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Ten Years of Visualization of Business Process Models: A Systematic Literature Review

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Highlights

- First systematic review about visualization applied to business process modeling
- Few studies base their proposals on the BPMN ISO standard
- Few proposals for visualizing business process models provide interactive features
- Few studies propose and evaluate approaches to display infringement feedback

Ten Years of Visualization of Business Process Models: A Systematic Literature Review☆

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Abstract

Business process modeling is an essential task in business process management. Process models that are comprehensively understood by business stakeholders allow organizations to profit from this field. In this work, we report what is being investigated in the topic "visualization of business process models", since visualization is known as improving perception and comprehension of structures and patterns in datasets. We performed a systematic literature review through which we selected and analyzed 46 papers from two points of view. Firstly, we observed the similarities between the papers regarding their main scope. From this observation we classified the papers into six categories: "Augmentation of existing elements", "Creation of new elements", "Exploration of the 3D space", "Information visualization", "Visual feedback concerning problems detected in process models" and "Perspectives". The less explored categories and which could represent research challenges for further exploration are "Visual feedback" and "Information visualization". Secondly, we analyzed the papers based on a well-known visualization analysis framework, which allowed us to obtain a high-level point of view of the proposals presented in the literature and could identify that few authors explore user interaction features in their works. Besides that, we also found that exactly half of the papers base their proposals on BPMN and present results from evaluation or validation. Since BPMN is an ISO standard and there are many tools based on BPMN, there should be more research intending to improve the knowledge around this topic. We expect that our results inspire researchers for further work aiming at bringing forward the field of business process model visualization, to have the advantages of information visualization helping the tasks of business process modeling and management.

Keywords:
Business Process Management, Process Model, Visualization, Visualization Analysis, Systematic Literature Review

1. Introduction

Business Process Management (BPM) is a set of methods, techniques, and tools for discovering, analyzing, redesigning, executing and monitoring business processes and, because of its potential to increase productivity and reduce costs, has received considerable attention in recent years [1, 2]. One of the ways organizations can document their business operations and implement reproducible processes as well as continually improve them is through the use of BPM and specific languages for business process modeling. There are a variety of business process modeling languages, such as Business Process Model and Notation (BPMN) [3], Event-driven Process Chains (EPC) [4], Unified Modeling Language 2.0 Activity Diagrams (UML AD) [5], Yet Another Workflow Language (YAWL) [6], Petri Nets [7], DECLARE [8], among others.

Business processes play an important role in organizations [9]. Employees from different business and technical departments, not necessarily advanced modelers, are more often involved with process modeling tasks nowadays [10]. Such tasks are known as being challenging to manage [11], generally because of the modeling notation's complexity caused by its variety of elements and semantics [3]. Beyond that, a business process model supports the understanding of an organization's business processes [12]. The choice of a process model design to represent the real world appropriately relies on the modeler expertise or the advice of an experienced modeler. Therefore, the understandability of process models is of growing importance for both stakeholders and process participants [10].

The business process modeling task aims at supporting the definition and representation of business processes through the construction of a set of activities capable of representing the real world functional behavior of these processes, taking into consideration all the elements of the organization that are involved in the process (e.g., departments, resources). Through a process model, an organization can achieve the reduction of communication inconsistencies [10].

When correctly implemented, process models can generate significant savings for the industry [13]. On the other hand, modeling problems can cause process execution errors in a production environment, creating extra costs for the organization [14]. According to Goldberg Júnior et al. [15], modelers with less involvement with the process modeling task frequently commit at least one mistake regarding understandability of the process model.

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Information visualization comprises a set of techniques developed for representing data through visual components and attributes, aiming at supporting users in comprehending such data and performing their tasks [16, 17]. Tufte [18] says a visualization should not be judged by the amount of information it displays but how easy it is to understand the information it conveys. Since the process participants and stakeholders do not necessarily hold expertise in process modeling, and business processes are often very complex, it is a challenge to find a user-friendly and easy to understand layout of the process (i.e., the different manners the various elements of a model may be distributed in the canvas) [19].

Process models can be enriched visually in a variety of ways [20, 21, 22], for example, through "omission" of a subset of elements to target on a specific process model part, or through "graphical highlight" to visually emphasize specific aspects of process model elements. However, few works suggest new approaches to the graphical representation of process modeling issues [23]. Visualization techniques help people in situations where it is desired to confirm patterns that are assumed to exist in datasets [24]. Considering this scenario, an important topic to be investigated is the use of visualizations in business process modeling.

Our work aims at identifying what has been published regarding visualization of business process models in the last ten years (i.e., between January 2009 and December 2018) through a systematic literature review [25]. To the best of our knowledge, no systematic literature review nor systematic mapping has been done to investigate this research topic. Although we know that a broad systematic literature review could start with surveying papers on visualization of conceptual models because there is a need on that [26], we restrain our focus mainly, but not exclusively, on articles that based their proposals on BPMN, since this notation is an ISO standard[1], in its version 2.0, and an Object Management Group (OMG) specification [27].

The contribution of such a review is to present the state-of-the-art on the use of visualization techniques in business process modeling with emphasis in BPMN. We analyzed the selected studies from two perspectives: (i) the first point-of-view is based on the observation of the similarities between the selected papers regarding their main scope. We aim at answering what the studies are proposing regarding visualization of business process models; (ii) the analysis from the second point-of-view intended to categorize the papers according to a visualization analysis framework proposed by Munzner [24]. We targeted answering questions like why the users use the visualizations and how the information about the process models is encoded.

This paper is structured as follows. In Section 2, we present the necessary background for this paper, while Section 3 gives a brief overview of related works. Section 4 describes the methodology we adopted for the systematic literature review, and Section 5 proposes the classification of the studies into six categories according to the analysis of their main scope. In Section 6, we present the high-level visualization analysis of the studies, whereas Section 7 discusses the results of the analysis. Finally, conclusions, limitations, and recommendations for future research are set out in Section 8.

[1]ISO/IEC 19510:2013: http://www.omg.org/spec/BPMN/ISO/19510/PDF

2. Background

The necessary background to understand this paper is provided in the following subsections. Initially, we present the main definitions related to BPM and BPMN. Then, we describe the visualization analysis framework we adopted to analyze the visualization approaches found in the selected papers.

2.1. *Business process management*

The Business Process Management discipline is composed of a collection of methods and tools to handle the tasks of modeling, managing and analyzing business processes. A business process is a set of collaborative and dynamically related activities, events, persons, hardware, software, and decision points, with the main objective of delivering value to an organization's customer through a service or a product [28]. When a business process becomes too complex, it can be decomposed into smaller processes, called sub-processes, which consist of a subset of elements comprising the process. The most popular process modeling techniques support this concept of sub-process, including BPMN [29].

The business process modeling task is the process of drawing business processes in a graphical workflow view, aiming at representing the current organization's processes (also known as "as is" processes) to further analyze and improve, achieving new versions of the processes (also known as "to be" processes), which thereafter may be implemented and monitored [1].

Organizations can implement reproducible processes, manage and continually improve them following the BPM life-cycle proposed by Dumas et al. [1]. The BPM life-cycle consists of six phases, two of them being most directly related to the task of process modeling itself: process discovery, where the current state of each process is documented in the form of "as-is" business process models; and process redesign, where the "to-be" process models are generated, considering improvement points identified by the analyst.

2.2. *Business process model and notation*

The BPMN is often the notation used in the process modeling task. Initially published in 2004 by the Business Process Management Initiative (BPMI) and maintained by OMG since 2006, BPMN aims at providing an easy-to-understand notation to all business users (e.g., analysts and technical representatives). Approximately 73.22% of the Business Process Management Suites (BPMS) analyzed by [30, 31] enables the automation of business processes modeled with BPMN. BPMSs are tools that support the application of BPM in business environments allowing the automation of business processes and the management of the BPM life-cycle [30].

To represent a process, BPMN provides a variety of elements with different purposes [27]. The basic BPMN modeling elements are (see Figure 1, for a usage example):

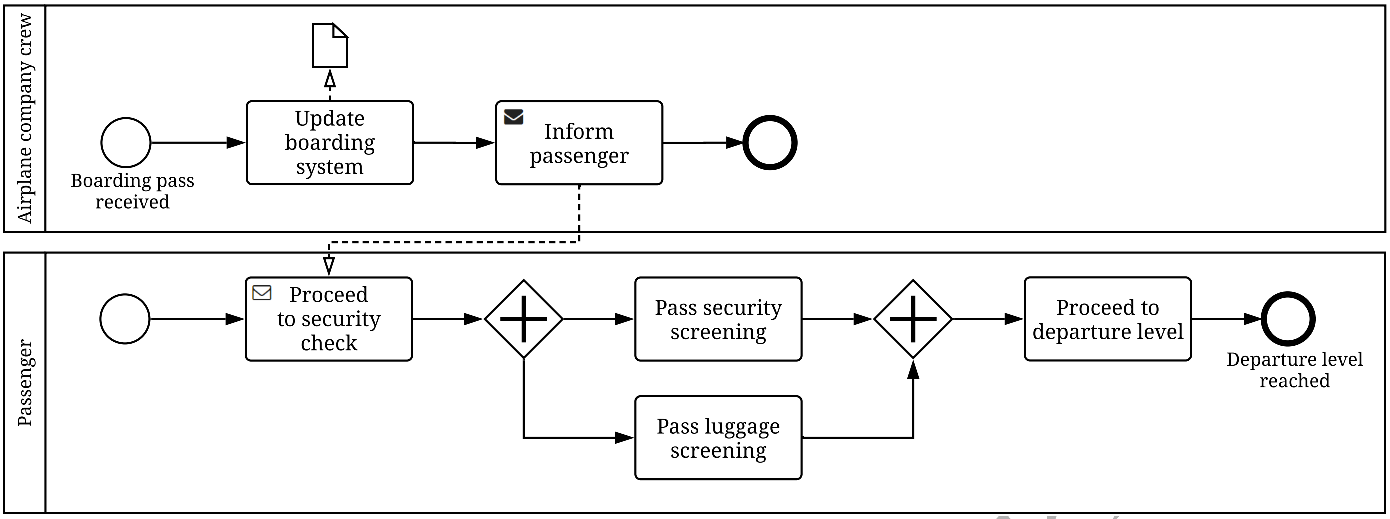

Figure 1: BPMN basic elements usage example, based on Dumas et al. [1]. In this example, the process starts when the boarding pass is received by the airplane company crew. The crew updates the boarding system and inform the passenger that proceeds to the security check, where s/he passes the security and luggage screening. Finally, the passenger advances to the departure level, whereas the process reaches its end.

- **Events:** which represent actions that require no duration to be performed. Events are basically of three types, based on when they affect the process flow: start, intermediate or end events;
- **Activities and sub-processes:** when seen as a single unit of work, an activity is called "task"; otherwise, it is called "activity". When a process is too complex (e.g., is composed by more than 50 elements [11]), subsets of its elements may be grouped up to comprise sub-processes within the main process;
- **Gateways:** that are used to split/join the performed actions flow within the process. Also called "decision points", the gateways may be of three types: AND, for concurrency; OR, for inclusive choices; and XOR, for exclusive choices;
- **Sequence and message flows:** where the first are used to link two elements and handle the order through which a process will be executed; and, the latter are used to display the flow of messages between two participants;
- **Data objects:** that display how data is required or produced by activities;
- **Pools and lanes:** pools group together elements of an organization while lanes divide a pool into different organization's resources (e.g., departments, participants).

2.3. *Visualization analysis framework*

Computer-based visualizations may be achieved through different forms and a variety of techniques and methods [24]. Such extensive visualization idiom space (i.e., diverse visualization possibilities to represent similar data) hampers the analysis task of visualization tools in terms of how visualization was created and how it implements interaction with users.

To support systematic thinking about the selected papers regarding the visualizations they propose or employ, we adopted the visualization analysis and design framework proposed by Munzner [24]. This framework helps researchers to structure the diversity of visualization tools according to abstract elements that can represent generically what each visualization is intending to deliver and, therefore, support researchers in comparing different visualization techniques according to their characteristics, by observing their differences and similarities. The framework guides the analysis of visualization through three questions: (i) **what** is the data that the user sees; (ii) **why** the user intends to use the visualization; and (iii) **how** the visualization is constructed in terms of design choices. Each question tuple what-why-how has a corresponding data-task-idiom answer tuple [24], and the choices in each of these questions are independent of each other.

To summarize, the framework supports researchers in analyzing visualizations from an abstract point-of-view instead of a domain-specific one, which eases the comparison of different visualizations. According to Munzner [24], when visualizations are analyzed and compared from a domain-specific point-of-view, they appear to be different, which is misleading from a visualization analysis perspective, since there are similarities among different visualizations when they are considered as abstract elements. She also says "the visualization analyst might decide to use additional terms to completely and precisely describe the user's goals". So, the framework is composed of, but not limited to, a small set of words to describe the goals of people using a visualization tool and how the idiom of this visualization tool supports people's goals.

In the following subsections, we describe the terms associated with each aspect of the framework to allow a better understanding of the results presented in this paper. The structure of the framework is presented in Figure 2.

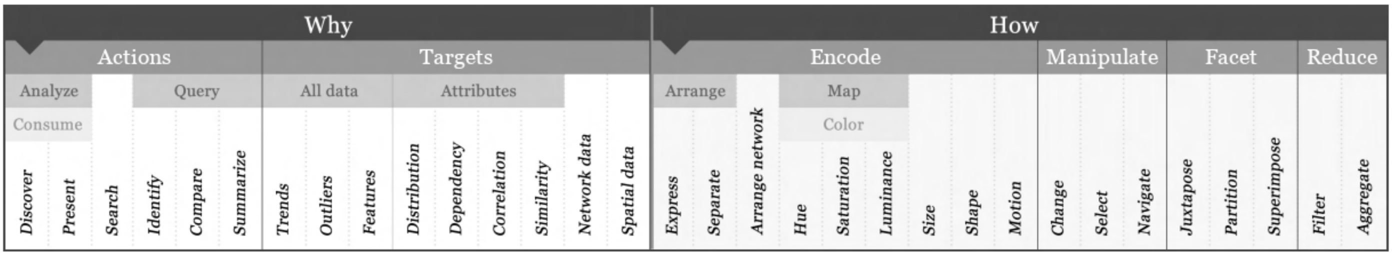

Figure 2: "Why" and "How" aspects of the visualization analysis framework proposed by Munzner [24].

2.3.1. What

The answer to "What is the data that user sees?" can be one or more datasets from four possible types: *fields, tables, geometry*, and *networks*. In this paper, the main dataset type used throughout the selected studies is networks, or graphs, which are used to represent relationships (links) between items (nodes) [24]. In BPMN, for example, a node may represent an activity, and a link, a control flow.

2.3.2. Why

To describe "Why the user intends to use the visualization?" one uses *actions* and *targets*. Actions represent possible user goals when using a visualization tool and can be of three types: analyze, search, and query. Each type of action represents different cases that are described as follows.

Firstly, "analyze" may be of two different types: consume or produce information. The consume type is the most common use case and corresponds to the consumption of information already generated. It is divided into three cases: *present*, when the visualization is used to communicate anything already understood by the viewer; *discover*, when the user wants to acquire new knowledge; and, *enjoy*, when the user is driven mostly by curiosity and not by a previous need to use the visualization. The produce type refers to visualizations that enable the user to generate new information. It can be divided into two cases: *annotate*, when the user is allowed to add graphical or textual annotations to visualization elements that already are present in the visualization; and, *record*, when the visualization provides a manner to persist elements of the visualization as screenshots, interaction logs or annotations made by the user [24].

Secondly, "search" can be of four different types, according to whether the user previously knows (or not) about the target location and identity. These types are: *look up*, when a user knows both location and identity of what he is looking for; *locate*, when a user knows the identity of what he is looking for but does not know its location; *browse*, when a user knows the location of what he is looking for but does not know its identity. For example, when looking for a range of possible items, the user may know where this type of item is but does not know exactly which is the item he is looking for; and, *explore*, when the user does not know the location nor the identity of what he is looking for [24]. It is important to highlight that a visualization may comprise any combination of search types at the same time. For example, the user may see a BPMN model and look up for a specific activity and, at the same time, the user may see the same model and browse for an event.

Finally, "query" can be of three different types: *identify*, when the user identifies a single target among others, the visualization tool returns the target's characteristics; *compare*, differently from identify, refers to multiple targets and allows the user to compare characteristics of these targets; and, *summarize*, that refers to all possible targets within the dataset, and the user obtains an overview of the dataset [24].

Regarding targets, i.e., the thing that the user presents, looks up or identify, there are four kinds of abstract targets: (i) all data, which refer to what user may retrieve from the dataset as a whole. When targeting all data, the user may find trends, outliers, and features. A *trend* is a behavior that exposes, for example, increases and peaks in a dataset. *Outliers* are data that overstep or stand out in any manner from the rest of the dataset. *Features* are any particular structure of interest in a visualization; (ii) attributes, which are specific properties encoded visually wherein the user may show interest for an individual value (finding *extremes* or *distribution* of values for an attribute) or for multiple attributes (finding *dependencies*, *correlations* and *similarities* between the attributes); (iii) network data, through which the user may find relationships between nodes and links, understand the *network topology* and the existing *paths* between the network's nodes; and, (iv) spatial data, which refers to the visualization of geometric *shapes* and its understanding and comparison [24].

An important statement from Munzner concerning this framework is that "why a visualization is used doesn't dictate how it is designed".

2.3.3. How

"How the visualization is constructed in terms of design choices?" can be answered using a set of options that represent visual forms and/or interaction features. The options are: encode, manipulate, facet and reduce. Encoding data within a view can be achieved through different choices for arranging and mapping data. When arranging data, the view may *express* data position distribution over an axis, and *separate* data into regions which have, in its turn, positions distributed along the spatial plane. When mapping data, the visualization designer has different choices such as color, size, shape, and motion. The color space is defined by *hue* (pure color without white and black), *saturation* (amount of white mixed with the pure color) and *lightness* (amount of black mixed with a color).

Size may be seen from three perspectives: length, which is a one-dimensional size that may be both in width or in height of any given element; area, which is a two-dimensional size; and, volume, a three-dimensional size. *Shape* may be represented by any drawable form using points and lines. *Motion* is represented by the movement of any visual element from one spatial position to another [24].

Manipulating a view may be performed in three different ways: change, select, and navigate. *Change* refers to any action that makes the way the dataset is being visualized to shift to another way (e.g., switching from a list view to a chart view; or merely switching between different chart views). *Select* refers to the possibility of the user to point out elements of interest. *Navigate* enables the user to, for example, move a large business process model to different directions within the viewport and, thus, visualize a complex dataset that may not fit into the limited screen [24].

Faceting (or splitting) data over multiple views offers three choices: juxtapose, partition, and superimpose. *Juxtapose* multiple views is when the same data is shown across multiple views, in a coordinated manner, and under different perspectives. *Partition* is when each view, for example, disposed side by side, is composed of a dataset, and represents different data. *Superimpose* is when different views of data are disposed over each other as different layers [24].

Reducing data comprises three design choices: filter, aggregate, and embed. *Filter* refers to the removal of visual elements from the vis. *Aggregate* refers to group elements that together represent a unique element. *Embed* refers to presenting a selected subset of the data within the same view, where the whole data is presented [24]. For example, enabling a user to select a BPMN collapsed sub-process to display to the user as a tooltip with the sub-process expanded.

3. Related Works

Although our work is the first systematic literature review on the use of visualization in business process modeling, we found some works that identified mechanisms and visual representations used either for reducing the perceived complexity of business process models or serving as components of visual embellishment of such models.

La Rosa et al. [20, 21] explore mechanisms to reduce the perceived complexity of process models through visual representations of the model. In their work, they identify and present sets of patterns that generalize existing mechanisms with the aim of simplifying the representation of process models. These patterns were gathered from a review of the BPM literature and existing or proposed standards by OMG and W3C, for example, followed by a survey of the identified patterns by BPM experts. For each identified pattern the authors found more than five languages, research approaches or tools which use them. Some examples of the patterns collected are: "enclosure highlight", which aims to visually enhance a set of model elements based on properties shared among the elements; "pictorial annotation", aiming at adding, for example, domain-specific information to the model (e.g., indicate criticality through annotating a task with an exclamation mark); "naming guidance", in order to transmit domain-specific information through nomenclature conventions; "merging", with the purpose of consolidating a family of variants of process models into a single reference model, without redundancies; and, "extension", aiming at making a model more straightforward to understand for a specific audience by extending a modeling language to adapt it to a given application domain.

Another related work is by Aysolmaz and Reijers [32], where eight possible components of visual embellishment of process models are identified. According to the authors, these components are still to be developed and exploited to reinvigorate process models visually. Examples of such components are: "usage of narration and on-screen text", to integrate narration and on-screen text using animation and visualization techniques, and "embedding process perspectives", to integrate different perspectives to a process model also with the use of animation and visualization techniques.

The main differences between these works and ours are that they are not based on a systematic review of the literature and have a different focus. In the case of the works by Rosa et al. [20, 21], the focus is on presenting an assessment of existing languages and tools regarding the identified patterns. For example, they show that for "pictorial annotation", tools like JDeveloper and Protos automatically assign icons and images to elements of process models, but do not allow customization. As for the work by Aysolmaz and Reijers [32], the proposed categorization is about components to be explored, and not about what is being investigated concerning the visualization of process models. Moreover, the proposal of these possible components for process model embellishment is not backed up by works from others.

4. Methodology

A systematic literature review aims at summarizing the topic being studied and identifying the existence of gaps in current research to position new research activities. We conducted our systematic literature review following Kitchenham and Charters [25] to summarize the research on visualization applied to business process modeling aiming at identifying, selecting, evaluating and interpreting the works we considered relevant in this topic. The gaps identified and the report of the analysis of our results are discussed in Section 7.

Before starting our systematic literature review, we conducted a preliminary research which provided us with a variety of papers exploring visualization of business process models. After that, we decided to investigate what is being studied and developed in the topic "visualization of business process models" from a wider point of view. Based on this prior research we directed our work.

A systematic literature review is a process composed of a sequence of phases: planning, where the review protocol is defined; execution, where the selection of studies and data extraction are performed; and publishing, where the results of the analysis phase are reported.

Although it is not possible to avoid publication bias, the definition of a review protocol, before the collection of the candidate papers, allows reducing the probability of generating a biased result [25]. The review protocol is composed by the research questions, the definition of the studies selection process, the search string and search sources, the exclusion and inclusion criteria and, finally, how data will be extracted and synthesized. We present details of our review protocol in the following subsections.

4.1. Research questions

The research question (RQ) is the most important element and drive the entire systematic review. Based on the RQ, the other components of the review protocol are generated, i.e., the search string, inclusion and exclusion criteria, and data extraction strategy, so the RQ may be properly answered [25].

Since the main goal of our systematic review is to identify what has been published about visualization of business process models, that goal defined our primary RQ to guide the entire research process. Thus, our RQ1 has been set as follows:

- **RQ1 (primary)**: What is being investigated in the topic visualization of business process models?

To help to obtain data and to summarize different aspects of the topic being studied as well as to identify gaps in current research, we defined four secondary RQs. Those RQs allow identifying what is being investigated specifically, which aspect is missing in the current set of publications, the frequency with which the topic has been addressed in publications, and who are the main authors publishing about the subject. The secondary RQs also guided the setting of some of the exclusion and inclusion criteria as we will see in the next sections.

- **RQ2**: Are the studies concerned with improving the understandability of process models?
- **RQ3**: Are there open problems for further research on this topic?
- **RQ4**: How active is the research on this topic since 2009?
- **RQ5**: Who is leading research on this topic?

4.2. Overview of the studies selection process

The studies selection process is the most important stage in the execution of a systematic literature review [25] and was carried out in a set of phases. Each phase and the respective amount of selected papers can be observed in Figure 3.

Initially, we applied the search strings to the search sources, without using any filters. Then, filters were used within the search engines, whenever possible, to restrain search results based on EC1 to EC4. After that, papers were imported to Zotero, EC1 to EC4 were manually reapplied, and the other ECs and the ICs were applied. The application of each step of the study selection process will be explained in more detail in Subsections 4.3, 4.4, and 4.5.

4.3. Search sources and search string

According to the York University Centre for Reviews and Dissemination (CDR) Database of Abstracts of Reviews of Effects (DARE) criteria[2], as cited by Kitchenham and Charters [25], a literature search is likely to cover all relevant studies when searching is performed in 4 or more digital libraries. Then, through the analysis of other systematic literature review's in the area of BPM [33, 34], and our preliminary research, we identified 5 relevant sources to be used in our literature review: ACM Digital Library[3], IEEE Xplore[4], SpringerLink[5], Science Direct[6], and Scopus[7]. We considered including Web of Science also, but it would return a subset of the papers retrieved within the chosen digital libraries.

After choosing the search sources, based on our previous results and on the RQs alongside discussions with BPM experts holding several years of academic and professional experience in the BPM discipline, we defined the search fields and search string as follows:

- **Search fields:** Title, abstract, and keywords;
- **Search string:** (bpmn OR "process model" OR "process modeling") AND (visualization OR understandability).

We justify our search string as follows. Initially, we wanted to focus our research only on studies based on BPMN, since BPMN is an ISO Standard broadly used in industry. However, the resulting set was too limited. Thus, based on our preliminary research and discussions with BPM experts, we adopted "bpmn OR" to be part of our search string. Moreover, we identified articles dealing with understandability of process models through visualization. Therefore, to have a more inclusive result space, we chose to use "visualization OR understandability". It is worthwhile to comment that we also considered the idea of using "comprehension" as a search term. However, since in a pre-analysis phase such a term retrieved fewer papers than "understandability", we opted for using the latter. Moreover, we were focusing specifically on the understandability influenced by visualization, and therefore, we discarded articles aiming exclusively at the understandability of process models.

Due to differences among each search engine, we adapted the search string to conform with the format and limitations of each digital library. For example, to apply the search string in ACM Digital Library, we used: acmdlTitle:(+(bpmn "process model" "process modeling") +(visualization understandability)) OR recordAbstract:(+(bpmn "process model" "process modeling") +(visualization understandability)) OR keywords.author.keyword:(+(bpmn "process model" "process modeling") +(visualization understandability))"; while in Scopus, we simply used: ((bpmn OR "process model" OR "process modeling") AND (visualization OR understandability)).

[2] http://www.york.ac.uk/inst/crd/crddatabase.htm#DARE
[3] http://dl.acm.org/
[4] http://ieeexplore.ieee.org/
[5] http://link.springer.com/
[6] http://www.sciencedirect.com/
[7] http://www.scopus.com/

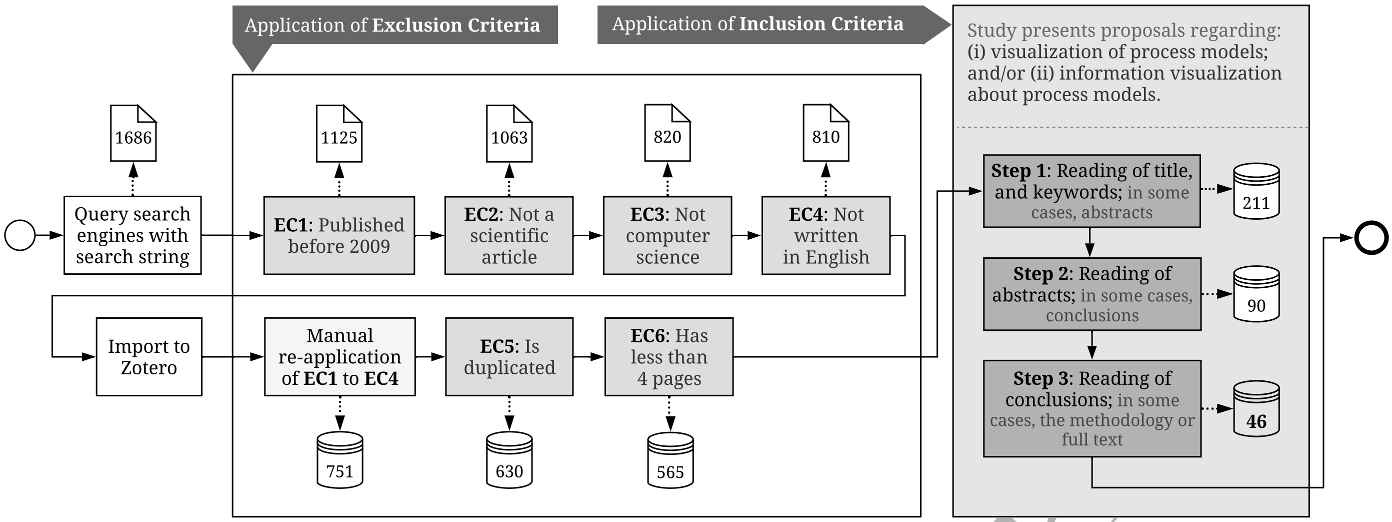

Figure 3: Studies selection process and the amount of articles obtained after each phase.

To confirm that the search string was returning the desired coverage of papers, we performed an iterative process using different versions of the search string within each search source, and the top relevant papers returned were compared to the results from the top relevant papers returned by the specified search string. The papers that fell outside the intersection between the results of the variant search strings and the specified search string were analyzed based on title, abstract, and keywords (and, in some cases, the conclusions and even other sections of the text). We observed that most of them were not relevant to our systematic literature review, which made us confident about the specified search string.

4.4. Exclusion criteria

The exclusion criteria (EC) were used to filter the papers obtained from the search sources based on their format and publication details. Thus, the following criteria were defined:

- **EC1**: published before 2009;
- **EC2**: not a scientific article;
- **EC3**: not computer science;
- **EC4**: not written in English;
- **EC5**: duplicated;
- **EC6**: having less than 4 pages.

The year of 2009 was chosen as the starting point of this literature review because the first beta version of the BPMN 2.0 was released in that year [35]. However, intending to minimize the probability of leaving significant contributions regarding visualization of process models behind, after the application of the whole selection process, we performed a final selection step over papers published before 2009, which we describe in Section 4.5. Criteria EC2, EC3, and EC4 were defined to restrain the initial set of papers to those that were within the desired scope of our survey, while EC6 guaranteed a certain measure of quality.

Criteria EC1 to EC4 were applied, where possible, directly through the search engines. The results were then imported into Zotero[8], through which EC5 and EC6 criteria were manually applied. After that, also manually, we reapplied criteria EC1 to EC4, in order to prevent any unwanted articles from being among the ones selected, and to remove the ones that could not be directly removed by the search engines. The total amount of papers obtained after applying the ECs is presented in Figure 3.

The studies resulting from the application of the ECs were imported into Mendeley[9] for reading and preparing for the subsequent application of the inclusion criteria and data extraction.

4.5. Inclusion criteria

The inclusion criteria (IC) were applied for selecting the papers that had their content related to the topic of this systematic literature review. They are as follows:

- **IC1**: The paper presents proposals regarding visualization of process models;
- **IC2**: The paper presents a proposal to visualize information about process models.

The method used to apply the ICs was performing the following steps, the result of a step being the entry for the next one:

- **IC Step 1** The set of articles resulting from the application of the ECs was analyzed regarding their titles and keywords and, in some cases, their abstracts;
- **IC Step 2** The abstracts of the selected articles were analyzed and, in some cases, also the conclusions; and

[8]http://www.zotero.org/
[9]http://www.mendeley.com/

- **IC Step 3** The conclusion of each article was analyzed and, in some cases, also the methodology section or, whenever necessary, the full text, to confirm the relationship between the article and the main scope of the systematic literature review.

After these steps, the paper was selected to be fully read if it fitted at least one of the ICs. The total amount of papers obtained in each step is presented in Figure 3. The whole selection process resulted in a set of 46 papers to go through the data extraction phase and compose the resulting set to be analyzed for producing the state-of-art report.

Nonetheless, we wanted to guarantee that no significant contribution to the visualization of process models was left behind due to having been published before 2009. Then, we performed a final selection step as follows. We applied our search string in the search engines to look for studies published before 2009. We compared the results of this search with the set of papers referenced by our 46 selected studies. The intersection of the two sets of papers resulted in 13 studies to which we applied our exclusion and inclusion criteria. As a result, only three papers emerged as possible candidates to be included in our systematic literature review [36, 37, 38], which were cited by 4, 6, and 6 papers of the 46-papers set, respectively. After analyzing these three papers, we were sure that they would not contribute significantly to the results of our state-of-the-art report, and thus we decided to maintain the 46 studies that resulted from the selection process (Fig.3) to be submitted to the data extraction process.

4.6. Data extraction

To extract data from our final set of articles and support answering the research questions, we developed a template based on Petersen et al. [39]. This template consists of a three-column table, where each line is a data extraction tuple (Data item, Value, RQ).

Table 1 presents the form used to extract data from each article. "Data item" is the data to be extracted; "Value" holds the result from the extraction, and "RQ" identifies the research question that motivated the need for extracting the respective "Data item". As can be seen in Table 1, apart from the articles' basic information, we recorded if the paper was based on BPMN, contained results from evaluation and/or validation, raised hypothesis, presented statistically significant results, aimed at improving understandability of process models, and dealt with collections of process models.

After reading each selected study, we built Table 2 as follows: whenever the article mentions a specific "Data item" with a binary "Value", for example, the article mentions the use of "BPMN", the corresponding cell received an "x" mark. Otherwise, it was left blank.

The same approach was used to fill the data extraction table related to the visualization analysis framework (Tables 4 and 5). The difference is that each column in these tables (i.e., "Data item") represents an element of Munzner's visualization analysis framework [24], and all columns together are used to answer the same research questions RQ1 and RQ3.

Table 1: Data extraction form. In this table, the field "Value" contains an explanation about the expected value, whenever it is necessary.

Data item Value	**RQ**
Identifier Integer	
Title Name of the article	
Author Set of names of the authors	RQ5
Publication year Calendar year	RQ4
Item type Binary Conference/Journal	RQ4
Main scope Text	RQ1 and RQ3
Category Name of the category assigned to the paper as presented in Section 4.6	RQ1 and RQ3
Based on BPMN Binary Yes/No	RQ1
Evaluation or validationn Binary Yes/No, the study performed evaluation or validation of its proposal	RQ1 and RQ3
Evaluation or validation with users Binary Yes/No	RQ1 and RQ3
Raises hypothesis Binary Yes/No	RQ1 and RQ3
Significant statistically Binary Yes/No	RQ1 and RQ3
Focuses on collections of process models Binary Yes/No	RQ1 and RQ3
Understandability Binary Yes/No, the study explicitly pursue improvement in the understandability of process model	RQ2

Moreover, we observed the frequency of keywords in the papers, to identify which were the most used ones among the selected papers. To perform this task, we extracted the keywords from the selected papers and manually removed the ones considered too generic (e.g., design, software, application) or that appeared only once. Then, we combined the ones that made sense to be combined (e.g., process models with process model, visualizations with visualization, and so on). The keywords "visualization" and "process model" are the most recurrent ones, appearing 39 and 33 times, respectively.

The choice of configuration of the reviewer team for the data extraction activity was based on Kitchenham [25], and we considered the following aspects: the number of available reviewers, the number of selected studies during the selection process and the time available to conclude the systematic literature review. Thus, we chose to use the configuration "one reviewer and one evaluator", which says that the reviewer is responsible for the data extraction from all studies, and the evaluator is responsible for the data extraction of a random sample

Table 2: Studies included in the review and the main data items extracted from them. A cell marked with "x" indicates that the paper includes information related to the corresponding data item. Totals and percentages for each column are presented; the dark bar represents the number of papers.

Article	BPMN	Evaluation or validation	Evaluation or validation with users	Raises hypothesis	Statistically significant	Focuses on collections of process models	Understandability
[15]	x					x	
[40]							x
[41]		x	x	x	x		x
[42]	x	x	x	x	x		x
[43]		x	x				x
[44]						x	x
[45]		x				x	
[46]		x	x		x	x	
[47]	x					x	
[48]							
[49]	x						x
[50]	x						x
[51]							x
[52]	x	x					x
[53]	x						x
[54]	x						x
[55]	x						
[56]	x	x	x				x
[57]	x	x	x				x
[58]	x	x	x		x		x
[59]							x
[60]	x						x
[61]	x	x	x	x			x
[62]	x	x					x
[63]	x	x					
[64]		x	x	x			
[65]							
[66]		x					
[67]		x					x
[68]							
[69]						x	
[70]			x		x		
[71]	x	x					x
[72]							
[73]			x		x		
[74]	x	x					
[75]		x	x			x	
[76]							
[77]	x						
[78]		x					
[79]	x	x	x	x	x		x
[80]	x	x	x				
[81]	x						
[82]		x	x	x			x
[83]		x					
[84]	x	x	x				x
Total	23	24	16	6	7	7	23
%	50.00	52.17	34.78	13.04	15.22	15.22	50.00

of the studies. Then, the data extracted by both are confronted with the purpose of identifying divergences. Whenever necessary, the reviewer may act as the evaluator.

5. Classification of Studies based on their Main Scope

We classified the 46 selected studies into six categories, after observing the similarities among the main scope of the proposals they present regarding the visual representation of process models. With this categorization, we aimed at answering "What" the studies are reporting regarding visualization of business process models. The main scope is one of the data items extracted from each article, as seen in Table 1. The distribution of the studies per category is presented in Table 3, and the following sections detail each one of the defined categories.

Table 3: Detailed distribution of articles per category over the 46 studies selected to be fully read.

Category	Articles	Total (%)
Augmentation of existing process modeling language elements	[40, 41, 42, 43, 48, 49, 50, 51, 52, 54, 56, 57, 58, 59, 61, 63, 64, 65, 66, 67, 68, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 83]	33 (71.74%)
Creation of new process modeling language elements	[53, 55, 58, 60]	4 (8.70%)
Exploration of the 3D space for process modeling	[58, 62, 76, 84]	4 (8.70%)
Information visualization about process models	[15, 43, 44, 45, 46, 47, 48, 66, 68, 69, 71, 74, 75, 77, 81]	15 (32.61%)
Visual feedback concerning problems detected in process models	[49, 50, 51, 52]	4 (8.70%)
Support for different perspectives of a process model	[43, 44, 46, 48, 57, 62, 63, 66, 67, 71, 74, 75, 76, 82]	14 (30.43%)

5.1. Augmentation of existing process modeling language elements

This category includes 71.74% of the selected studies. They propose various ways to improve elements of a process modeling language, by augmenting their semantics. Many studies explore highlighting of elements through the use of different colors or transparency of certain cohorts of the process model to enable users to comprehend the model. Some authors [64, 65, 72, 81, 83] propose the coloring of modeling language elements and its control flows to highlight changes and facilitate the identification of differences and similarities in business process models, while other ones [40, 41] highlight matching operators (i.e., split ANDs with their respective join ANDs). Emens et al. [43] and Jošt et al. [79] propose making transparent the portions of a process model that are not reachable from the activity being executed. Another interesting study framed in this category is the work by Kriglstein et al. [68]: among other propositions, they increase the thickness of the control flow lines to improve the perception of the process model's paths that are being most executed.

Other studies [54, 56, 78, 61, 80] explore the use of different elements such as icons, text or images to improve the way a process model element represents its information or to represent domain-specific aspects. For example, Figure 4 shows the use of a key locker icon to represent that an activity demands some level of permission to be executed in the security domain [56]. Salnitri et al. [61] also attach icons to existing process model's elements to represent security aspects. Mueller-Wickop et al. [54] attach textual information to represent financial auditing aspects, while Kathleen et al. [78] use images attached to activities of a process model, aiming at improving its expressiveness by picturing what each activity's task is.

Figure 4: Example of annotation on modeling language elements, based on the proposal of Leitner et al. [56]: the augmentation of the process model element is made through the superposition of an icon (indicated by the dotted circle) to an activity and, in this case, represents that the augmented activity involves some kind of access permission.

5.2. Creation of new process modeling language elements

This category aggregates 8.70% of the selected papers, which propose different approaches to extend a process modeling language by means of adding new types of elements, with different behavior than the ones already existing in the current languages to which the new elements are being proposed. For example, Joschko et al. [55] propose a wind farm signal event that sends specific malfunctioning signals, and a gateway capable of influencing the path through which a process model would execute, according to weather information received from a proprietary weather information provider.

More recently, Merino et al. [60] propose an element that is capable of measuring characteristics of a product whenever it is necessary within a process model workflow (Figure 5). They also propose another element capable of detecting if quality aspects about that product and its measurements are being met in any other desired process model's workflow point.

5.3. Exploration of the 3D space for process modeling

Usually business process models are two-dimensional (2D) representations, so modeling tasks take place in a 2D plane. However, a small number of studies (4 out of 46 papers) propose the use of a higher dimensional space to draw the process

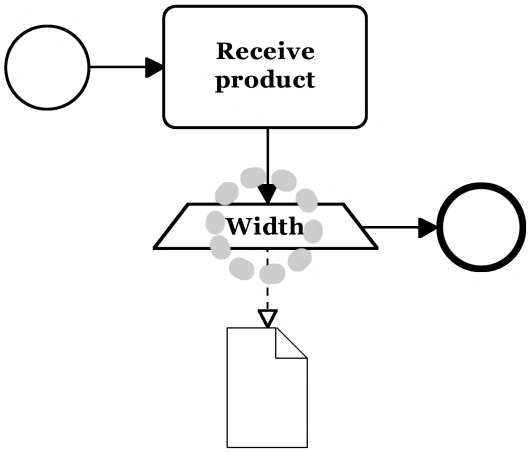

Figure 5: Example of new process modeling language element, based on the proposal of Merino et al. [60]: the new process modeling language element (indicated by the dotted circle) measures the width of a received product and stores this information within an object data.

model (Figure 6). Hipp et al. [58] introduced the BPMN3D visualization concept, where the object data is represented on a plane in 3D, while the rest of the process model diagram is drawn on the 2D plane. To enhance the communication among stakeholders and business analysts, Guo et al. [76] proposed a 3D simulation representing the behavior of what a process model's activity task should be (e.g., a process model's activity task named "Receive product" would be represented by a 3D simulation where a product is being received).

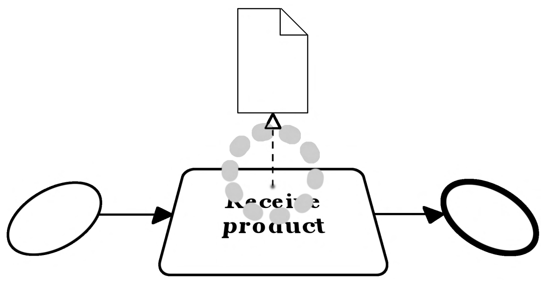

Figure 6: Example of a process model represented in 3D space [58]: the object data is drawn in the third dimension (highlighted by the dotted circle) while the rest of the process model diagram is laid out on the 2D plane.

In Effinger and Spielmann [62] proposal, the process model lanes (generally representing users' roles within an organization) are represented in different layers spread one above the other across the 3D space. Each layer holds the process model lanes' elements which it represents, in a 2D plane. The control flow across the process models' elements is represented in 3D, just as each lane. In this approach, when the process model is seeing from above, it seems as it was modeled in a 2D plane. But when the process model is seen from another point of view in the 3D space, it is depicted from a resources' perspective, where it is possible to see the activities and events belonging to each process model lanes separately.

A very recent work by Oberhauser et al. [84] proposed a solution for representing BPMN models in virtual reality, including navigation, interaction and annotation features. The authors report findings from an empirical study for evaluating effectiveness, efficiency, and intuitiveness of the 3D representation compared to other model representations.

5.4. Information visualization about process models

This category corresponds to 32.61% of the selected papers, and is composed by studies proposing different approaches to represent information about a process model or a collection of process models. For example, Figure 7 shows how Kriglstein and Rinderle-Ma [69] use a horizontal stacked bar chart to display, at the same time, the total number of operations on a process model (e.g., adding or removing a process model activity) for each process model's version, and the number of users that performed these operations. The central, reference line facilitates comparison of variables among versions.

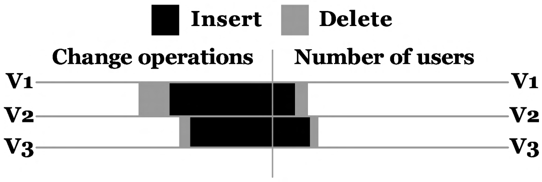

Figure 7: Example of information visualization technique ([69]): a horizontal stacked bar chart, where each bar represents a process model's version, with the left side showing the number of insertions and deletions of elements for building that version, while the right side presents the number of users that performed the change operations.

Pini et al. [75] propose different approaches to present information about a process model execution log. All their approaches suggest the use of graphics right above (or below) the activities in the process model, so data about the execution of each activity can be seen right within the process model itself. One of the proposals still explores the use of a horizontal stacked bar. But, differently from Kriglstein and Rinderle-Ma [69], they use only one horizontal stacked bar per activity, which is divided into three parts, each one representing a shift of the day (i.e., morning, afternoon, night). The size of the parts may vary according to the whole amount of time that the activity took to execute in each shift of the day.

5.5. Visual feedback concerning problems detected in process models

Although feedback about problems in process models are important during modeling tasks, only 8.70% of the selected studies propose some kind of graphical representation for improving the perception of issues. We found studies employing different approaches to present feedback to the modeler about any type of problem within a given process model or a collection of process models. Figure 8 shows a proposal by Laue and Awad [50], in which they attach a graphic symbol, a white "x" surrounded by a red circle (indicated by the dotted circle in the figure), to the process model's element that generated the process modeling problem. Besides that, a textual description about the problem is triggered by a mouse over action.

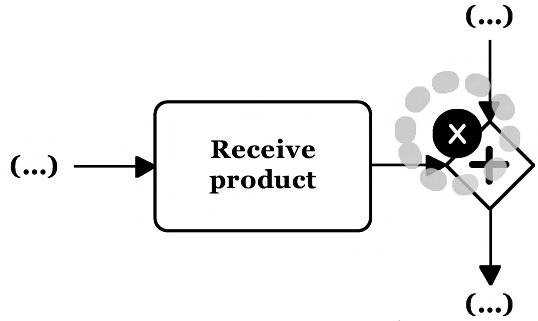

Figure 8: Example of visual feedback [50]: the visual feedback is marked through a white "x" surrounded by a black circle (indicated by the dotted circle) attached to the element that caused the process modeling problem which, in this case, could be the use of the wrong join gateway.

The process model's elements that are part of the detected process modeling problems are highlighted in red in other proposals [49, 52]. Moreover, Corradini et al. [52] present a list of guidelines infringed in a process model and allows the user to select each of them separately to see the process model's cohort that is related to the guideline's infringement highlighted in red.

5.6. Support for different perspectives of a process model

Studies proposing different approaches to distinguish parts of a process model to different type of users and/or situations compose this category. Reichert [71] proposes different visualizations of process models depending on users' roles. He aggregates process model's elements to give an overview of the process model diagram to managers, and provides filters based on user role to allow a specific business process participant to view only elements corresponding to his/her process model's activities.

In another study [43], a control flow perspective is presented by making less opaque the process model's activities not reachable from the one currently being executed. Other two studies [74, 75] propose a time perspective, so the user is provided with visual features to observe the processing time of each process model's activities.

6. Visualization Analysis

To analyze the studies from an information visualization point of view, we adopted Munzner's visualization analysis framework [24] (refer to section 2.3). We decided to base our visualization analysis on Munzner‘s framework once it is well-accepted in the visualization community due to it provides for a high-level abstract view of the visualizations while covering all aspects that might be involved.

To answer the questions "Why the users use the visualization" and "How the visualizations are encoded", we extracted from the studies the data presented in Tables 4 and 5. The data items extracted correspond to *actions* and *targets* for the "Why?" aspect, and *design choices* for the "How?". As for the aspect "What?" of the framework, the majority of the studies has graphs representing the process models as their main dataset (i.e., network data according to the framework). Therefore, for space-saving purposes, we did not add this information to the visualization-related data table. Moreover, we extracted information to know which studies allow user interaction in their proposals, resulting in 65.12% of the papers [15, 40, 41, 43, 44, 45, 46, 47, 48, 50, 51, 52, 53, 57, 62, 66, 67, 68, 71, 74, 75, 77, 79, 80, 81, 82, 83, 84].

After extracting the data for this analysis, we wanted to group the studies to get a general and abstract view of their proposals. To avoid missing any possible existing grouping or relation among studies, we decided to use the *k*-means method for clustering them based on the extracted data. Using RapidMiner Studio[10], 8.2 version, which is a data science platform that provides an integrated environment to data analysis and visualization, we experimented *k*-means with different parameters: $k = [2, .., 7]$, max runs = [10, 300, 3000] and maximum optimization steps = [10, 100, 1000, 10000]. The analysis of the outcomes showed that the most meaningful results were obtained using $k = 6$, max runs = 300 and maximum optimization steps = 1000. Some data extraction elements that were present in only one study, such as *Annotate*, *Record* and *Order*, were suppressed from the data extraction table, so they would not generate bias within clusters.

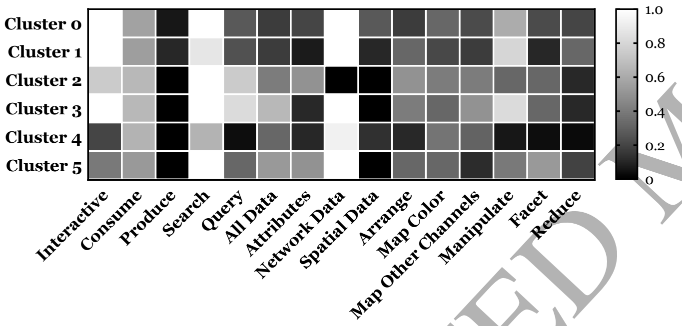

Figure 9: Representation of the incidence of the data items per cluster of papers. For simplification of the heatmap, data items were grouped according to the framework. Values close to 1 represent high incidence of the respective data item in the cluster, while the ones close to 0 represent low incidence.

Figure 10: Representation of the incidence of the most representative data items characterizing *Why?* and *How?* per cluster for visualization analysis purposes. Values close to 1 represent high incidence of the respective data item in the cluster, while the ones close to 0 represent low incidence.

[10]https://www.rapidminer.com/

The distribution of studies in each cluster generated by the application of the *k*-means technique is presented in Table 6, and two heatmaps of visualization-related data items per cluster are shown in Figures 9 and 10. Figure 10 was derived from the heatmap generated from RapidMiner. Figure 9 was built based on the incidence of the frameworks' elements in each cluster, but instead of representing the low level aspects of the framework, we grouped the elements as the framework does. We refer to "Consume" instead of "Present/Discover", "Produce" instead of "Annotate/Record", and so on (refer to Sections 2.3.2 and 2.3.3).

Although we had 46 selected studies, only 43 of them passed through the visualization analysis process, since 3 articles [56, 59, 70] were mainly results from other systematic literature reviews. The difference between those reviews and ours is the scope. Our work provides an overview of how information visualization techniques have been used in business process models, while theirs focused on a specific category we have already identified as the main scope of some papers: augmentation of existing process modeling language elements. Figl et al. [70] investigate different visualization strategies for the arrangement of nodes and links in the process model diagram, while Leitner et al. [56] address the use of symbols attached to process model elements (in the security domain), and Koschmider et al. [59] review the literature to provide an overview of the design of labels for process model element.

In the following subsections, we discuss the clustering results and describe the main characteristics of each cluster as well as the studies they grouped.

6.1. Cluster 0: characterized by "manipulate" and "query" tasks

Approaches proposed in the studies composing this cluster do not target "all data", which means that they do not intend to support users in discovering *trends*, *outliers* or *features* within the whole dataset. As cluster 5, it is in the third position of clusters composed of papers that mostly explore "query" tasks. Articles in this cluster also place it among the three clusters to explore "manipulate" tasks the most (Figure 9). However, when the analysis goes to the level of the framework elements themselves, i.e., which elements are targets of the tasks, which interaction techniques are used and how feedback is provided, we notice finding *dependency* between attributes, *identify* elements with some characteristics, *navigate* in the diagram, *aggregate* elements, and use *motion* as visual representation of some feature in the diagram (Figure 10).

To exemplify, Peralta et al. [74] propose an approach which assigns, to each BPMN element, information such as time or resources needed by the element. Such information is represented through *shape* transformation of each activity according to each information desired to communicate (e.g., processing time may be represented by transforming the width from thinner to wider, as the time needed by the activity to be executed increases). This proposal allows the user to gain insights from the process, *identify outliers* and *features*.

Other studies [43, 79] use similar ways to represent different information. They use transparency through *luminance* and

Table 4: Data extracted regarding aspects "Why?" for the visualization-related analysis based on Munzner's framework [24]: each mark indicates that the paper, referenced in the line, describes visual representations and/or interactive features that can be mapped to the framework's concept in the corresponding column. Totals and percentages for each column are presented; the dark bar represents the number of papers with the corresponding feature.

	Why															
	Actions						**Targets**									
	Analyse			**Query**			**All Data**			**Attributes**						
	Consume															
Article	**Discover**	**Present**	**Search**	**Identify**	**Compare**	**Summarize**	**Trends**	**Outliers**	**Features**	**Distribution**	**Dependency**	**Correlation**	**Similarity**	**Network data**	**Spatial data**
[15]	x	x	x	x	x	x		x		x			x		
[40]	x	x							x			x		x	
[41]	x	x							x			x		x	
[42]		x							x					x	
[43]		x	x	x					x		x			x	
[44]	x	x	x			x			x					x	
[45]	x	x	x		x	x	x	x		x		x			
[46]	x	x	x	x	x	x		x	x		x			x	
[47]	x	x	x		x	x		x		x		x			
[48]	x	x	x	x	x	x	x		x					x	
[49]	x	x	x						x					x	
[50]	x	x	x	x					x					x	
[51]	x	x	x	x					x		x			x	
[52]	x	x	x			x			x			x		x	
[53]									x					x	
[54]	x	x	x						x					x	
[55]		x							x						
[57]	x	x	x	x								x		x	
[58]	x	x	x						x					x	x
[60]	x	x	x						x					x	
[61]	x	x	x						x					x	
[62]	x	x	x											x	x
[63]		x	x						x					x	
[64]	x	x	x		x				x			x	x	x	
[65]	x	x	x						x			x	x	x	
[66]	x	x	x	x	x			x	x			x	x	x	
[67]	x	x	x			x								x	
[68]		x	x		x		x	x	x			x	x	x	
[69]	x	x	x		x	x	x			x		x			
[71]	x	x	x	x					x					x	
[72]		x	x		x				x			x	x	x	
[73]		x			x				x			x	x	x	
[74]	x	x	x	x				x	x		x			x	x
[75]	x	x	x	x	x	x	x	x	x			x		x	
[76]	x	x	x						x			x		x	x
[77]	x	x	x	x					x					x	
[78]	x	x	x						x			x		x	
[79]	x	x	x	x					x		x			x	
[80]	x	x	x	x					x					x	
[81]	x	x	x						x		x			x	
[82]		x	x		x							x		x	
[83]	x	x	x	x					x					x	
[84]		x	x	x					x		x			x	x
Total	33	42	37	16	13	10	5	8	35	4	7	17	7	38	5
%	76.74	97.67	86.05	37.21	30.23	23.26	11.63	18.60	81.40	9.30	16.28	39.53	16.28	88.37	11.63

Table 5: Data extracted regarding aspects "How?" for the visualization-related analysis based on Munzner's framework [24]: each mark indicates that the paper, referenced in the line, describes visual representations and/or interactive features that can be mapped to the framework's concept in the corresponding column. Totals and percentages for each column are presented; the dark bar represents the number of papers with the corresponding feature.

	How																
	Encode									**Manipulate**			**Facet**			**Reduce**	
	Arrange			**Map**													
				Color													
Article	**Express**	**Separate**	**Arrange network**	**Hue**	**Saturation**	**Luminance**	**Size**	**Shape**	**Motion**	**Change**	**Select**	**Navigate**	**Juxtapose**	**Partition**	**Superimpose**	**Filter**	**Aggregate**
[15]	x	x		x		x	x	x		x	x		x				
[40]				x						x							
[41]				x						x							
[42]				x													
[43]				x		x			x	x		x	x			x	
[44]			x					x		x		x				x	
[45]				x				x		x				x	x	x	
[46]	x	x		x				x		x	x	x	x			x	
[47]	x	x		x				x		x				x			
[48]	x	x		x				x		x	x	x	x				
[49]				x													
[50]			x	x				x							x		
[51]			x	x	x									x		x	
[52]			x	x						x		x					
[53]			x					x		x	x	x	x				
[54]			x	x													x
[55]								x									
[57]			x	x						x	x	x	x				
[58]			x	x			x	x									
[60]			x					x									
[61]				x				x									
[62]			x					x		x		x					
[63]								x									
[64]			x	x											x		
[65]			x	x						x	x			x	x		
[66]			x	x				x		x	x	x	x		x	x	
[67]			x	x							x	x		x		x	x
[68]			x	x			x			x				x	x		x
[69]	x	x		x				x									
[71]			x	x				x		x	x	x				x	x
[72]			x	x											x		
[73]				x	x			x									
[74]				x				x		x	x		x				
[75]	x			x			x	x			x						
[76]				x	x	x	x	x	x			x			x		
[77]			x						x		x	x	x				x
[78]			x	x	x	x	x	x									
[79]	x				x						x	x					
[80]			x	x				x		x	x	x					
[81]								x	x	x	x		x				
[82]			x	x						x	x					x	
[83]				x			x	x		x	x	x	x		x		
[84]			x	x						x	x	x					
Total	7	5	22	34	5	4	7	25	4	23	18	17	11	6	9	9	5
%	16.28	11.63	51.16	79.07	11.63	9.30	16.28	58.14	9.30	53.49	41.86	39.53	25.58	13.95	20.93	20.93	11.63

Table 6: Detailed distribution of the 43 studies per cluster after being processed using the visualization analysis framework [24]. The clustering was based on data presented in Tables 4 and 5.

Cluster	Articles	Total (%)
Cluster 0	[43, 51, 74, 77, 79, 81, 84]	7 (16.28%)
Cluster 1	[44, 52, 53, 57, 62, 67, 71, 80, 82]	9 (20.93%)
Cluster 2	[15, 45, 47, 69]	4 (9.30%)
Cluster 3	[46, 48, 75, 83]	4 (9.30%)
Cluster 4	[40, 41, 42, 49, 50, 54, 55, 58, 60, 61, 63, 73, 76, 78]	14 (32.56%)
Cluster 5	[64, 65, 66, 68, 72]	5 (11.63%)

saturation, respectively, to represent process models' paths that are not reachable from the current *selected* activity (in the case of the latter study) or the current one being executed (in case of the former study). Both proposals allows *navigating* the process model diagram and *identifying dependencies* of the current activity, which is also present in [84]. While the research by Jost et al. [79] indicates that their approach seems to increase the cognitive effectiveness of business process models, the prototype implemented by Emens et al. [43] was evaluated by users participating in the process, and the authors concluded that their proposal had preference over static visualizations. The main difference between both studies is that Emens et al. [43] use highlighting of parts of a process, either by blocks referring to a certain activity in focus (being currently executed) or by the role of the user (process participant) who is visualizing the process. Moreover, their study explores *motion* of the token indicating the current activity being executed.

Holzmuller-Laue et al. [77] present an interface called BPESi, composed of 3 visualization areas. The first visualization area is used for displaying the process model itself. The second employs *motion* to animate the process model execution token, which is similarly present in [81]. The third is used to show information regarding the activity being currently executed. This study is similar to the one by Emens et al. [43] regarding displaying the process model's execution token animation and allowing users to *identify features* of the current activity.

Finally, the proposal by Witt et al. [51] is similar to the studies by Emens et al. and Jost et al. [43, 79] considering the use of transparency to support the *identification* of *dependencies* of a certain part of the process model. The main difference is that Witt et al.'s motivation is related to rules being violated by a certain activity of the process model. This approach provides the user with an image of the rule pattern that was found as being violated in the process model under analysis, thus allowing the user to *identify features* about the process.

6.2. Cluster 1: characterized by "manipulate" and "produce" tasks

This cluster is the one with most papers exploring "manipulate" tasks (i.e., *change* and *select* elements, and *navigate*) and "produce" information [53, 62] (see Figure 10). The use of *aggregate*, *navigate* and *summarize* is also evident among the papers as represented by the incidence index shown in Figure 10. For example, Polderdijk et al. [80] report a solution that enables users to manipulate the process model defining risk characteristics to activities, so the reader may identify which tasks are safer to be performed.

Cluster 1 contains two studies that support actions to "produce" information [53, 62]. One of them [62] describes a tool to visualize, in different planes, the activities of different actors of a process model, allowing the visualization of the process model from the perspective of the activities of the process participants and, therefore, providing a layered view. This proposal allows the user to *change* the point of view from which he or she is viewing the process model in the three-dimensional space, and taking "snapshots" (i.e., *record* it) so, after a few "snapshots", the user can pass through the different point of views easily, avoiding to *navigate* again from one point of view to another. The second study [53] proposes and implements a tool that enables the use of BPMN to represent agent-based simulation conceptual models. This tool provides modelers with *annotate features* by attaching a *shape* containing extra information about the process model activity to what it is attached, extending somehow to process model's elements. In practice, according to the authors, this proposal can be exploited as a communication tool between simulation modelers and business users.

Other studies in this cluster [44, 67, 71] are similar because they present information related to users' roles and their approaches allow users to *navigate* the process model diagram. Hipp et al. [44] present a new concept for navigation where the main focus is to display information about collections of process models by manipulating *filters*. Their proposal allows the user to *change* the point of view from what he or she wants to inspect the process model. One point of view is to show all portions of a process model that belongs to a certain user role. Another one is a time-based view that *summarizes features* of the process model's data (e.g., showing a wider *shape* depending on the gap between the start and end dates of the process model's lifetime). A third one is a logic-based view, which displays the process model diagram itself. Kolb and Reichert [67] propose and implement a proof-of-concept prototype framework, which adapts process models to each user's perspective by *filtering* and *aggregating* elements that are not important to the role of a specific user. Managers generally need an overview of the process model, while process participants need a more detailed view, especially of the activities in which they are engaged. Finally, the main focus of the proposal presented by Reichert [71] is to view process models according to different user roles through *filtering* and *aggregating* process models' elements. In the same sense of visualizing process models from different point of views, the study presented by Krenn [82] enables users to visualize different aspects of process models such as interaction diagrams and function-oriented visualization.

Koschmider et al. [57] investigate different approaches to visually align objects and roles from the organizational context to the activities of a process model. It presents a *juxtaposed* multiple-view visualization approach combining linking and brushing techniques. In other words, when the user *selects* and element in one view, the other views are *changed* accordingly, i.e., selecting an activity from a process model displays information about the objects and roles related to that activity in another view. Statistics from their study indicated that the users easily understood the information displayed in the multiple views coordinated using linking and brushing.

Corradini et al. [52] propose a tool to visualize which modeling guidelines were not satisfied by a given model. The tool does not correct any non-followed guidelines, only displays text indicating the guidelines being violated and, in some cases, the activity that generated the guideline violation is highlighted in the red. Moreover, the visualization *summarizes* all the guidelines being infringed in a list view of guidelines that shows in green the name of the guidelines that are followed and, in red, the ones infringed. The user can *change* the view to the different portions of the process model highlighted according to each one of the infringed guidelines, if there is more than one. This way the user can observe the *correlation* between the infringed guideline and the part of the process model which generated that visual feedback.

6.3. Cluster 2: characterized by "attribute targets", and "arrange" and "query" tasks

In this cluster, most articles present features characterized as "query" elements (*compare*, *summarize*) with "attribute targets" (*distribution*, *correlation*). Moreover, it is the second cluster that has more elements classified as "arrange" (*express*, *separate*, as can be seen in Figure 9). Among these papers, it is more evident the presence of features like *distribution*, followed by *separate*, *express* and *compare*, targeting *summarize*, *outliers* and *trends* (Figure 10). All studies in this cluster explore information visualization for displaying data about collections of process models, mainly using bar charts and stacked bar charts. Three studies [15, 45, 47] propose the visualization of quantitative information of a set of process models (e.g., total number of activities within the collection), while another one [69] proposes visualizing information about different versions of the same process model.

Kriglstein and Rinderle-Ma [69] suggest a visualization concept to compare differences between distinct versions of process models. This visualization approach is not about the process model itself, but about the characteristics of the model. It is based on a chart composed by multiple lines of stacked bar charts, where each line represents one version of the process model data, and each stack represents one type of operation that was performed in that version of the model. With that chart, the user can *discover* which version of a process model was subjected to more or fewer operations, i.e., which process version had more elements inserted or deleted. Also, the user can *search* for *correlations* among the versions of the process model. Another task that may be performed is to *compare* the displayed information between different versions of the model to *discover trends* about the operations, e.g., after which version of a process model the operations start to decline.

Two studies [15, 45] propose different visualizations to represent information about the quality of a process model or a collection of process models. In the study presented by Storch et al. [45], one of the proposed visualizations is a *superimposed* bar chart that allows users to view and *compare* the number of violations per the total of elements of process models created by each type of user, for example, students or scientists. Another task that may be performed by the users is to *search* for *correlations*, *trends* and *outliers* among this data. For example, the user is capable of *changing* the chart by choosing to view only the data about models created by one or another type of user. In a recent study [15], the authors propose an interface that enables users to identify, out of a collection of process models, which are the models that do not follow a set of process modeling guidelines well known in the literature [11].

Ivanchikj et al. [47] present a tool that displays different information (around 100 different metrics) about processes modeled using BPMN. This information, e.g., the total number of XOR-Split used in a collection of process models, is presented in bar charts format, supporting users to *compare* this data and finding *correlations* and *outliers*. The user can still *change* charts displaying different information about the collection of process models.

6.4. Cluster 3: characterized by "query" and "manipulate" tasks, targeting "all data", and"map" and "arrange" design choices

This cluster stands out by being the one that mostly explore "query" elements, i.e., *identify*, *compare*, *summarize*, targeting "all data", i.e., targeting finding *trends*, *outliers* and *features*, by means of "arrange" design choices, mainly *express* and *separate*. It is also the second cluster with more proposals related to "manipulate" elements (Figure 9), being more evident the use of *express* and *separate* followed by *summarize*, *outliers*, *trends*, *compare* and *identify* (Figure 10). Three out of four papers in this cluster [46, 48, 75] present some kind of chart (e.g., bar chart, stacked bar) to represent information about a collection of process models or process models' execution logs. These charts *summarize* the datasets, which are the basis for generating the views. Cluster 3 differs from cluster 2 because it displays the process models' diagram alongside the corresponding graphics, and supports users in *identifying* process models' elements characteristics.

Two studies [46, 83] present a navigation concept composed by different *juxtaposed* views. The proposal by Hipp et al. [46] allows the user to *navigate* collections of process models (or process models per se) to view related process information. The user can *identify* characteristics of *selected* elements of interest. Moreover, using a time-based view, the user can *discover* each task execution period as well as *compare* execution periods within different tasks to *identify outliers*. In the work by Caballero et al. [83], the focus is to enable users to *identify* results regarding the validation of the soundness of a process model.

Gulden and Attfield [48] provide an approach to visualize information about logs of business process models' execution. The main focus of their approach is to support users in discovering causal-temporal information related to the process or cohorts of interest of the process model. Concerning the *identify/select/discover/compare* tasks, this study [48] differs from the one by Hipp et al. [46] in the granularity of what is being compared. While Hipp et al. target the elements of user's interest, Gulden and Attfield's target are the process model's cohorts of interest. These elements of interest are pointed out by the user through the *selection* of an activity, which triggers a *filtering* mechanism that provides the data related to the portion that comprehends the selected activity and its subsequent activities. The multiple-view based prototype *juxtaposes* three mini-charts horizontally in the first row, which initially *summarizes* the process model's execution data being analyzed and displayed in a fourth view that occupies the second row. When the user selects any activity, the mini-charts are updated to display information related to the respective model's cohort of user's interest.

The study by Pini et al. [75] aims to improve the way data is displayed aiming user's comparisons tasks within the process mining domain. The user is capable, for example, in one of the proposed plots, to compare behaviors of each activity over time. One of the plots that are drawn over each process model's activity presents execution data related to that activity along the day. It is composed by a bar chart that comprises *superimposed* triangular *shapes*, through which it is possible to see, for each activity, in what shift of the day that activity is executed more often. This way, users can *identify trends* and *outliers*, for example. Further, these charts use *color* to differentiate the shifts of the day.

6.5. Cluster 4: characterized by exploring design choices classified as "map" but not user interaction

This cluster is noticeably composed by studies that, in majority, do not explore user interaction. Only 3 out of 14 studies propose interactive visualizations of process models as their main scope [40, 41, 50]. Also, few studies explore "query", "arrange", "manipulate" and "reduce" features, which makes sense, since this cluster comprises the papers that does not include user interaction. Moreover, it is the second cluster to less explore "attribute targets". However, as for design choices, it is one that most explores "mapping" elements, mostly *color* and *shapes*. Some studies have in common proposals to augment process models' elements through map encoding [42, 49, 50, 54, 73, 78].

Regarding "map" as design choice, a number of studies explore only color mapping [40, 41, 42, 49, 54]. For example, Eckleder et al. [40] and Reijers et al. [41] propose the coloring of split gateways and their respective joins. Both studies are from the same group: in the first one [40], the authors implemented an algorithm to perform the mapping and argued that one limitation of their approach refers to the limited number of colors a human being can differentiate. Reijers et al. [41] describe an experiment with users to investigate hypotheses, one of them being "The use of colors to highlight matching operator transitions will have a significant, positive impact on understanding accuracy", which was supported by the experiment's result with statistical significance.

Kummer et al. [42] discuss that different sets of colors accepted by different cultures make a difference when used to highlight parts of a model for using this model as a communication means. One of their hypotheses was that models with colored elements would be easier to understand than the ones with no coloring, to members of the Confucian culture. They performed experiments with users (holding same level of familiarity with BPMN process modeling) and found the hypothesis was statistically supported.

Mueller-Wickop et al. [54] use colors to distinguish, for example, different event types (e.g., a green event means a financial value entry) in the context of accounting information systems. According to the authors, for auditors understand financial entries flow in this context, they should be provided with a process-oriented view of these entries.

Other studies explore only shape mapping [55, 60, 63]. For example, Stroppi et al. [63] propose a BPMN extension to provide a better understanding of requirements from the resource perspective. Their extension is composed by a squared shape containing relevant textual information from the resource point of view (e.g., privileges the resource has to execute the activity) attached through a line to any process model activity.

Two articles [55, 60] propose new elements to increment process models represented in BPMN and explore shapes for different symbols with distinct semantics. In the first one [55], the new elements intend to smooth control operations on wind farms domain. An example of a proposed element is the "wind farm signal event", represented by a symbol that is a windmill in a circle, which could be used to send malfunction signals. On the other hand, Merino et al. [60] propose new elements to convey more information about activities in a workflow. They aim at improving machine-understandability of process models for real-time monitoring in manual services contexts. One of these new elements is called "advanced decision point", represented by an interrogation point in a circle. It is capable of identifying if a particular condition is met to decide to which branch move during process execution (e.g., if the process is of a tire to be calibrated, the decision point may enter a loop to inflate tire while the value of calibration is lower than the desired value).

Color and shape mapping are addressed by other authors [50, 61, 73, 76, 78]. Salnitri et al. [61] describe a security-oriented BPMN extension. They aim at representing real-world requirements of the security domain through a set of proposed symbols that can be attached to BPMN elements. One of these symbols represents the availability of an element as a circular clock shape with the number "24" in the center. Another symbol indicates that a data object can only be accessed by authorized personnel, being visually represented by a circular red wax seal. Both symbols are surrounded by a thick circular border colored in orange. Under different configurations of models presented during an experiment, the users found the models more understandable with the proposed symbols than without them.

The study by Gall et al. [73] investigate the use of symbols such as green-check marks and red-subtraction marks to represent, respectively, elements that were added to and removed from different versions of a process model. Laue and Awad [50] focused on sequence flow errors and portions of the model that can make it difficult to understand. To highlight the elements that are responsible for any identified error, they suggest attaching a white "x" in a red circle mark to the element. Then, when the user hovers the mouse over this mark, a textual message about the error should be exhibited.

Although this cluster is characterized by focusing on color and shape mappings, we also observed other features being used. In the article by Laue and Awad [50], the query action *identify* is present when the user hovers the mark and can read the characteristics of the element it represents. Reijers et al. [41] use the manipulate action *change* when the user is enabled to activate and deactivate the coloring of matching operators.

6.6. Cluster 5: characterized by "faceting", "attribute targets", and "all data targets"

The studies in cluster 5 are the ones that most explore "faceting" elements, i.e., *juxtapose*, *partition*, *superimpose*). As those in cluster 2, they are directed to "attribute targets", although also targeting "all data", as can be observed in Figure 9. In this cluster, it is more evident the use of *similarity* when dealing with attribute targets, *superimpose* as facet, *compare* (as query action) and *outliers*, for "all data targets" (see Figure 10). Moreover, all studies in this cluster, as seen in Table 6, explore the visualization of differences between processes models. Their main focus is to make users able to *compare* process models identifying *similarities* and differences among them. In some studies [64, 72], when an element is removed, its control flow is shown in different colors (orange [64] or red [72]), while the added elements are displayed in green (in both); and, the changed elements are displayed in yellow [72].

Kriglstein and Rinderle-Ma [65] conduct a systematic literature review about how visualization is used to show differences among process models, and performed a survey to identify the expectations of users regarding this. Among the findings of their study, the authors identified that the tools only highlight changes between processes but do not allow users to trace the changes across the processes' different versions.

Kabicher-Fuchs et al. [66] presented an approach for visualizing the differences among versions of a process model. In their paper, they explored many of the visualization data analysis elements (Tables 4 and 5), such as *change*, by allowing the user to change the way a process model is presented. In their proposal, at first, the process model is displayed as is, i.e., with no visual augmentation. When the user *selects* a month of the year, in the timeline view, the differences between process model versions can be seen through the *superposition* of the different versions of the process model with *color* changes applied to activities and control flows (e.g., red corresponding to removed elements and green to added elements). This timeline view is a Gantt chart, presenting all process models' lifetime durations across the months. They adopted multiple views, which are *juxtaposed* and coordinated.

Another study [68] proposes highlighting not only the differences but also similarities between process models aiming to support both the comparison of two process models as well as the comparison of instance traffic between two process models at different moments in time.

Finally, other articles [66, 68] also present proposals to enable users to find *outliers*. While in Kabicher-Fuchs et al.'s proposal [66] the timeline view allows observing which are the months when a specific process model changed the most, the work by Krigelstein et al. [68] identify which are the paths that are most executed along the process.

7. Results and Discussion

In this section, we discuss our findings by answering the research questions we addressed in our systematic literature review.

7.1. Research question 1 (primary): what is being investigated in the topic visualization of business process models

The main research question, RQ1, is the most generic one. The objective of this review was to identify, broadly, what is being investigated regarding visualization of process models, avoiding restrictions to this answer as much as possible.

After the data extraction, on the one hand, we classified the selected studies into six categories, as shown in Section 5, so we could have an overview of the literature from the main scope of the papers' proposals. We found out that the articles deal with (i) augmentation of existing process modeling elements, (ii) creation of new elements, (iii) exploration of the 3D space, (iv) suggestions of different ways for visualizing process models information and (v) process modeling mistakes, and (vi) visualization of process models from distinct point of views. While most studies focus on the visualization of the process model diagram itself, 16.28% explore both information visualization and process model diagram in the same view, and 9.30% of them only explore information visualization about process models.

On the other hand, after the data extraction related to the visualization analysis framework, the absolute majority of the studies, specifically 93.02% of them, provide ways to the users "to consume" information rather than "to produce". A little more than half of the papers, more precisely 65.12% of them, provide some kind of user interaction within their proposals, either by selecting elements or navigating through process models, for example. Surprisingly, still, almost 35% (34.88%) of the studies are static visualizations.

To avoid missing any possible existing grouping or relation among the studies analyzed under Munzner's visualization analysis framework, they were clustered using the *k*-means algorithm. We obtained six clusters differing from each other in different aspects, although one of them (identified as Cluster 0) is more neutral facing the others (see Figure 9), with its set of papers not showing any particular feature that might differentiate them from the others.

All clusters contain studies that allow users to "search" for information at some extent, only Cluster 2 showing no papers that handle "network data". So, Cluster 2's articles address mostly information visualization features. Cluster 4 is the largest one and mainly constituted of studies that do not explore user interaction in their design choices.

Considering the 46 selected studies, exactly half of them are based on BPMN and 52.17% present evaluation or validation of their proposals, while in 34.78% such evaluation or validation involves experiments with users. 13.04% of the articles investigate hypotheses, and 15.22% present results that are considered statistically significant. Exactly half of the studies aims at improving the understandability of process models explicitly. It is noteworthy that only 19.56% of the papers describe an online tool, out of which one is not accessible anymore. Also noteworthy is the fact that, according to Google Scholar[11], only 28.26% of the studies we surveyed here, are referenced by 10 or more other papers.

7.2. Research question 2: are the studies concerned with improving the understandability of process models

RQ2 focus on identifying the papers that aim at improving the understandability of process models. Since there are many studies [40, 44, 49, 53], just to cite a few, addressing this issue, we hypothesized that the majority of the selected papers would focus on this problem. However, the analysis of the frequency of the keywords showed that not all selected papers have that goal.

After performing the data extraction process (Table 2), we could not confirm our hypothesis since only half of the studies are concerned with improving the understandability of process models by proposing different ways of visualizing the process models or visualizing information about process models. Although there are studies like [63] that are not explicitly concerned with that issue, they are concerned with, for example, improving communication between different parties involved with the process modeling (e.g., process participants, process owners, process analysts). Approximately 89.00% of the papers in Cluster 1, 64.28% of the studies in Cluster 4, and 57.14% in Cluster 0 explicitly mention being concerned with improving the understandability of process models. This scope was not found in papers belonging to Clusters 2, 3 and 5.

7.3. Research question 3: are there open problems for further research on this topic

We answer this research question from two perspectives: the studies' main scope and the visualization analysis. Regarding the studies' main scope, Figure 11 presents the recurrence of data-extraction per category. As can be seen, the "visual feedback" category may pose challenges for further research since it is the one that most lacks studies presenting evaluation or validation of their proposals, especially involving experiments with users. This category does not show any paper providing results with statistical significance. Also, 3 out of 4 of the papers in this category include user interaction in their design choices. Since half of the studies base their proposals on BPMN and, being BPMN an ISO standard, this also could indicate space for further research on visualization of process models modeled with BPMN.

[11] https://scholar.google.com/

From the high-level visualization analysis point of view, only two studies present proposals that enable users "to produce" information. This is an important characteristic yet to be explored in future research. Furthermore, although Clusters 2 and 3 are composed of studies proposing visualization of data about process models or collections of process models, only 30.43% of all studies indeed present proposals regarding such features. So, information visualization applied to process models or collections of process models could also be further explored, mainly to improve user interaction and the understanding of process models diagrams. Finally, few studies explore 3D representations for displaying process models and related information, this finding corroborating what is stated by Oberhauser et al. [84].

Table 7: Distribution of articles per year (2009-2018).

Year	Articles	Total (%)
2009	[40]	1 (2.17%)
2010	[49, 62]	2 (4.35%)
2011	[41, 50, 53, 54, 63, 64]	6 (13.04%)
2012	[44, 65, 66, 76]	4 (8.70%)
2013	[45, 55, 56, 57, 67, 68, 69, 70, 71, 77]	10 (21.74%)
2014	[46, 78]	2 (4.35%)
2015	[47, 51, 58, 72, 73, 74, 75]	7 (15.22%)
2016	[42, 43, 48, 59, 60]	5 (10.87%)
2017	[52, 61, 79]	3 (6.52%)
2018	[15, 80, 81, 82, 83, 84]	6 (13.04%)

Table 8: Distribution of articles per publication type (2009-2018).

Type	Articles	Total (%)
Conference paper	[15, 40, 45, 46, 47, 53, 54, 55, 62, 63, 64, 65, 66, 70, 76, 78, 80, 81, 82, 83, 84]	21 (45.65%)
Journal	[41, 42, 43, 44, 48, 49, 50, 51, 52, 56, 57, 58, 59, 60, 61, 67, 68, 69, 71, 72, 73, 74, 75, 77, 79]	25 (54.35%)

7.4. Research question 4: how active is the research on this topic since 2009

Research question 4 is related to the year and source (journal or conference) of publication of each paper. We grouped the selected articles per year to investigate if the literature in this area tends to growth or decrease in the coming years. As can be seen in Figure 12, linear regression shows that the number of articles per year is increasing, i.e., there is a tendency of more publications about visualization of process models in the next years. Table 7 provides the distribution of papers per year, and Table 8 presents articles per source. One can notice that 54.35% of the articles were published in journals and 45.65% in conferences, in the last ten years (i.e., the period between January 2009 and December 2018).

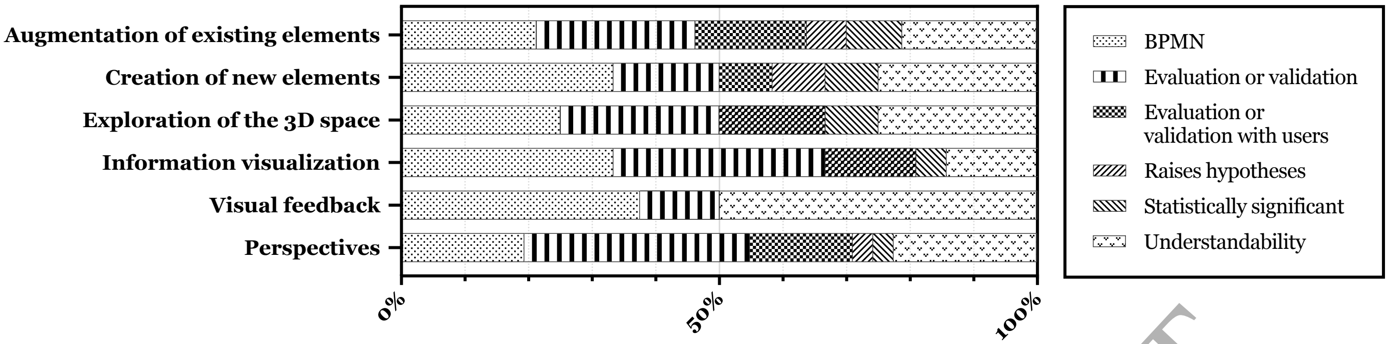

Figure 11: Data extraction distribution over each category.

Table 9: Distribution of articles, in ascending order, per most recurrent author among the selected papers from 2009 to 2018.

Author	Article	Affiliation	Total (%)
Ralf Laue	[50]	Univ. of Leipzig, Computer Science Faculty, Germany	2 (4.35%)
	[45]	Univ. of Applied Sciences of Zwickau, Dept. of Info. Science, Germany	
Jan Mendling	[40]	Humboldt-Universität zu Berlin, Germany	3 (6.52%)
	[41]	Humboldt-Universität zu Berlin, Germany	
	[42]	Wirtschaftsuniversität Wien, Austria	
Hajo A. Reijers	[40]	Eindhoven Univ. of Technology, Netherlands	3 (6.52%)
	[41]	Eindhoven Univ. of Technology, Netherlands	
	[43]	Eindhoven Univ. of Technology, Netherlands	
Manfred Reichert	[44]	Univ. of Ulm, Institute of DB and Information Systems, Germany	5 (10.87%)
	[67]	Univ. of Ulm, Institute of DB and Information Systems, Germany	
	[71]	Univ. of Ulm, Institute of DB and Information Systems, Germany	
	[46]	Univ. of Ulm, Institute of DB and Information Systems, Germany	
	[58]	Univ. of Ulm, Institute of DB and Information Systems, Germany	
Stefanie Rinderle-Ma	[64]	Univ. of Vienna, Faculty of Computer Science, Austria	5 (10.87%)
	[65]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[68]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[69]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[73]	Univ. of Vienna, Faculty of Computer Science, Austria	
Simone Kriglstein	[64]	Univ. of Vienna, Faculty of Computer Science, Austria	9 (19.56%)
	[65]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[66]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[57]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[68]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[69]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[70]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[78]	Univ. of Vienna, Faculty of Computer Science, Austria	
	[73]	Univ. of Vienna, Inst. for Design and Assessment of Technology, Austria	

7.5. Research question 5: who is leading research on this topic

RQ5 is concerned with the most recurrent authors, both in the selected studies and in publications cited by these studies. The search sources and the research assistant applications we used, provided us with a variety of data about the articles, and we extracted the authors and title of each one of the 46 selected papers. We also obtained the authors and titles of around 1450 papers referenced by the selected articles.

All of the most recurrent authors of the selected studies (see Table 9) appear among the most recurrent referenced authors in these papers. A possible conclusion about this finding is that we could gather the most relevant papers in the research field, which makes us confident about the results obtained with our systematic literature review. The most recurrent authors within the selected studies are Simone Kriglstein, authoring 9 papers, which represent 19.56% of our selected papers; Stefanie Rinderle-Ma and Manfred Reichert, authoring 5 articles each; Jan Mendling, Hajo A. Reijers, and other 4 authors, authoring 3; Ralf Laue, and other 10 authors, authoring 2 articles. The most recurrent referenced author is Jan Mendling, with 110 ci-

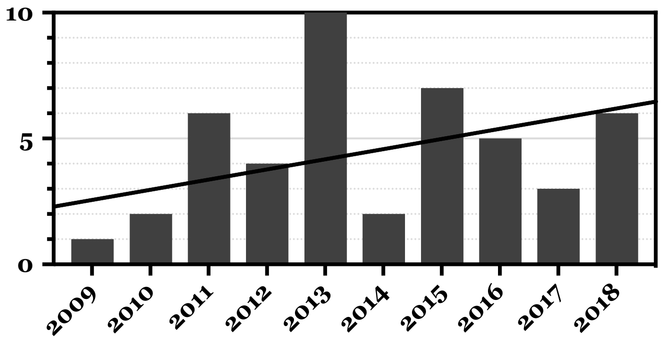

Figure 12: Total articles published per year (2009-2017).

tations distributed among his 59 papers.

Also, Table 9 allows observing the cooperation among authors. For example, Simone Kriglstein and Stefanie Rinderle-Ma were the two authors that most cooperated, having worked together in 5 papers [64, 65, 68, 69, 73], while Jan Mendling and Hajo A. Reijers co-authored 2 papers [40, 41].

8. Conclusions

We conducted a systematic literature review on the visualization of business process models, considering papers published in the last ten years (from January 2009 to December 2018). After the application of the exclusion and inclusion criteria on a set of 1686 papers, 46 studies were selected to be fully read and pass through the data extraction process.

Based on the data extracted from the 46 selected papers, we analyzed them from two point of views. The first one enabled us to group them into six categories, according to their main scope: augmentation of existing process modeling language elements, creation of new process modeling language elements, exploration of the 3D space for process modeling, information visualization about process models, visual feedback concerning problems detected in process models, and support for different perspectives of a process model. Then, we identified which are the main areas that are being explored regarding visualization of business process models. We concluded that the categories less explored and which could present research challenges for further exploration are “visual feedback” (concerning problems detected in process models) and “information visualization” (about process models) since the papers addressing these aspects present no or few results from evaluation or validation of their proposals.

From the second point of view, we analyzed the selected studies based on a visualization analysis and then we obtained a high-level abstract view of the studies’ proposals. After that, we identified open problems concerning the approaches presented in the articles, such as few studies exploring user interaction and, mainly, few proposals allowing users to produce information from process models. It might be interesting, for example, to explore how to enable users to annotate process models with their own domain-specific (or subject specific) information for further reuse during the modeling task.

Among the selected studies, 52.17% of the papers performed evaluation or validation, out of which only 30.43% conducted tests with users. Moreover, although some papers propose generic approaches theoretically easy to adapt to specific modeling languages, another interesting finding is that half of the selected studies base their approaches on BPMN. From 2014 to 2017, there are 23 studies within the selected papers, roughly half of them have based their approaches on BPMN. We understand this aspect as an open opportunity too. Since BPMN is an ISO standard and there are many tools based on BPMN, there should be more research intending to improve the knowledge about this standard.

As a limitation of our systematic literature review, we understand that the data extraction was constrained to some extent, mainly regarding the understandability aspect: if a study did not express to be aiming at improving the understandability of the process model explicitly it was not marked as addressing this aspect during the data extraction process, which produced Table 2. One can also consider as a limitation the fact that current business process modeling tools, which also provide visualization features, were not included in this work since they are not described in papers that passed through our selection process.

Besides identifying the current research concerning to visualization of business process models, our motivation with this review was also to support and inspire researchers for further work aiming at bringing forward the field of business process model visualization, to have the advantages of information visualization helping the tasks of business process modeling and management.

8.1. Future research

Although we have already highlighted potential future work previously in this section, we can identify other aspects that might be addressed in future research. First, one can evaluate how existing tools give visual feedback to the modelers about business process modeling problems and how much satisfied are the modelers regarding the visual feedback provided by the tools they use. Another aspect of future research is related to user interaction. Only 65.12% of the papers report some kind of user-interactive features on their approaches, so there could be opportunities on this topic as well. Moreover, considering that only 16.28% of the selected studies explore ways of displaying information about process models linked to the process model itself, we believe there is a gap for further exploration here too. Regarding our systematic literature review, it would be interesting to broaden its scope by including works describing different layout techniques employed for the representation of business process models and visualization of conceptual models as well.

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