Choice of the report type required	No	No
(Maines et al., 2016)	/	Security	Air traffic management	No	Experiments with students
(Mandal et al., 2017)	/	Event handling	Shipping goods by truck	Camunda	no
(Martinho & Domingos, 2014)	/	IoT	No	No	No
(Martinho et al., 2015)	CF4BPMN	Flexibility	Elaboration phase of the unified process (UP)	No	no
(Mazzola et al., 2017)	FCE4BPMN	BP flexibility	Key-holder production	New tool	No
(Merino et al., 2016)	/	BP mining	Manufacturing chain of metal pieces	No	Comparison with BPMN
(Meyer et al., 2015)	/	IoT	Temperature measurement with an IoT device	No	No
(Neumann et al., 2016)	BPMNSIX	Healthcare	No	No	No
(Onggo et al., 2017)	BPMN4SIM	Healthcare	Emergency care of elderly patients	No	no
(Polderdijk et al., 2018)	/	Manufacturing	Loading profiles on racks (Company of Thomas Regout Int)	Microsoft Visio	Interviews with experts
(Pufahl & Weske, 2016)	/	Batch processing	Shipping of customers' orders	Camunda	No
(Pullonen & al., 2017)	PE-BPMN	Security	RapidGather mobile application	No	No
(Ramos-Merino & al., 2018)	/	Healthcare	Management of hazardous drugs	No	Expreiments with experts
(Ramos-Merino & al., 2018)	BPMN-E2	Monitoring	Parenteral nutrition	Graphviz	Comparison with BPMN
(Rekik & al., 2016)	OutyBPMN	BP outsourcing	Abstract example	BPMN2 Modeler	no
(Respicio & Domingos, 2015)	/	Reliability	Paper reviewing	No	No
(Salles et al., 2018)	BLA@BPMN	Quality of service	Credit application	Bizagi	Survey with experts
(Salnitri et al., 2017)	SecBPMN-ml	Security	Air traffic management	New tool	Experiment with experts
(Sang & Zhou, 2015)	/	Healthcare	Remote healthcare monitor system	Activiti	No
(Tranquillini et al., 2015)	BPMN4Crowd	Crowdsourcing	Crowd-based mining of mashup model patterns	Activiti	no
(Vogel et al., 2018)	BPMN4SGA	IoT	Movement of goods in a distribution center	No	No

(Yahya et al., 2015)	BPMN4Social	Social aspects	Online course planning	BPMN2 Modeler	No
(Yahya et al., 2018)	BPMN4Social	Social aspects	Maintenance of devices in a commercial company	BPMN2 Modeler	no
(Yousfi et al., 2015)	uBPMN	Ubiquitous computing	Time banking (request fulfillment)	No	Comparison with BPMN
(Yousfi et al., 2016)	uBPMN	Ubiquitous computing	Order eyeglass frames	No	no
(Zerbato etl al., 2015)	/	Healthcare	Catheter-related bloodstream infections	No	No

In figure 6, we calculate number of BPMN extensions for each domain. We note that the targeted areas are very diversified as we have identified 189 different domains knowing that some close domains have been grouped together. For instance, the CPS, IoT, and Ubiquitous computing domains have been grouped since they all involve the interconnection of physical entities via a network. Extensions that specify the BP requirements in terms of performance, reliability, QoS, etc. have been considered in non-functional properties.

We also note in figure 6 that healthcare is among the most targeted areas. The interest in healthcare is explained by the fact that it is very broad, very sensitive, and highly regulated. Indeed, processes in this area manipulate medical data that must be archived, remain confidential and always available to caregivers for decision-making. In addition, this area is highly regulated by extraterritorial laws (e.g., Health Insurance Portability and Accountability Act (HIPAA), Health Information Technology for Economic and Clinical Health (HITECH), International Health Regulations (IHR) (WHO, 2007)) and by standards (e.g., the norm ISO 18308: 2011 (ISO, 2017) for structuring electronic health record).

The domains involving the interconnection of physical entities are also very focused since they are very trendy these last years and they have many specific characteristics that should be considered such as energy consumption constraints, limited resources, data transfer, etc. Another domain also targeted by BPMN extensions is the flexibility and variability of processes allowing their adaptation to changes of the environment that becomes more dynamic and unpredictable with increasingly demanding customers.

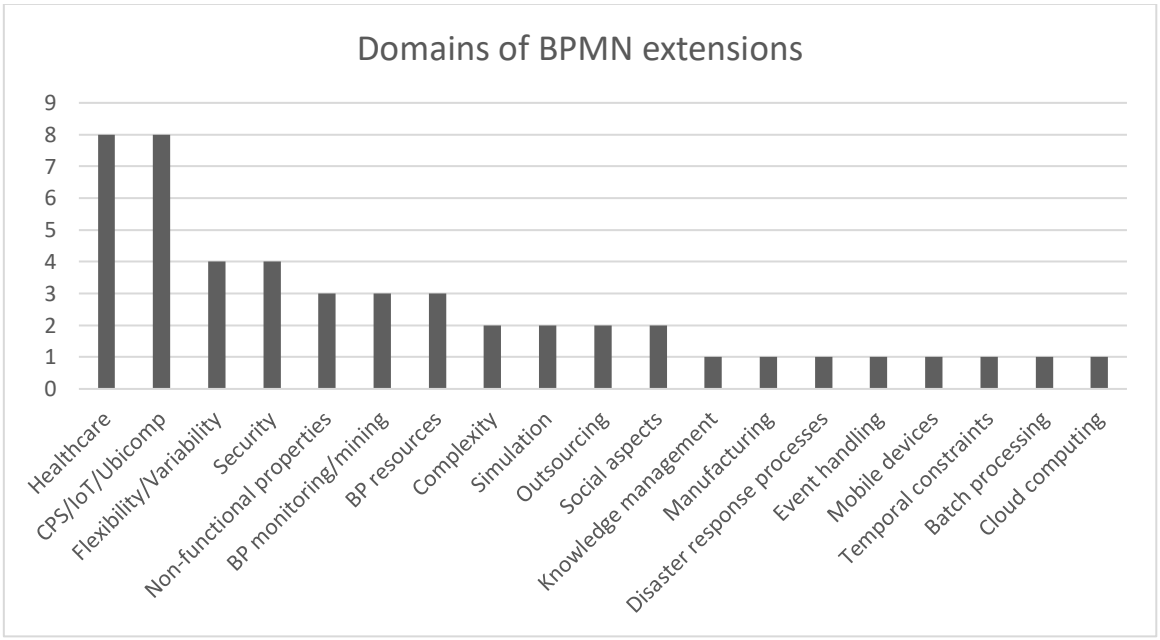

Figure 6. Distribution of BPMN extensions according to the targeted domain

Figure 7 shows the tools used by authors to implement their extension. The BPMN2 Modeler tool is widely used. This is probably due to the ease and documentation offered by BPMN2 Modeler to help users in integrating the new elements of their extension. In fact, a tutorial on an extension example is explained in detail on the Eclipse website. To integrate new elements of an extension, it is enough to add a plugin to BPMN2 Modeler (which is itself a plugin integrated in Eclipse) contrary to other tools that require code injection or modification. Furthermore, many authors prefer to develop their own modelling tool although this method is costly and time-consuming.

In figure 8, we observe that almost all the examples provided by the authors to demonstrate their BPMN extension are concrete processes (i.e., they are derived from real world scenarios).

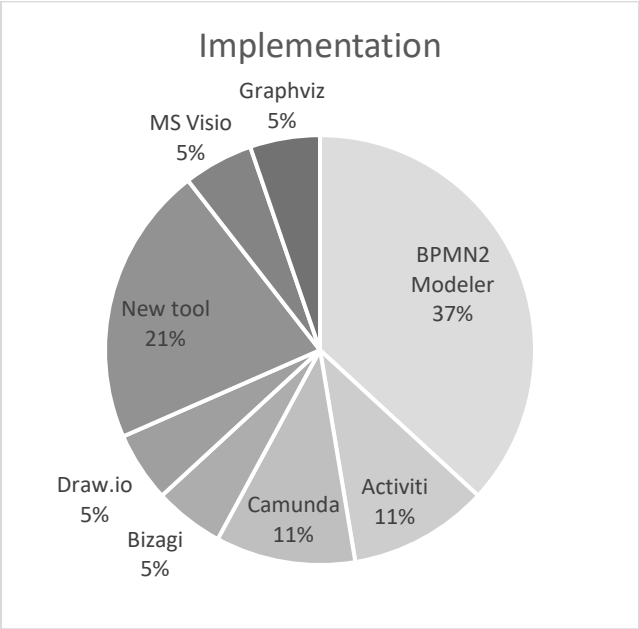

Figure 7. Distribution of BPMN extensions according to the implementation tool

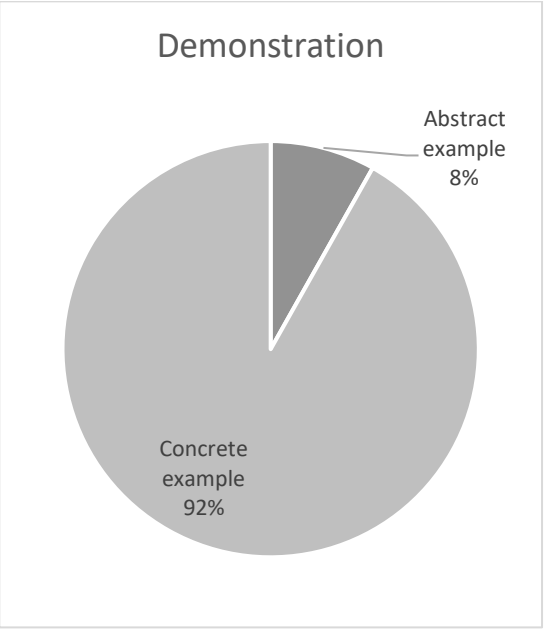

Figure 8. Distribution of BPMN extensions according to the type of illustrative example

In table 3, we compare the BPMN extensions by taking into account their conformity, the formats adopted for their representation as well as the affected BPMN elements. For the conformity criterion, we specify between brackets whether one of the two methodologies of (Stroppi et al., 2011) or (Braun & Schlieter, 2014) has been followed.

Table 3. Comparison of BPMN extensions according to their conformity, representation, and affected BPMN elements

BPMN extension	Conformity	Extension representation	Affected elements

		Meta model	XML Schema	Graphical elements	Event	Activity	Gateway	Sequence flow	Message flow	Association	Pool	Lane	Data object	Group	Text annotation
(Anseeuw & al., 2015)	No			X	X	X	X	X					X		
(Arevalo et al., 2016)	No	X		X	X	X	X	X							
(Ben Hassen et al., 2017a)	Yes (Stroppi)	X	X	X		X			X						
(Ben said et al., 2017)	Yes	X		X	X	X					X				
(Betke & Seifert, 2017)	Yes (Stroppi)	X		X		X									
(Bocciarelli et al., 2017a)	No	X				X									X
(Bocciarelli & al., 2017b)	No	X							X						
(Bocciarelli et al., 2016)	No	X				X									X
(Braun & Esswein, 2015)	Yes (Stroppi)	X		X		X							X		
(Braun et al., 2015)	Yes (Braun)	X		X		X	X						X		
(Braun et al., 2016)	Yes (Braun)	X		X		X	X			X			X		
(Cartelli et al., 2016)	Yes		X		X	X	X	X				X			
(Carvalho et al., 2018)	No			X		X		X		X	X	X			
(Chergui & Benslimane, 2018)	Yes (Stroppi)	X	X	X		X									
(Chiu & Wang, 2015)	No	X		X	X										
(D'Ambrogio et al., 2016)	No	X			X								X		
(De Giacomo et al., 2015)	No			X		X		X							
(Domingos et al., 2016)	Yes (Stroppi)	X	X		X	X	X	x							
(Dorndorfer & Seel, 2017)	Yes	X		X	X	X								X	X
(Dukaric & Juric, 2018)	Yes	X	X	X		X									
(Graja et al., 2016) implemented in (Graja et al., 2017)	Yes	X		X	X	X					X	X			

(Jankovic et al., 2015)	Yes	X		X						X			X		
(Laue & Mueller, 2016)	Yes			X	X	X	X	X							
(Maines et al., 2016)	No			X	X	X	X	X	X	X	X	X	X	X	X
(Mandal et al., 2017)	Yes (Stroppi)	X	X			X									
(Martinho & Domingos, 2014)	Yes		X			X									
(Martinho et al., 2015)	Yes	X		X	X	X	x					X	X		
(Mazzola et al., 2017)	No		X			X									
(Merino et al., 2016)	No			X		X		X					X	X	
(Meyer et al., 2015)	Yes	X		X		X					X				X
(Neumann et al., 2016)	Yes (Braun)	X		X	X	X	X			X		X			
(Onggo et al., 2017)	Yes	X		X		X	X						X		
(Polderdijk et al., 2018)	No			X		X									
(Pufahl & Weske, 2016)	No			X		X									
(Pullonen & al., 2017)	No	X		X	X										
(Ramos-Merino & al., 2018)	No			X		X									
(Ramos-Merino & al., 2018)	Yes	X	X	X		X		X		X			X		
(Rekik & al., 2016)	Yes	X		X		X								X	X
(Respicio & Domingos, 2015)	Yes		X			X		X							
(Salles et al., 2018)	Yes	X		X						X		X		X	
(Salnitri et al., 2017)	No			X		X	X		X				X		
(Sang & Zhou, 2015)	No	X		X	X	X						X			
(Tranquillini et al., 2015)	No			X		X							X		
(Vogel et al., 2018)	No			X		X									
(Yahya et al., 2015)	No	X		X	X	X	X				X		X		
(Yahya et al., 2018)	No	X		X	X	X	X					X	X		
(Yousfi et al., 2015)	Yes	X		X		X							X		
(Yousfi et al., 2016)	Yes	X	X	X	X	X							X		
(Zerbato etl al., 2015)	No			X		X				X			X		

We notice in figure 9 that most authors represent their BPMN extension in the form of a meta-model and graphical elements. However, the XML Schema is little used despite it specifies an interchange and storage format for BP models (OMG, 2013).

As for the affected BPMN elements, we see in figure 10 that the Activity element is by far the most affected by BPMN extensions. In fact, it is affected in almost all extensions (43 out of 49). This heavy use is probably due to the fact that the Activity element defines the works performed within BPs whether atomic (task) or compound (sub-process) (OMG, 2013). We also perceive that Event and Data Object elements are widely used. Indeed, the first element allows to take into account the external environment by defining everything that can occur during the BP execution and that may have an impact on the process flow while the second element provides information about what activities require to be performed and what they produce (OMG, 2013).

More generally, we observe that the Flow Objects category, which includes Event, Activity, and Gateway elements, is the most affected with an average of 25 uses among 49 BPMN extensions. We find this result logical as this category encompasses the main elements for defining process behaviour (OMG, 2013).

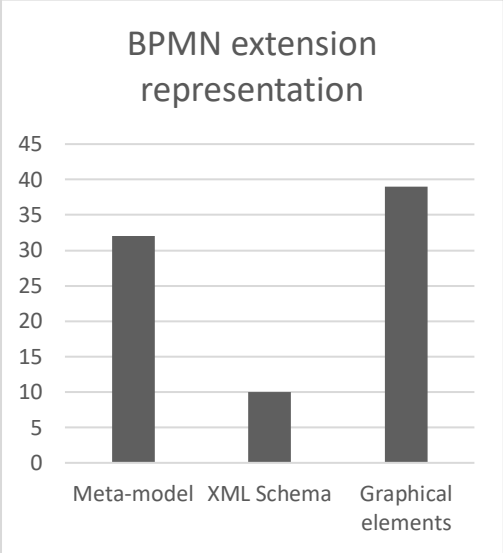

Figure 9. The number of uses of each format for representing BPMN extensions

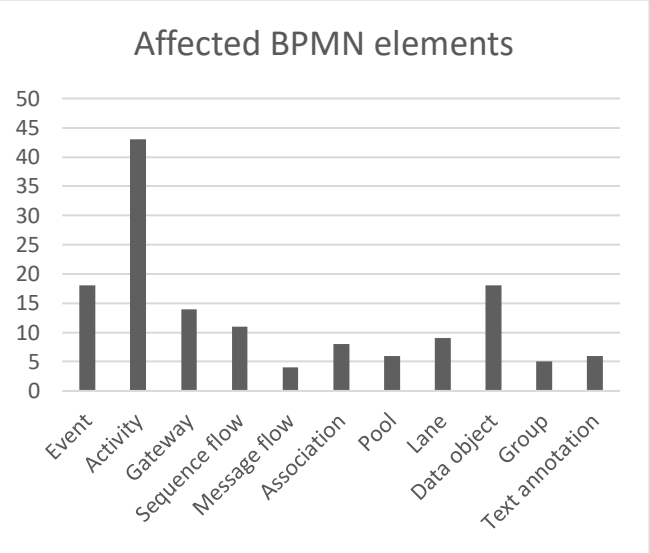

Figure 10. The number of affectations of BPMN elements by extensions

In figure 11, we based on tables 2 and 3 to evaluate BPMN extensions in terms of conformity, demonstration, evaluation, and implementation. The statistics reveal that:

- Less than half of the extensions (47%) comply with the BPMN extension mechanism what hampers comprehensibility and comparability of BPMN extensions and impedes their straightforward integration in modelling tools. This low conformance rate is due to the absence of a standard methodology for developing extensions since the OMG specifies only the representation formats, namely the MOF meta-model and the XML Schema. Given also the number of meta-models defined in the BPMN documentation, authors have trouble finding which one to extend. Moreover, authors have to know the basics of XML Schema to be able to use it in the representation of their extension. Other reasons are also possible such as the length of BPMN documentation (more than 500 pages) and the lack of clarity on how to extend the meta-models.

- Apart from three BPMN extensions, all the others have been demonstrated through examples that are in most cases concrete. This helps to understand the usefulness of the proposed extensions.
- Only 29% of BPMN extensions were evaluated. Generally, authors evaluate their extension by comparing it with the BPMN language, with other extensions, or with a domain-specific modelling language (DSML). For instance, (Carvalho et al., 2018) compared their extension with BPMN through LOC metrics, (Braun et al., 2015) compared their extension with a DSML while the extension proposed in (Arevalo et al., 2016) was compared with another BPMN extension. The comparison is often used because it allows to highlight the added values of the proposed extension. Other authors opt for interviews and questionnaires with a group of experts. For example (Salles et al., 2018) used the Goal Question Metric (GQM) technique while (Salnitri et al., 2017) opted for an online survey left for 20 days.
- Only 39% of extensions have been implemented despite the fact that most modelling tools such as Activiti, Bizagi, and BPMN2 Modeler are extensible and offer the possibility of adding new graphic elements and integrating them into their palette. We have also noted that several authors mention at the end of the paper that they plan to implement their extension in the future. Therefore, we can expect publications implementing the extensions already proposed as the authors did in (Graja et al., 2016) and (Graja et al., 2017).

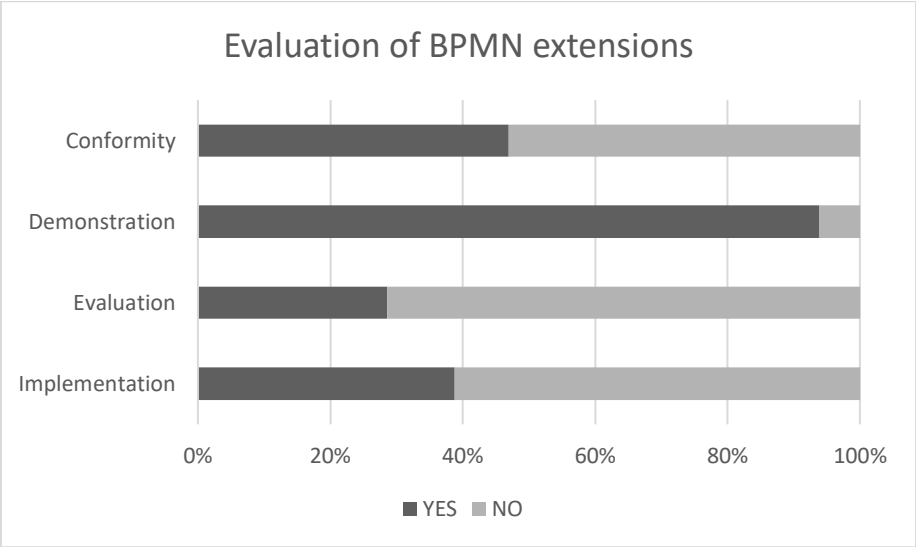

Figure 11. Evaluation of BPMN extensions according to conformity, demonstration, evaluation, and implementation criteria

In addition, we have noticed that all authors explain the need to extend the BPMN language in their context and justify each of the new added elements.

5. Related work

To the best of the authors' knowledge, (Braun & Esswein, 2014) is the only work that has conducted a literature review on BPMN extensions through a descriptive analysis and classification of 30 domain-specific BPMN extensions. We are very grateful to the authors for their efforts. However, we found the following limitations:

- The classification of 11 extensions published before the existence of the extension mechanism that was introduced in the version BPMN 2.0 in January 2011. Therefore, these extensions cannot be considered as non-conform.

- The authors focused on extensions devoted for specific domains and neglected those that aim to improve the BPMN language or contribute to BPM activities.
- The non-consideration of the XML Schema format in representing BPMN extensions.
- The non-consideration of certain criteria such as the implementation, demonstration, and evaluation of BPMN extensions.
- The extended BPMN elements that were compared are not of the same level. For example, the Task element was compared with the Activity element, yet Task is a subtype of Activity. Artefact was also compared with Text annotation, which is an element of the Artefact category. To obtain significant results, it is required to compare either BPMN elements or their categories.
- The literature review is not exhaustive as some publications such as (Rodriguez et al., 2012; Zor et al., 2011 ; Baumegrass et al., 2014) have not been examined despite they propose a BPMN extension and are published over the covered timespan (2007 to 2014).

The objective of our literature review is to complement that of (Braun & Esswein, 2014) in terms of both literature and criteria. Indeed, the last paper treated in the literature review of (Braun & Esswein, 2014) was published on November 2, 2014. Therefore, in our literature review, we examined all BPMN extensions published after this date.

In order to see the evolution of extensions since the appearance of BPMN, we compared in figure 12 some of our results with those obtained by (Braun & Esswein, 2014).

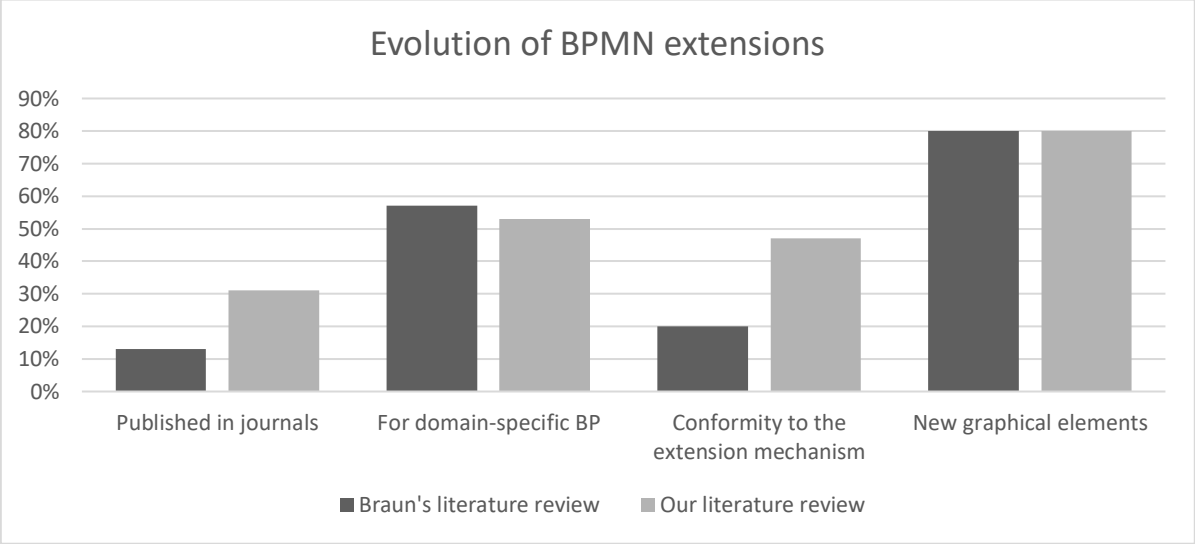

Figure 12. Evolution of BPMN extension characteristics over the past few years

From this comparison, we have noted the following points:

- The publication of BPMN extensions in journals has slightly increased. This proves that this research axis has gained in maturity and the extensions are more consistent, especially with their implementation and evaluation. However, this percentage remains low (31%) and we believe that it will increase further in the coming years.
- The extensions reviewed in (Braun & Esswein, 2014) are slightly more oriented towards specific domains than the improvement of BPMN. This is related to the choice of the literature of (Braun & Esswein, 2014) which as we mentionned previously, focused on extensions dealing with processes of specific domains.
- Extensions are becoming more conform to the BPMN extension mechanism. This result is logical given that many extensions analyzed in (Braun & Esswein) were published before the OMG introduced the extension mechanism and are considered non-conform.

- New graphic elements are introduced in the majority of BPMN extensions, whether old (extensions treated in (Braun & Esswein, 2014)) or recent (extensions treated in our SLR).

Furthermore, we noticed that the domains highly targeted by the extensions have changed. Indeed, in (Braun & Esswein, 2014), the two most targeted fields are performance and risk management, whereas in our SLR, healthcare and interconnection of physical entities are the most targeted.

There are also work that have conducted a literature review on the extension of other languages. For instance, (Kopp et al., 2011) have classified 62 BPEL extensions while (Pardillo, 2010) has reviewed UML-profiling practices based on the analysis of 39 publications.

Some researchers have conducted literature reviews focusing on business process modelling more generally and independently of a specific language. For example, (Aguilar Saven, 2004) reviewed the main process modelling techniques existing in the literature and classified them according to their purpose. An SLR was performed in (Moreno-Montes de Oca et al., 2015) for determining what quality aspects have been addressed in BP modelling and which gaps remain to be covered.

(Aldin & Cesare, 2011) have surveyed the existing literature that addresses the problem of reusability in BP modelling for discovering reusable artefacts in the form of patterns. In the same field, (Zaaboub Haddar et al., 2014) have given an insight into existing types of reusable artefacts, their limitations, and reuse context. This latter two works intend to assist BP designers in choosing the appropriate types of reusable artefacts in their modelling project. Finally, a thorough SLR was reported in (Awadid & Nurcan, 2017) on consistency requirements in BP modelling with a categorization of existing consistency approaches.

6. Conclusion and future work

BP modelling is arguably one of the major research areas in recent years as it takes an important part in the development of modern information systems. Although there exist several languages, BPMN has become the leader in BP modelling thanks to its expressiveness and simplicity. However, the latter provides generic elements and often needs to be extended. Since the development of a DSML from scratch is very time-consuming, a large number of extensions are proposed in the literature whether for dealing with domain-specific BPs (e.g., manufacturing, ubiquitous computing, healthcare) or for enhancing the BPMN language in terms of flexibility, security, complexity, etc.

In this paper, an SLR was conducted based on the guidelines depicted in (Kitchenham, 2007) in order to determine the current state of the art of BPMN extensions and identify their gaps. The extraction and filtering of papers resulted in a set of 49 BPMN extensions that were thoroughly examined and compared. Given that there already exists a literature review on BPMN extensions presented in (Braun & Esswein, 2014), our SLR has complemented it by considering all extensions published after the last extension treated in (Braun & Esswein, 2014). More precisely, we considered all BPMN extensions published between November 2014 and December 2018 in conference proceedings, journals, and chapters.

The BPMN extensions were evaluated and compared according to a set of criteria, including among others, the objective, targeted domain, representation formats, affected BPMN elements, conformity to the extension mechanism, demonstration, implementation, evaluation, etc. Furthermore, our SLR can serve as an inventory for BP designers by helping them in choosing the BPMN extension that best suits their needs and avoid developing a new extension. After the presentation, interpretation, and analysis of the obtained results, we can deduce essentially the following points:

- The targeted areas and objectives are very diversified.
- Despite a slight improvement in recent years, less than half of the extensions are conform to the BPMN extension mechanism.

- The XML Schema is often overlooked when representing BPMN extensions, yet it specifies an interchange format for BP models.
- The majority of BPMN extensions are graphically represented and demonstrated through concrete examples, which allows understanding their usefulness.
- BPMN extensions are rarely evaluated and little implemented despite the existence of several extensible modelling tools.

Based on these deductions, we suggest the following recommendations that may bridge the identified gaps and advance the field of BPMN extensions:

- Authors must strictly adhere to the BPMN extension mechanism so as to provide a valid extension and enable BP model exchangeability.
- In addition to the MOF meta-model and XML schema formats, a clear methodology should be provided to guide authors throughout the development of their extension from the specification of target domain requirements to the implementation.
- It is desirable to define standard metrics for the evaluation and comparison of the proposed BPMN extensions.
- Finally, authors should make more effort in the implementation of their extension by integrating it into at least one modelling tool in order to prove its feasibility.

For future work, we plan to strengthen this literature review by taking into account other evaluation criteria and by covering more literature such as extensions not written in English and those proposed in master and doctoral theses. We also envisage to conduct a literature review on existing DSMLs and the extension of other BP-related languages like BPEL and UML. Finally, another literature review on BPMN extensions should be performed in the coming years in order to see the evolution of BPMN extension features.

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